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# PA MONG OPTIMIZATION AND DOWNSTREAM EFFECTS STUDY

WORKING PAPER 1

# ENVIRONMENTAL EFFECTS OF PA MONG

COMPILED BY THE SECRETARIAT

Committee for Coordination of Investigations of the Lower Mekong Basin

Bangkok August 1976

## NOTE

This working paper, prepared by an environmental consultant in collaboration with Mekong Secretariat staff, contains a detailed compilation of environmental information from over 300 publications gathered in support of the presentation made in Chapter IV, "Environmental Effects of Pa Mong", of the Report on the Pa Mong Optimization and Downstream Effects Study. Except in a few instances noted in the working paper, the information presented is considered current as of mid 1976.

While the recently changed official names of several of the riparian countries have been incorporated in the main text of the working paper, it has not been practicable to make the changes in previously prepared material, principally maps and figures, due to cost and time limitations.

# REPORT ON ENVIRONMENTAL EFFECTS OF PA MONG

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## List of abbreviations used in report

| | |
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| Mekong Committee | - Committee for Coordination of Investigations of the Lower Mekong Basin |
| ADB | - Asian Development Bank |
| AIT | - Asian Institute of Technology, Bangkok |
| ASRCT | - Applied Science Research Corporation of Thailand (RTG) |
| EGAT | - Electricity Generating Authority of Thailand (RTG) |
| ESCAP | - Economic and Social Commission for Asia and the Pacific |
| FAO | - Food and Agriculture Organization (UN Affiliate) |
| IAEA | - International Atomic Energy Agency (UN Affiliate) |
| IBRD | - International Bank for Reconstruction and Development (World Bank) (UN Affiliate) |
| ILO | - International Labour Organization (UN Affiliate) |
| Lao PDR | - Lao Peoples Democratic Republic |
| NEA | - National Energy Administration (RTG) |
| NEB | - National Environment Board (RTG) |
| NESDB | - National Economic and Social Development Board (RTG) |
| RED | - Regional Economic Development (USAID) |
| RTG | - Royal Thai Government |
| SEADAG | - Southeast Asia Development Advisory Group, the Asia Society, New York |
| UNDP | - United Nations Development Programme |
| UNEP | - United Nations Environment Programme |
| UNESCO | - Educational, Scientifical Cultural Organization (UN Affiliate) |

| | |
|---|---|
| USAID | - United States Agency for International Development |
| USBR | - United States Bureau of Reclamation |
| USDA | - United States Department of Agriculture |
| WHO | - World Health Organization (UN Affiliate) |
| WMO | - World Meteorological Organization (UN Affiliate) |

CHAPTER I

# INTRODUCTION

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# CHAPTER I

# INTRODUCTION

## 1. Purpose of study

The Pa Mong Optimization and Downstream Effects Study has as its objective the analysis of all the important factors involved in the proposed Pa Mong project, including consideration of alternative pool levels, to serve as a basis for selecting the plan which will maximize the balance of benefits. Hence the selected plan would provide a maximum contribution to advancing the welfare of the peoples of the lower Mekong basin.

Of the many factors involved in the project, its impact on environmental values in the lower basin is one of the most important. It is necessary to be sure that the total benefits from the project, including power generation, enhancement of agriculture through irrigation, enhancement of industrial development, etc., do in fact far outweigh possible adverse effects. The purpose of this study is to determine that Pa Mong would in fact have a very great net positive effect on overall lower basin environmental values.

It is important to note that the term "environmental values" means all environmental values or resources which may be affected by the project, regardless of whether these effects may be assessed in terms of monetary values. Thus the concept of environmental assessment is far broader than the cost-benefit ratio traditionally used for evaluating reservoir and other engineering projects. Its scope includes virtually all values of interest to man. It recognizes that many evaluations of effects will be subjective and intangible, but assumes that all effects must be nevertheless taken into account using the best methods available at the time.

## 2. Development of Mekong Committee's environmental planning programme

### 2.1 Concept of environmental assessment

From the beginning of the Mekong Committee's activities in 1957 the programme of studies carried out under Committee sponsorship has included numerous projects concerned with preservation of environmental values. The organizational structure of the working staff (the Mekong Secretariat), including divisions for agriculture, navigation, and social and economic studies as well as engineering, indicates the broad scope of interests involved in the programme.

About the same time that the Mekong Committee was established, another development was beginning to take place around the world, relating to public attitudes on the importance of protecting environmental values from adverse effects of man-made projects. Prior to about 1960 the level of public concern was actually not very significant, due to lack of public recognition that essential environmental resources, needed in perpetuity, were gradually being used up and lost. The decade of the 1960's was tremendously significant in environmental protection history in that public awareness of the seriousness of the problem finally became widespread, with the result for the first time in history the public upgraded its concern to a level demanding primary political attention.

In the evolution of the concept of environmental assessment, attention was more or less limited in the beginning to traditional pollution effects, namely water pollution, air pollution, land pollution, noise pollution, and public health effects, but rapidly this concept was enlarged so that it now encompasses virtually all types of environmental values including socio-economics as well as human uses and effects on physical and ecological resources. The whole subject is still in the beginning stages of evolution, hence much confusion exists as to what properly should be included in or excluded from a competent environmental assessment. The discussion of environmental impact assessment experience in the United States (Chapter II) indicates the present practice of including every environmental value that can possibly be affected by the proposed project.

The rapid rise in public interest in environment has been a worldwide phenomenon, leading to the UN Conference on Environment at Stockholm in 1972 and to establishment of the UNEP and numerous other international activities including global monitoring of pollution in marine waters sponsored by the WMO and the International Committee on Oceanography. The programme of the Mekong Committee has, of course, felt the impact of these developments and has responded with many new studies and projects. These have the objective of assuring the riparian nations and other countries participating in the lower Mekong basin development programme that all essential environmental resources and values will in fact be given proper attention in the planning, design, construction, and operation of water control systems and structures.

## 2.2 SEADAG contribution

One of the first significant efforts to assist the Mekong Committee's programme with respect to assessment of environmental effects stemmed from the Mekong Seminar of the Southeast Asia Development Advisory Group (SEADAG) at New York in 1968. The majority of the seminar participants

were social anthropologists, geographers, rural economists, sociologists, and environmental biologists, and others concerned with impacts of man-made projects on ecology. While the primary concern of the seminar was on problems of resettlement of displaced farmers, an additional concern on ecological effects led to a modest grant (SEADAG No. 69007e) for an initial evaluation of the riverine ecosystem. The objective was to furnish information to engineers and planners so that ecological risks arising from development projects could be properly considered. The report of this study (Ref. 3) included contributions relating to effects on (1) tropical forests, (2) wildlife, (3) public health and nutrition, and (4) fisheries. These contributions helped in formulating basic guidelines subsequently used by the Mekong Committee in planning and implementing its programme of research and studies. They are reviewed in the body of this report in the sections dealing with these subjects.

2.3 Mekong committee policy statement

A formal statement of Mekong Committee policy on environmental protection was presented at the 45th Plenary Session of the Committee on 13 February 1970 (Ref. 4). The key points included in the statement are summarized as follows:

(a) Human well-being moreso than material progress should be the aim of development. This means careful assessment of the likely effects of development on standards of human values as well as the conventional standards of living.

(b) The largest untapped resource in the Mekong Basin is its people. Developments should be planned to mobilize and utilize the people's potentials for contributing to higher standards of living and of human values.

(c) Mekong Committee planning must show real progress in assuring the greater well-being as expressed above.

(d) To achieve success in developing the lower basin will require preparation of a first-class comprehensive plan which encompasses not only engineering features but all of the associated human values noted above. To develop this plan will require particular importance be given to (a) physical planning, protection of public health, stimulating public participation, and safeguarding the public well-being; (b) assessment of manpower requirements and provisions of additional effort to fill gaps; (c) emphasis on increased agriculture production and related industrial

production possible through irrigation and hydropower from Mekong tributaries; and (d) joint planning for future development in the basin in cooperation with the riparian governments.

2.4 UNEP collaboration

In 1973 the Mekong Committee undertook discussions with UNEP to explore ways by which UNEP could assist in the continuing development of the Committee's environmental programme. This led to assignment of a UNEP consultant to appraise the Committee's needs, and to a report by the consultant, "The Environmental Needs of the Mekong Committee, Tentative Appraisal and Recommendations", submitted in March 1974 (Ref. 5).

Since submittal of the consultant's report the UNEP has approved a proposal for financing staff activities within the Mekong Secretariat, and a beginning effort has been made in implementing these activities.

2.5 Ad Hoc Panel of environmental consultants

At its 58th Plenary Session the Mekong Committee took a further step for evaluating the environmental aspects of its numerous research and study programmes by authorizing a project (funded by the Ford Foundation) for a review of the Committee's overall programme to insure competent attention to all significant environmental aspects. The panel, composed of experts from within Southeast Asia, was active for the period from mid-1973 to December 1974, including three panel meetings held together with the Mekong Committee staff.

The specific assignment to the panel was (1) to review the Committee's overall work programme as this relates to environmental conditions in the basin, (2) to identify further studies which might be required to insure adequate attention to environmental values including preparation of terms of reference and cost estimates, and (3) to encourage involvement and leadership of Southeast Asia environmental experts in the basin development programme. At the third meeting, held 2-10 December 1974, the panel presented its final report (Ref. 6), which included a listing of projects and activities which the panel felt would be needed for filling gaps in the existing programme, together with terms of reference and an indication of priorities.

2.6 Pa Mong optimization and downstream effects study/ objectives of environmental study

The present evaluation of environmental impacts is limited to effects relating to the Pa Mong project (Figure 1) as part of the overall Pa Mong optimization study. Because Pa Mong is a major mainstream project, located in the

northern or upstream portion of the lower Mekong basin, its effects in most instances will extend throughout most of the basin. Thus the current evaluation represents a further step in the Committee's continuing attention to assuring competent environmental protection.

The specific objectives of the present environmental study of the probable effects of Pa Mong are (1) to describe the various individual effects on environmental values and, to the extent feasible, to quantify these effects, and to relate them to each other to permit an overall view of the combined effects, and (2) to relate the effects to different Pa Mong pool level alternatives. This information will thus be available as one basis for guiding the selection of the optimum plan for Pa Mong.

## 2.7 Magnitude of Mekong Committee's programme on environment

Since 1957 the Mekong Committee through the Secretariat has carried out a great number of projects and studies on various water resource development projects in the lower Mekong basin included in the Indicative Basin Plan (Ref. 7). The listings of the reports on these activities (Ref. 8) show more than 1,350 publications over the period 1957-1974.

The total cost of all Mekong Committee projects and studies for the period 1957 through June 1975 (the latest detailed tabulation available) is estimated at approximately US$ 297.3 million, as shown in Table 1 (Ref. 11). Of this total the bulk has been utilized for projects and studies relating to the overall aspects of water resource development planning, but a significant portion, estimated at not less than $ 10,950,000, or about 3.7 per cent of the total, has been invested in special projects and studies giving specific attention to environmental concerns associated with development of the Pa Mong project complex. It is believed this investment for the Pa Mong project represents a greater investment in environmental attention at the feasibility stage of planning, than for any other major water resource development project elsewhere.

Table 2 shows the breakdown of sources of the total $ 297.3 million budget through 1974. This is included here to indicate the wide basis of support for the Mekong Committee's programme.

## 3. Terminology

Because environmental assessment technology is a newly evolving field, there is as yet little consensus on the precise terminology to be used. However, the following concepts appear to be evolving at this time (Ref. 2, 9, 10):

5

(a) Environment: The surrounding zone (usually the specific zone to be affected by the project).

(b) Environmental resource or value: An aspect of the environment which is of benefit to man (including all ecological resources and values).

(c) Ecology: Study of interrelationship of organisms to their environment.

(d) Ecosystem: A community and its environment (living and non-living considered collectively); may range in extent from very small units to very large).

(e) Environmental effect: Result of natural or man-made action on the environment (as measured by physical, chemical, and bioligical parameters).

(f) Environmental impact: An effect on an environmental resource or value resulting from man-made project development.

(g) Environmental planning: Planning activities with the objective of preserving or enhancing environmental values or resources.

(h) Environmental assessment: Environmental planning activities which assess environmental impacts, i.e., compare the quality of the environmental values or resources with and without project development. An environmental impact assessment is an environmental assessment of a particular impact.

(i) Environmental impact statement: Document describing a proposed project, its probable environmental impacts, and alternatives to the proposed project and associated environmental impacts.

References

(1) "Water Pollution Control in the Bangkok Metropolitan Region". Report prepared by H.F. Ludwig for National Research Council of Thailand with USAID support, 5 January 1973.

(2) "An Ecological Glossary for Engineers and Resource Managers". Institute of Ecology (TIE), Madison, Wisconsin.

(3) "Some Environmental Considerations for the Mekong Basin Project". Southeast Asia Development Advisory Group of Asia Society (SEADAG Grant 69007e), April 1973.

(4) "Statement by Acting Executive Agent, Mr. W.J. van der Oord, to 45th Plenary Session of Committee for Coordination of Investigations of the Lower Mekong", 9-13 February 1970.

(5) "The Environmental Needs of the Mekong Committee, Tentative Appraisal and Recommendations". Christian de Laet, UNEP, Bangkok, March 1974.

(6) "Final Report, Ad Hoc Panel of Environmental Consultants". Mekong Committee Document E/CH.11/WRD/MKG/L.402, 10 December 1974.

(7) "Report on Indicative Basin Plan", Mekong Committee publication E/CH.11/WRD/MKG/L.340, 1970.

(8) "Mekong Project Documentation" for 1957-72, 1973, and 1974, Mekong Committee publications WRD/MKG/INF/L. 571 Rev. 1, WRD/MKG/INF/L. 575, and WRD/MKG/INF/L.591 respectively.

(9) "Working Papers, Environmental Assessment of the Bermejo River Basin, Argentina" (Draft). By Threshold Advisory Group, Organization of American States, Washington, D.C., January 1975.

(10) "Environmental Impact Assessment: Principles and Procedures", SCOPE Reports, Paris, 1975.

(11) "Operational Resources at 31 December 1974". Mekong Committee publication WRD/MKG/INF/L.593, Rev. 1, 13 November 1975.

TABLE 1

SUMMARY OF INVESTMENT IN LOWER MEKONG BASIN

WATER RESOURCES PROJECT DEVELOPMENT WITH ESTIMATED ALLOCATION FOR ENVIRONMENTAL ACTIVITIES

(Amounts in Equivalent US Dollars) (References, Mekong Committee Publications WRD/MKG/INF/L. 593, Rev.1, 13 Nov. 1975 and WRD/MKG/INF/L. 595 Draft, 17 Dec. 1975)

| Investment as of 31 December 1974 | Co-operative Assistance | Mekong Countries | Total | Estimated Allocation to Pa Mong Environmental Activities: Per Cent of Total | Estimated Allocation to Pa Mong Environmental Activities: $ (1,000's) | Pertinent References/Remarks |
|---|---|---|---|---|---|---|
| Basin planning | $ 3,754,297 | $ 21,600 | $ 3,905,987 | 5 | 190 | See Indicative Basin Plan, Stage One and Phase II reports, annual reports. |
| Hydrologic network | 3,036,910 | 1,033,000 | 4,069,910 | 10 | 407 | Includes basic hydrology, sediment loads, salinity and water quality. |
| Flood forecasting and control | 504,284 | - | 504,284 | 20 | 101 | Initial effort at environmental protection, to set guidelines for operation of Pa Mong. |
| Mainstream projects: Reconnaissance surveys | 1,721,662 | 105,000 | 1,826,662 | 5 | 91 | Basic data needed for environmental planning/assessment as related to Pa Mong. |
| Pa Mong | 15,571,900 | 5,278,000 | 20,849,900 | 5 | 1,042 | Basic data needed for environmental planning/assessment as related to Pa Mong. |
| Sambor | 1,092,500 | 18,171 | 1,110,671 | | | |
| Stung Treng | 600,000 | - | 600,000 | | | |
| Tonle Sap | 534,755 | 72,857 | 607,612 | | | |
| Delta | 2,429,543 | 234,458 | 2,664,001 | 5 | 133 | Basic data needed for environmental planning/assessment as related to Pa Mong. |
| Tributary projects: Regional reconnaissance | 236,559 | - | 236,559 | 5 | 12 | Basic data needed for environmental planning/assessment as related to Pa Mong. |
| Project implementation: | - | - | - | | | |
| Democratic Kampuchea | 21,322,870 | 9,426,600 | 30,749,470 | | | |
| Thailand | 20,490,283 | 75,316,269 | 95,806,552 | | | |
| Lao PDR | 56,510,689 | 2,577,500 | 59,088,189 | | | |
| Viet-Nam | 448,702 | 122,622 | 571,324 | | | |
| Total | 98,772,544 | 27,442,991 | 126,215,535 | | | |
| Navigation improvement | 4,249,907 | 1,243,800 | 5,493,707 | 5 | 275 | Navigation programme include many activities for socio-economic improvements to be enhanced by Pa Mong. |
| River ports and ramps | 569,970 | 493,210 | 1,063,180 | | | |
| My Thuan bridge | 7,353,965 | 11,218,757 | 18,572,722 | | | |
| Vientiane-Nongkhai bridge | 149,484 | - | 149,484 | | | |
| Irrigated agriculture; experimental/demonstration farms | 3,705,725 | 2,677,933 | 6,383,664 | 30 | 1,915 | Estimate probably low - A key activity for achieving environmental potentials of Pa Mong. |
| Pioneer agricultural projects | 11,505,000 | 11,391,000 | 22,896,000 | 10 | 2,282 | Again, a key programme for achieving environmental potentials of Pa Mong. |
| Fisheries | 715,298 | 61,193 | 776,491 | 100 | 776 | Entire programme focussed on preservation/enhancement of fisheries. |
| Power transmission, markets and industries surveys | 370,145 | - | 370,145 | 5 | 19 | Assurance of equitable distribution and sustained use of power. |
| Mineral surveys | 2,469,466 | 647,995 | 3,117,461 | 5 | 1,559 | Promotion of utilization of environmental resources enhanced by Pa Mong power and navigation. |
| Social development | 371,469 | - | 371,469 | 100 | 371 | Socio-economic improvements needed as part of Pa Mong overall project development. |
| Water quality programme | 45,430 | - | 45,430 | 100 | 45 | Basic data for planning for preservation of water quality as affected by Pa Mong. |
| Waterborne pests and diseases | 950,803 | - | 950,803 | 100 | 951 | Protection of public health from disease hazards possibly stemming from Pa Mong. |
| Institutional support | 14,395,634 | 17,269,761 | 31,675,395 | 2 | 632 | Estimate probably low for considering increasing attention to environment in Mekong Committee activities. |
| Other administrative support | 1,243,381 | - | 1,243,381 | 2 | 25 | Estimate probably low for considering increasing attention to environment in Mekong Committee activities. |
| Expert services and consultants | 797,614 | - | 797,614 | 10 | 79 | Estimate probably low for considering increasing attention to environment in Mekong Committee activities. |
| Mekong Cadre | 530,076 | - | 530,076 | 5 | 27 | Estimate probably low for considering increasing attention to environment in Mekong Committee activities. |
| Fellowships and study tours | 1,124,174 | - | 1,124,174 | 2 | 22 | Estimate probably low for considering increasing attention to environment in Mekong Committee activities. |
| Post-war reconstruction | 2,250,000 | - | 2,250,000 | | | |
| Laboratory equipment | 117,905 | - | 117,905 | 50 | 59 | Basic data measurements for assessing environmental background and changes. |
| Fuel supplies | 340,684 | - | 340,684 | 2 | 7 | |
| Other | 1,086,744 | 194,625 | 1,281,369 | 2 | 25 | |
| Totals as of 31 December 1974 | 182,607,758 | 139,244,337 | 321,852,115 | 3.43 | 11,044 | Overall percentage of 3.43 allocated to environmental projects/studies probably low. Real total may be 4 or 5 per cent |
| Totals as of 17 December 1975 | - | - | $354,222,843 | | 12,150 | Assumes 3.43 per cent allocation to environmental projects/studies. |

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TABLE 2

SOURCES OF MEKONG COMMITTEE'S OPERATIONAL RESOURCES THROUGH 1974

(Amounts in Equivalent US Dollars, Reference 11)

| Sources | Pre-Investment | Investment (Construction and Other Public Works) | Total |
|---|---|---|---|
| Australia | 589,000 | 4,650,996 | 5,239,996 |
| Austria | 75,000 | | 75,000 |
| Belgium | 579,500 | | 579,500 |
| Canada | 1,865,000 | 7,427,000 | 9,292,000 |
| Denmark | 10,000 | 1,217,725 | 1,227,725 |
| Egypt | 5,000 | | 5,000 |
| Finland | 10,000 | | 10,000 |
| France | 2,090,416 | 5,464,811 | 7,555,227 |
| Germany, Fed. Rep. of | 554,412 | 21,947,000 | 22,501,412 |
| Hong Kong | 20,000 | | 20,000 |
| India | 610,538 | 353,000 | 963,538 |
| Indonesia | 30,000 | | 30,000 |
| Iran | 352,184 | | 352,184 |
| Israel | 317,180 | 876,800 | 1,193,980 |
| Italy | 62,200 | 1,000,000 | 1,062,200 |
| Japan | 1,968,830 | 26,606,189 | 28,575,019 |
| Netherlands | 3,935,077 | 7,722,463 | 11,657,540 |
| New Zealand | 375,378 | 1,060,428 | 1,435,806 |
| Norway | 10,000 | | 10,000 |
| Pakistan | | 250,000 | 250,000 |
| Philippines | 430,957 | | 430,957 |
| Sweden | 20,000 | | 20,000 |
| Switzerland | 475,000 | 310,000 | 785,000 |
| United Kingdom | 1,200,688 | 2,281,000 | 3,481,688 |
| United States | 24,580,961 | 25,502,301 | 50,083,262 |
| | 40,166,821 | 106,669,713 | 146,836,534 |
| Democratic Kampuchea | 5,230,086 | 9,284,960 | 14,405,947 |
| Lao PDR | 4,748,463 | 1,236,110 | 5,984,573 |
| Thailand | 14,156,347 | 88,402,869 | 102,559,216 |
| Viet-Nam | 4,772,098 | 11,380,424 | 16,269,621 |
| | 28,914,994 | 110,304,363 | 139,219,357 |
| UN/ESCAP | 799,804 | | 799,804 |
| UNDP | 21,430,322 | 810,900 | 22,241,222 |
| UNDTC | 452,799 | | 452,799 |
| UNEP | 205,000 | | 205,000 |
| FAO | 140,050 | | 140,050 |
| IAEA | 55,650 | | 55,650 |
| ILO | 13,104 | | 13,104 |
| UNESCO | 17,800 | | 17,800 |
| UNICEF | 50,000 | | 50,000 |
| UNIDO | 86,820 | | 86,820 |
| WFP | 173,083 | | 173,083 |
| WHO | 8,277 | | 8,277 |
| WMO | 45,300 | | 45,300 |
| | 23,478,009 | 810,900 | 24,288,909 |
| World Bank | | 3,450,000 | 3,450,000 |
| Asian Development Bank | | 7,100,000 | 7,100,000 |
| | | 10,550,000 | 10,550,000 |
| Asia Foundation | 35,574 | | 35,574 |
| Ford Foundation | 600,639 | | 600,639 |
| Magsaysay Foundation | 10,000 | | 10,000 |
| Others | 243,242 | 67,860 | 311,102 |
| | 93,449,279 | 228,402,836 | 321,852,115 |

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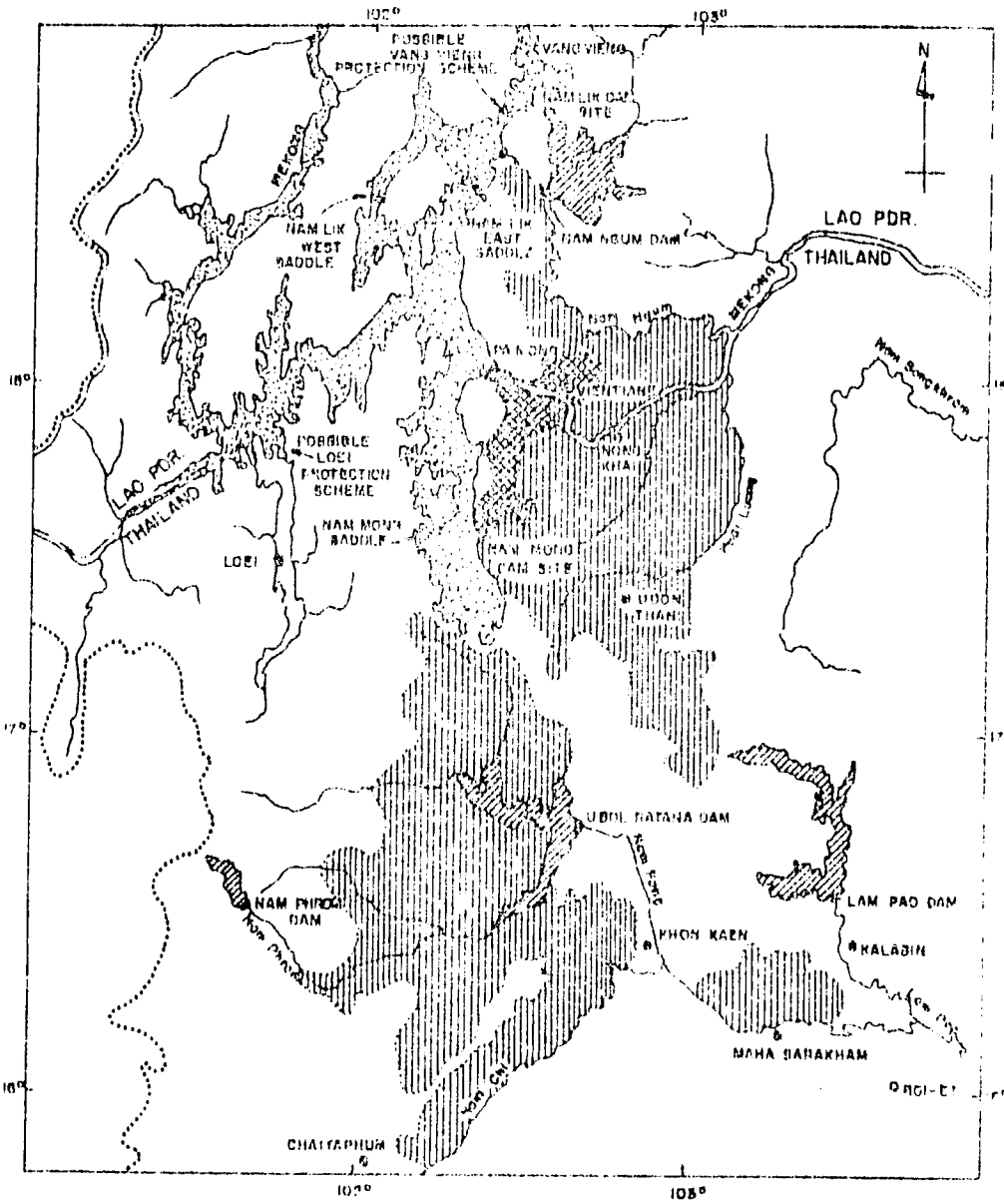


LEGEND

- COUNTRY BOUNDARY
- BASIN BOUNDARY
- STAGE I SERVICE AREA
- PHASE II
- RESERVOIR EXISTING
- RESERVOIR PROPOSED

SCALE 0 10 20 40 60 80 km

| MEKONG COMMITTEE | |
|---|---|
| PA MONG OPTIMIZATION AND DOWNSTREAM EFFECTS STUDY | |
| PLAN LOCATION OF PA MONG PROJECT | |
| FIG I | DATE June 1990 |

CHAPTER II

# ENVIRONMENTAL ASSESSMENT TECHNOLOGY

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# CHAPTER II

## ENVIRONMENTAL ASSESSMENT TECHNOLOGY

### 1. Introduction

Most of the efforts to develop a technology for environmental assessment has been in the United States, where preparation of such an assessment (called an "environmental impact statement") is now a requirement for virtually all types of new projects which are of sufficient size to have significant environmental effects. Most of this work has been done only in the past four years, hence the concept is still quite new and the methodologies are in continuing evolution. For purposes of helping formulate guidelines for evaluating the effects of Pa Mong, a review was made of the existing methodologies in use in the United States, and also a review was made of the environmental impact statements prepared over the past three years for 20 representative dam and reservoir projects now being implemented in the United States.

### 2. Environmental assessment methodology

Although numerous efforts have been made to formulate systematic approaches for making environmental assessments, with efforts to quantify the effects and relate them to each other, thus far there is no concensus on any particular procedure (Ref.1 to 16). This is because of the difficulty in attempting to quantify effects because of their often intangible nature or scientific complexity - for most of the effects meaningful parameters which can be used as inputs for quantified analysis, for example in modelling, have yet to be developed. Even in the traditional field of waste treatment and disposal, now about 100 years old, it is still difficult to correlate different levels of waste treatment with different levels of effects on water quality in the water bodies to which the waste effluents are discharged. For these reasons all attempts to develop quantified approaches to environmental assessment, including use of checklists, matrices, networks (flow chart relationships) and map overlays, have been essentially subjective with the quantification depending greatly on the background and bias of the observer.

It was concluded that the best general approach for use for the current Pa Mong study is a review, item by item, of effects on individual environmental values, including both identification of the value and description and quantification of the effect to the extent possible.

Within this context, of evaluating environmental effects one by one, it is possible to group these effects in a systematic manner. The approach used by the Mekong Committee for Pa Mong is that described in the "Environmental Assessment

Manual" prepared in May 1974 by Battelle for the U.S. Corps of Engineers for review of the Columbia river and tributaries (Ref. 1). This approach groups the environmental effects into four levels or tiers, as shown in Figure 1, which progressively "ascend" from physical effects to ecological effects to human uses to human effects. Table 1 is a listing of the various environmental effects considered in the Pa Mong study, arranged according to the four-tier concept.

3. Environmental assessments for selected projects in the United States

As noted previously, a review was made, for purpose of helping develop guidelines for Pa Mong, of the detailed environmental assessments (environmental impact statements) recently made for 20 selected representative dam and reservoir projects under implementation in the United States. The purpose of the review was primarily to check the present status of environmental assessment technology for dam and reservoir projects in the United States, including notation of the particular environmental effects considered and the methods for evaluating effects. It was recognized that these effects would be considerably different for an industrialized country like the United States than for the lower Mekong basin, and that most of the projects reviewed are much smaller than Pa Mong (although they are the largest projects in the United States for which such detailed environmental assessments have been made).

Table 2 summarizes the projects and project functions of the 20 project statements reviewed. With respect to environmental effects, the important parameters of a project include total area to be inundated, total storage capacity of a reservoir, and shoreline created by the impoundment. Other parameters, such as the length of the dam and embankment, material of construction, and total area acquired for the project are also important, but they are not listed in the table. Of the 20 selected projects, the reservoir areas range from as small as 56 acres (140 ha) to more than 35,000 acres (87,500 ha). The storage capacities range from 1,600 acre-feet (1.97 million cubic meters) to more than 2 million acre-feet (2,467 million cubic meters). The minimum reservoir shoreline is 13 miles (21 km) and the maximum is 400 miles (640 km).

Table 2 also illustrates that most of the selected projects are multipurpose in nature. The major purposes include flood control, water supply, irrigation, power generation, recreation, and enhancement of fish and wildlife. Of the 20 projects, 14 were proposed primarily for recreation, 14 for fish and wildlife enhancement, 10 for flood protection and water supply, 9 for power generation, and 5 for irrigation.

3.1 Results of review: The results of the review of the 20 projects are presented in detail in Annex A of this report, and are summarized in Table 3.

While it is not possible to quantify the extent of impact on environmental resources without a great deal of subjectivity, for purposes of this review a simple method was selected for evaluating the comparative importance of the environmental parameters and of effects on these both during construction and operation periods. As shown in Table 3, the information presented in the environmental impact statement was rated using the letters A, B, C and D. The letter A, which is assigned when an effect is mentioned only, is given a weight of 0.5. The letters B, C and D represent respectively the adquacy of discussion of the environmental effects, adequacy of proposed mitigating measures, and adequacy of field work for supporting the evaluation. These letters (B, C, D) were assumed to carry equal weights, depending on their subscripts. The weights indicated by subscripts 1, 2 and 3 are 1, 2 and 3, respectively. For instance, a parameter marked $2A_1$, $2B_1$, $3C_2$, $1D_3$ (indicating that this parameter was mentioned or discussed in eight of the 20 projects) will have a total weight equal to 2(0.5) + 2(1) + 3(2) + 1(3) = 12. This total weight is called the "index of importance" (I). Values of indices of importance are given at the bottom of Table 2. Thus the higher the index value for a given environmental parameter, the more important it is indicated to be, based on the information on the selected 20 projects. The ratings were based on the information contained in the environmental impact statements, regardless of the stated purpose of the project.

The order of importance of environmental parameters, placed according to the indices of importance, were found to be as follows: water quality (I = 86), fish (83), wildlife (64), recreation (53), aquatic animals other than fish (50); land use pattern (42), etc. Ranks of importance for other environmental parameters are given in the last row of Table 3. Thus it could be said that, for the parameters which are indicated to be the most important, priority should be given to them in environmental assessment activities prior to project construction.

3.2 Conclusions: The review shows that the environmental impact statements prepared for reservoir development projects in the United States normally include virtually all environmental parameters known to exist. A careful pre-assessment of environmental impacts likely to be induced by a proposed project is essential for proper design and planning to help alleviate the expected problems. As a consequence, the project construction and operation can be made as economically beneficial as possible and at the same time adverse impacts on the existing environment can be kept to a minimum and in a considerable number of instances the net impact can be positive.

It can be seen from this review that some parameters, which seem to be of major concern in Southeast Asia, are not much stressed in the environmental impact statements for projects in the United States. Examples are public health problems, agricultural production, and resettlement problems. As noted previously, these differences relate to the difference in stage of developmental conditions in the United States as compared to Southeast Asia.

4. Environmental planning related to overall water resources project planning

Implementation of a water resource development project such as Pa Mong involves a succession of stages, which may be classified as feasibility studies, design and planning, construction, start-up operations (filling and stabilizing), and "steady state" operations. Usually the pre-construction study phases extend over many years, progressing from pre-feasibility studies to feasibility studies to preliminary engineering to final design. The Pa Mong studies began in 1957 and have progressed over the intervening period of 19 years to the current optimization report, which presumably will set the stage for key decisions and for proceeding with design.

Planning to provide for conservation of environmental values should be a part of all phases of project implementation, but the proper timing of attention to individual environmental values will depend on the stage of project development. For example, resettlement planning must be undertaken early in the planning stages, to ensure that adequate resettlement measures will be included in the project plan and budget when the project concept becomes crystallized. At the other extreme, monitoring of the complex limnology of the new reservoir can hardly be undertaken until the reservoir has been formed, hence the prior attention to this subject must be limited to planning for the facilities, organization, and programme for such monitoring based on experience in other similar reservoir projects. Figure 2 is a schematic representation of how attention to individual environmental subjects may be phased to suit overall project evolution and development. Figure 3 shows the actual phasing of Mekong Committee efforts thus far relating to the environmental aspects of the Pa Mong project.

As noted previously, although environmental effects may be studied individually, they are related to each other, as illustrated by Figure 4. Also, the impact of these effects will be maximum in the immediate project area but will also extend to the adjacent and even more distant areas, much like the ripples emanating from a splash in a pool.

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## TABLE I

## PA MONG ENVIRONMENTAL EFFECTS ARRANGED BY CORPS OF ENGINEERS CLASSIFICATION OF LEVELS

| Corps of Engineers Classification | Subject Areas in Pa Mong Environment Effects Study |
|---|---|
| **LEVEL 1/PHYSICAL EFFECTS** | |
| WATER | Flood Control<br>Ground Water<br>Salinity<br>Surface Waters<br>Water Quality |
| AIR | Climate |
| LAND | Geology<br>Sediments and Erosion<br>Soils |
| **LEVEL 2/ECOLOGICAL EFFECTS** | |
| AQUATIC BIOLOGY | Aquatic Biology<br>Reservoir Ecology |
| TERRESTRIAL BIOLOGY | Watershed Management<br>Wildlife |
| **LEVEL 3/HUMAN USES** | |
| WATER SUPPLY | Agriculture<br>Fisheries<br>Irrigation and Drainage |
| NAVIGATION | Navigation |
| RECREATION | Recreation and Aesthetics |
| POWER | Power |
| DEDICATED AREA USES | Recreation and Aesthetics<br>Wildlife |
| **LEVEL 4/HUMAN EFFECTS** | |
| SOCIO-ECONOMIC | Agro-Industries<br>Human Ecology<br>Mineral Development<br>Public Health<br>Resettlement<br>Socio-Economics |
| CULTURAL | Archaeology |
| AESTHETICS | Recreational Aesthetics |

# TABLE 2

## DESCRIPTIONS AND FUNCTIONS OF TWENTY REPRESENTATIVE DAM/RESERVOIR PROJECTS IN THE UNITED STATES

| Project No. (1) | Reservoir Description | | | Project Functions | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Capacity, Acre-feet | Area, Acres | Shoreline, Miles | Flood Control | Water Supply | Irrigation | Power (3) | Recreation | Fish & Wildlife |
| 1 | 845,000 | 12,425 | 20 | x | x | | x (75) | x | x |
| 2 | 24,580 | 287 | 20 | | | | x (28) | | x |
| 3 | 11,000 | - | 13 | | | | x(410) | x | x |
| 4 | 400,000 | 6,800 | 400 | | | | x | x | |
| 5 | 410,000 | 15,800 | - | x | x | | | x | x |
| 6 | 126,000 | 16,500 | - | x | | | x | | x |
| 7 | 375,000 | 25,800 | 53 | x | | | | | x |
| 8 | 103,000 | 4,650 | 50 | | x | | | x | |
| 9 | 107,500 | 4,750 | 30 | | x | | | x | |
| 10 | 315,000 | 3,440 | - | x | x | x | x (49) | x | x |
| 11 | 478,000 | 18,290 | 60 | | x | | | x | x |
| 12 | 357,000 | 5,675 | - | x | | x | x | x | x |
| 13 | 2,018,000 | 35,000 | - | x | x | x | | | |
| 14 | - | 10,800 | 70 | x | | | | x | x |
| 15 | 204,000 | 12,500 | 125 | | x | x | | x | x |
| 16 | (4) | - | - | x | x | | x(113) | x | x |
| 17 | 203,600 | 3,160 | - | x | | | | x | |
| 18 | 34,500 | 365 | - | | | | x(1,000) | | |
| 19 | 1,600 | 56 | - | | | x | | x | x |
| 20 | 1,083,000 | 17,400 | - | | x | | | x | x |
| | Total Number of Projects | | | 10 | 10 | 5 | 9 | 14 | 14 |

Notes:

(1) See Annex A for identification of project

(2) x - Proposed function

(3) Values in parentheses are in megawatts

(4) A project composed of 10 reservoirs which have a total storage capacity of more than 2,000,000 acre-feet.

# TABLE 3

## SUMMARY OF ENVIRONMENTAL EFFECTS OF TWENTY REPRESENTATIVE DAM/RESERVOIR PROJECTS IN UNITED STATES

| | | PROJECT NUMBER (3) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | TOTAL A | B1 | B2 | B3 | C1 | C2 | C3 | D1 | D2 | D3 | I | R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PHYSICAL ENVIRONMENTAL EFFECTS | WATER RESOURCES | GROUND WATER | B1 | | A | | B1 D2 | B1 | | B1 | A | | | | B3 | B1 | | | A D2 | B2 D | A | B3 | 4 | 5 | 1 | 2 | 0 | 0 | 0 | 1 | 2 | 0 | 27 | 12 |
| | | SURFACE HYDROLOGY | A | A | A | B1 | B1 D2 | A D2 | | | A | | B2 | | B3 | B2 | B3 | B2 D1 | | B2C1D2 | B2 | | 5 | 2 | 5 | 2 | 1 | 0 | 0 | 1 | 3 | 0 | 29 | 11 |
| | | WATER QUALITY | B2 C1 | B1 | B1 C1 D1 | B2 C2 | B3 C2 | B2C1D3 | B2 | B3C2D3 | B2 C1 | B2 C2 | B3C1D2 | B2 C1 | B2 C1 | 91 | B3 C2 | B3C1D1 | B2C2D3 | B2C2D3 | B2 C1 | B3C2D3 | 0 | 3 | 12 | 5 | 9 | 8 | 0 | 2 | 1 | 5 | 86 | 1 |
| | LAND RESOURCES | GEOLOGY | B1 | A | | A | B1 | A D3 | | A | A B1 | | | A | | A | B2 C1 | B1 | | | A | B1C1D3 | 8 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 17 | 14 |
| | | LAND USE PATTERN | B1 | | A D1 | B2 | B2C1D1 | B1 D3 | B1 D1 | B2 C1 | B2 D1 | B3C1 | B3 D1 | B2 | B3 | B2 | B2 | B2 | B2 | | B1 | B2 | 1 | 4 | 11 | 2 | 3 | 0 | 0 | 5 | 0 | 1 | 42 | 6 |
| | | EROSION | A | A | A | B1 C1 | A | B1 C1 | A | B2 C2 | A | B2C1 | A | A | B2 C1 | A | B2 C1 | B2 C1 | B1 | B3 C2 | A | B2 C2 | 15 | 3 | 6 | 1 | 6 | 3 | 0 | 0 | 0 | 0 | 35 | 8 |
| | OTHERS | AIR POLLUTION | B1 C1 | | B1 C1 | B1 C1 | A | B2 C1 | A | A | A | A | B2 C1 | A | B2 C1 | A | B1 | B1 | B1 | B2C1 D1 | A | A | 9 | 6 | 4 | 0 | 7 | 0 | 0 | 1 | 0 | 0 | 27 | 12 |
| | | NOISE POLLUTION | A | | A | B1 C1 | A | | A | A | | A | B2 | A | B2 | A | | A | A | B1 | A | A | 12 | 2 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 13 | 16 |
| | | SOLID WASTE, WASTEWATER | A | | A | A | A | | A | A | | A | A | | A | A | A | A | A | A | A | A | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 18 |
| ECOLOGICAL EFFECTS | AQUATIC BIOLOGY | FISH | B2 C1 | B2 C1 | B2C1 D2 | B2C1 D1 | B2C1 D3 | B2C1 D3 | B2C1 D1 | B3C1 D1 | B1C1 D1 | B2 | B2 D2 | B2 C1 | B3 C2 | B2 C1 | B3C1 D3 | B3C2D3 | B2 C2 | B1 C1 D2 | B2 C1 | B2C2D1 | 0 | 2 | 13 | 5 | 14 | 4 | 0 | 5 | 3 | 4 | 83 | 2 |
| | | OTHER AQUATIC ANIMALS | A | | A D2 | B2 | B2 D3 | B1 | A | B1 D2 | A | | B3C1D2 | B2 | B3 C1 | B2 C1 | B3 D2 | | A | B3C2D3 | B2 | B3 D1 | 5 | 2 | 5 | 5 | 3 | 0 | 1 | 1 | 4 | 2 | 50 | 5 |
| | | AQUATIC VEGETATION | B1 C1 | | A | | A | B3 C1 | B1 | A | | | B2 | | B2 C2 | | B3C1 | | A | | A | B2 C2 | 5 | 1 | 3 | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 20 | 13 |
| | | VECTORS OF DISEASES | | | | B1 C1 | | A | | | | | | | | | B2 C1 | | | | | | 1 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 6 | 19 |
| | TERRESTRIAL BIOLOGY | WILDLIFE | B1 C1 | A | A D1 | B2C2D3 | B2C1 D3 | B2C1 D1 | B1 D1 | B2 C1 | B3C1 D1 | B1 | B2 | B1 C1 | B3 C1 | B2 C1 | B2C1 D3 | B3 C2 | B1C1 D2 | B1 C1 D3 | B1C1 D1 | B2C1 D2 | 2 | 7 | 6 | 3 | 13 | 2 | 0 | 5 | 2 | 4 | 64 | 3 |
| | | WATERFOWL | A | | A | A | A | B1 | | B | A | A | | B1 | A | | B1 | A | | A | A | A | 11 | 4 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 17 |
| | | VEGETATION | A | A | A | B1 C1 D3 | B1 | A | B1 | A | B2C1 D1 | A | A | A | B2 C2 | B2 C1 | A | B3C1 D2 | B2 | A | A | A | 12 | 3 | 4 | 1 | 4 | 1 | 0 | 1 | 1 | 1 | 32 | 9 |
| EFFECTS ON HUMAN USES | WATER RESOURCES | FLOOD CONTROL | A | | | | A D2 | A | A | A D1 | | B2 | A | A | B2 | A | B | A | B2 | | | A | 9 | 1 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | N/A | |
| | | WATER SUPPLY | A | A | A | A | A D2 | | A | | A | | A | B1 | B2 | | | A | | | | F | 9 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | N/A | |
| | | POWER GENERATION | A | | | | | A | | | | A | | A | | | | B2 | | B2 | | | 4 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N/A | |
| | | RECREATION | B1 | B1 | B1 C1 | B3C1 | A | B1 | B1 C1 | A D2 | B2 D2 | B2 | B2 | B1 C1 | B3C1 | B2C2 | B2 | B3 C1 | B2C1 D2 | B1 D2 | B2C2 | B2 C1 | 2 | 7 | 8 | 3 | 6 | 2 | 0 | 0 | 4 | 0 | 53 | 4 |
| | LAND RESOURCES | AGRICULTURE | | A | | B1 | | | | B2 | B1 | B2 | | | B1 C1 | | | | | | | | 1 | 3 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 8 | 18 |
| | | MINERAL RESOURCES | A | | A | A | B1 | | A | A | B1 | | A | | B1 C1 | | A | A | A | B2 | | B C | 9 | 4 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 12 | 16 |
| HUMAN EFFECTS | SOCIO-ECONOMIC EFFECTS | AGRICULTURAL PRODUCTION | | | A | | | B1 | A | B2 | B2 | A | | | B2 | | | | | B2 D1 | | | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 12 | 16 |
| | | FISHERY PRODUCTION | B1 C1 | A | | | B1 | B1 | | B2 | B2 | B2 C2 | B3 | B2 C2 | B2 | B3 | B2 | B1 | B2 C2 | | | B3 C1 | 1 | 4 | 7 | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 35 | 8 |
| | | RESETTLEMENT PROBLEMS | A | A | A | B1 C1 | B1 C1 | B1 C1 | A | B2 C2 | B2 C1 | B2 C2 | B2 C1 | B1 C1 | | B2 C1 | B1 C1 | | | | | A | 5 | 3 | 5 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 30 | 10 |
| | | RURAL DEVELOPMENT | B1 | | | | | | | B1 | A | B1 | B1 | B1 | A | A | B2 | B2 | A | B1 D1 | | B2 C1 | 4 | 6 | 3 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 16 | 15 |
| | | EMPLOYMENT INCOME | | A | A | A | A | A | B1 | A | A | A | A | A | A | A | B1 | B2 | A | | | B2 | 13 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 11 |
| | | PUBLIC HEALTH | | | A | B1 | | | | A | | | | | | B2 C2 | | | B1 C1 | | | | 1 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 8 | 18 |
| | CULTURAL VALUES | LIVE STYLE | A | A | A | B2 | A | A | B1 | A | | A | A | | A | | A | A | | A | | B2 | 12 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 17 |
| | | ARCHEOLOGY | A | | A | B1 C1 | B1 C1 | B1 | B1 C1 | B2 C1 | A | B1 | B2 C2 | | B2 C2 | B1 C1 | B2 C2 | A | B1 C1 | A | A | A | 7 | 7 | 4 | 0 | 6 | 3 | 0 | 0 | 0 | 0 | 30 | 10 |
| | | AESTHETIC VALUES | B2 C1 | A | A | B1 C1 | A | B1 C1 | B1 C1 | B2 C1 | A | B3C2 | B1 | B2 C2 | B1 | A | B1 | B2 C2 | B2C1 | B2 | B2 C2 | A | 6 | 6 | 7 | 1 | 8 | 4 | 0 | 0 | 0 | 0 | 40 | 7 |

**NOTES**

(1) NOTATIONS

A - When an effect is mentioned without details

B - Effect of an environmental parameter is discussed in some detail

C - Mitigating measures are discussed

D - Adequacy of field data to support discussion

I - Index of importance

N/A - Not applicable

R - Rank of importance

(2) SUBSCRIPTS

1 - Low level of effect

2 - Medium level of effect

3 - High level of effect

(3) See Annex A for identification of project

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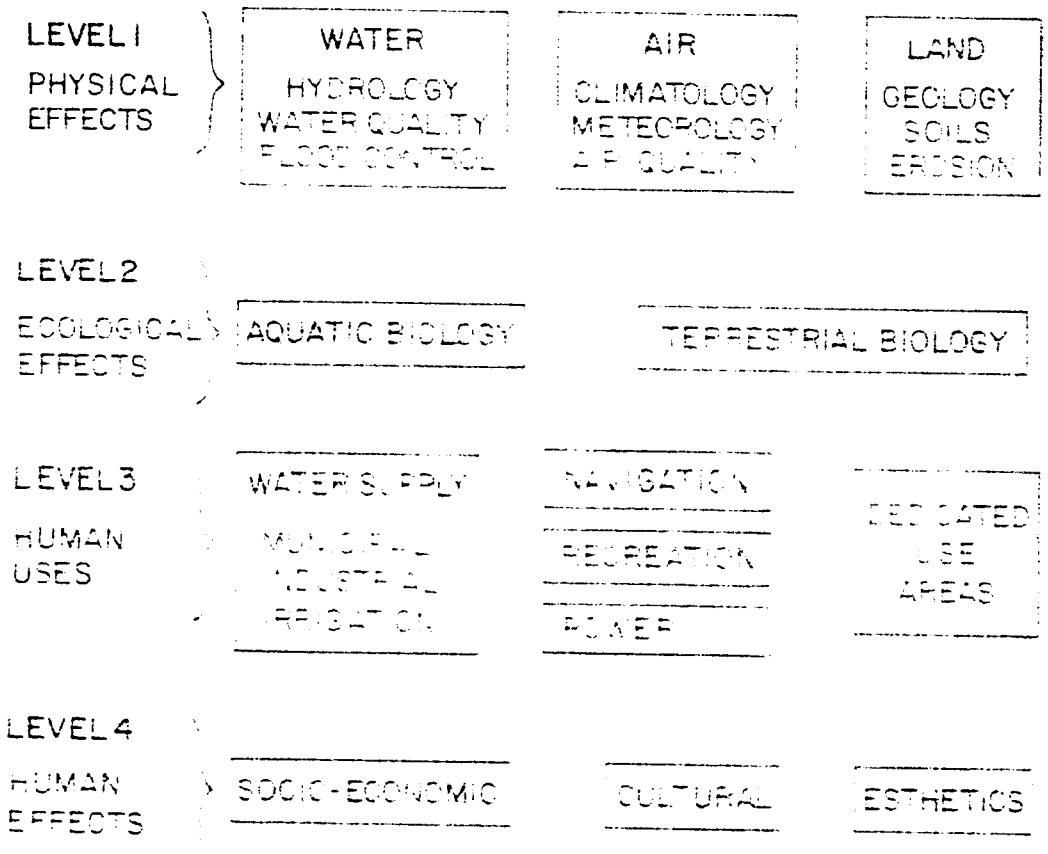



FIGURE 1

LEVELS OF ENVIRONMENT EFFECTS

(After U.S. Corps of Engineers)

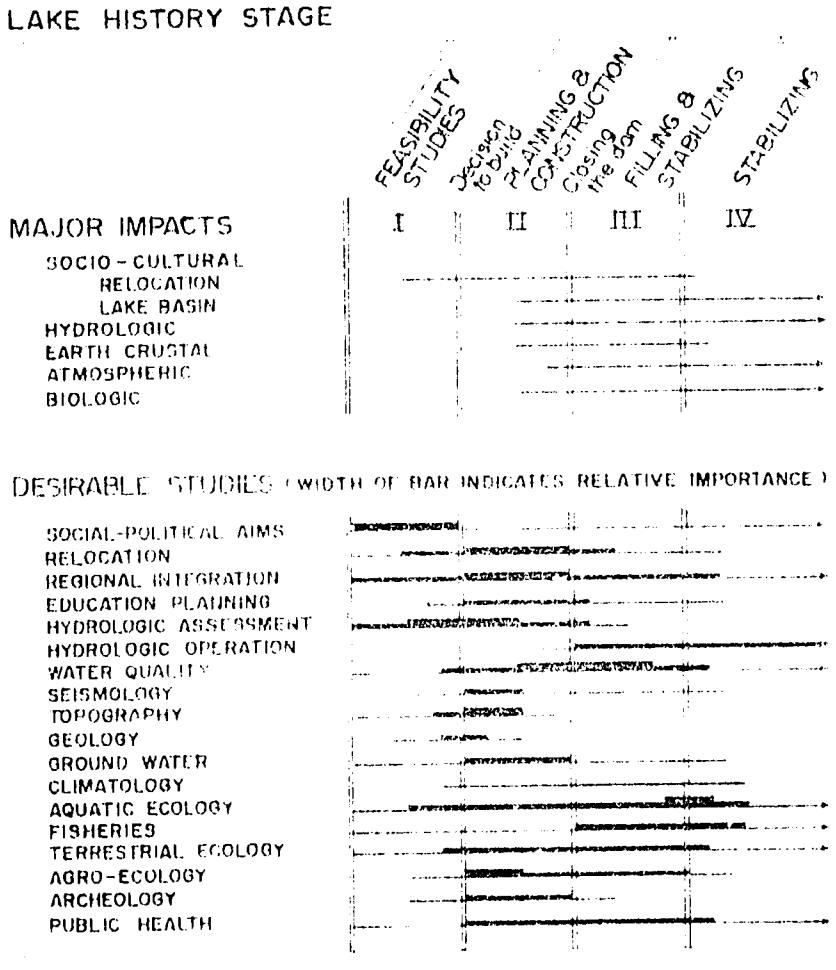


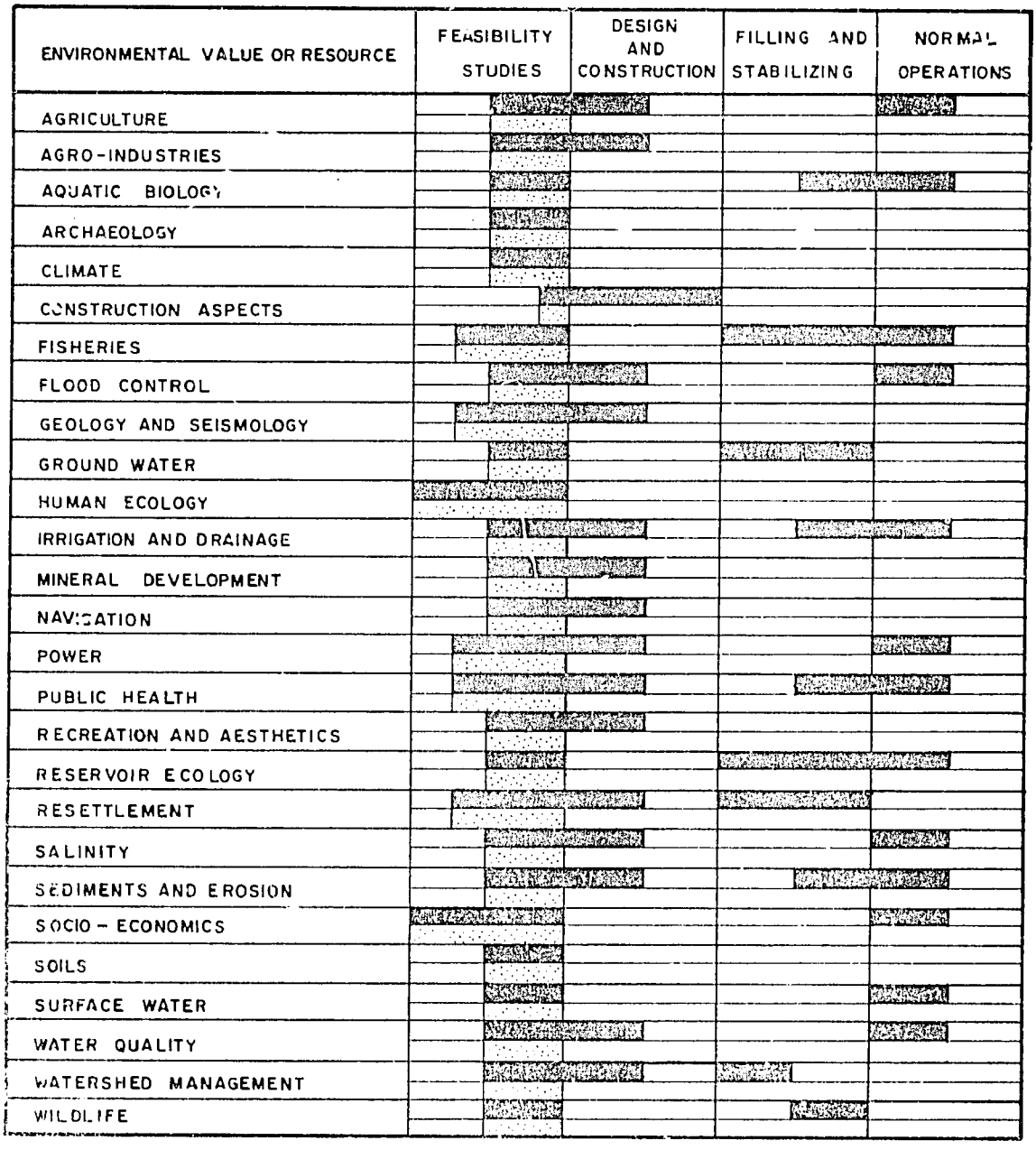

FIGURE 2

TYPICAL RELATIONSHIPS BETWEEN ENVIRONMENTAL ACTIVITIES AND OVERALL WATER RESOURCE DEVELOPMENT

(FROM SCOPE, REFERENCE 2)

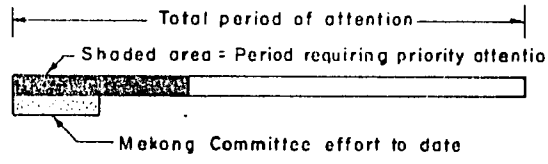
# FIGURE 3

## RELATIONSHIP BETWEEN PA MONG ENVIRONMENTAL ACTIVITIES AND OVERALL PROJECT DEVELOPMENT




NOTES:

Explanation of bar graphs :–



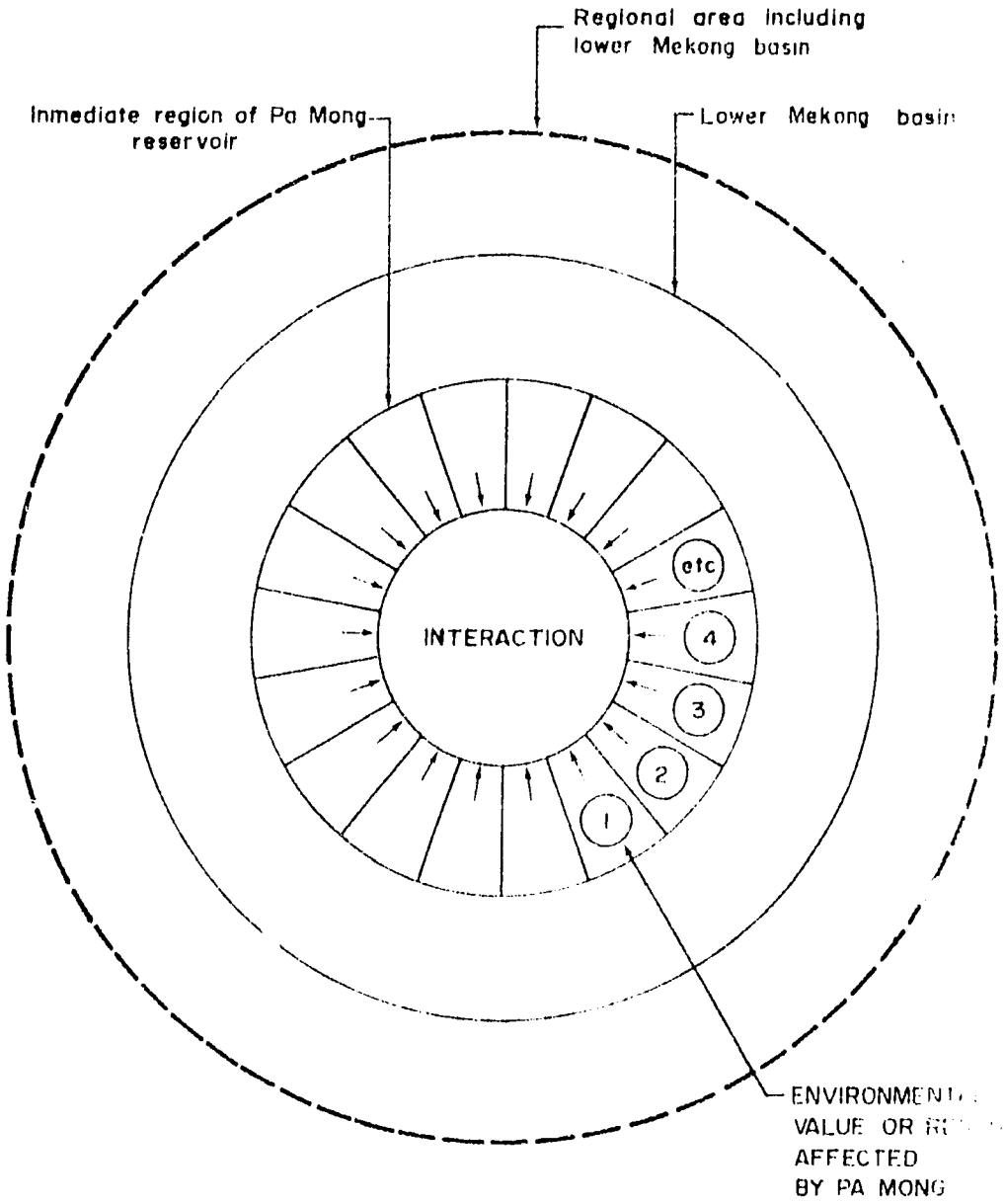



FIGURE 4

SCHEMATIC REPRESENTATION OF PA MONG ENVIRONMENTAL EFFECTS AND THEIR INTER-RELATIONSHIPS

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

### INTRODUCTION

The probable effects of Pa Mong on the environmental values of the lower Mekong basin have been evaluated for each of 28 subject areas which together are believed to include all parameters of significance in environmental impact assessment. Discussion of these has been organized, for ease of reference, by alphabetical order of the title.

With the exception of the category on basic data and tools, all of the subject areas represent environmental resources or values to be affected by Pa Mong. The category on basic data and tools has been included to evaluate the adequacy of the Mekong Committee's programme for collection and use of basinwide basic data for serving the needs of its operating divisions carrying out environmental planning.

The approach used in each evaluation was first to collect, collate, and evaluate all work done by the Mekong Committee and other agencies relating to the subject, and from this data base to develop (1) a picture of the existing environmental situation, (2) the probable effects of Pa Mong, both adverse and beneficial, and (3) adequacy of the Mekong Committee's programme, at the current stage of planning of Pa Mong, for providing proper attention to the particular area of environmental concern. A summarization of all of the environmental effects is given in Chapter IV.

The individual subject areas are the following:

| | |
|---|---|
| Agriculture | Navigation |
| Agro-industries | Power |
| Aquatic biology | Public health |
| Archaeology | Recreation and aesthetics |
| Basic data and tools | Reservoir ecology |
| Climate | Resettlement |
| Construction aspects | Salinity |
| Fisheries | Sediments and erosion |
| Flood control | Socio-economics |
| Geology and seismology | Soils |
| Ground water | Surface water |
| Human ecology | Water quality |
| Irrigation and drainage | Watershed management |
| Mineral development | Wildlife |

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## AGRICULTURE

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# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## AGRICULTURE

### 1. Introduction

Planning for enhancing the agricultural productivity of the lower Mekong basin, taking advantage of the opportunities from water resource development, has been a major aspect of the Mekong Committee's overall programme. The Mekong Committee's agricultural development programme, centered in the Secretariat's Agriculture Division, comprises numerous activities which may be classified into three major categories, (a) experimental and demonstration farms, (b) pioneer agricultural projects, and (c) irrigation planning. Fisheries, also administratively a part of the agricultural programme, are discussed separately. Also, the socio-economic aspects of the agricultural programme are discussed under the heading of socio-economics excepting for the Mekong delta area.

Work on the agricultural development programme was started in 1967 and since then has involved expenditures by the Mekong Committee for studies alone estimated at approximately 70 man-years of professional effort (through 1975) plus approximately $3 million in contracts. In addition expenditures for investments have included about $10 million in experimental farms, $8 million in various tributary irrigation projects, and $21 million for pioneer agricultural projects (with another $62 million scheduled for presently planned projects). Also, annual operating expenditures for the experimental farms in 1975 averaged about $150,000 per farm per year. Because of the importance of agriculture in the overall Mekong development programme, a special Agricultural Sub-Committee was established in 1971 to assist in the agricultural planning activities. All of the activities are implemented through the riparian governments.

The basic philosophy of the Mekong Committee's entire agricultural programme is to guide the continuing development of agricultural practices in the lower Mekong basin so that existing practices can be gradually transformed, so that the maximum yields of the region can be realized on a sustained basis. The Mekong Committee's plan is two-fold, to demonstrate how to achieve maximum sustained productivity, and to plan for applying these methods on a comprehensive scale throughout the basin taking advantage of the increased opportunities resulting from water resource development.

From the point of view of environmental effects, it is envisioned that the Mekong Committee's agricultural programme will result in great benefits to the general welfare

of the region. While it is true that farming of lands previously not farmed will decrease the extent of virgin lands available for wildlife and other purposes, this trend is considered inevitable for meeting basic human needs. Similarly it is inevitable that increase in irrigated agriculture will be accompanied by increasing transpiration or loss of water to the atmosphere that otherwise would be retained in the river system, which conceivably could depreciate some river use values. Also, increased use of agricultural chemicals such as pesticides, herbicides, and even fertilizers will result in some adverse effects on wildlife (and conceivably even on humans) as residuals from these chemicals are absorbed into the environment. Again, however, increasing population growth will require the highest priority be given to increased food production.

## 2. Perspective of agriculture in Pa Mong irrigation area

As a basis for planning its agricultural development programme in the lower basin, particularly in the areas to be affected by irrigation from Pa Mong, the Mekong Committee has studied the history and evolution of farming practices in the region, especially in the last several decades which have been characterized by both rapid population increase and by availability of new technologies for increasing yields. The object of this evaluation has been to assess the potentials of existing cropping methods for meeting future needs and the extent it will be necessary to improve these practices to meet minimum food production levels (Ref. 1, 2).

Since about the end of nineteenth century, most of the lands in the lower reaches of the Mekong and Chao Phraya rivers, including dense inundated riverine and tidal forests, have been reclaimed to become centres for agricultural production. Large forest and savanna areas of the northeast and central plain of Thailand have been newly exploited, so that the paddy areas are now more than 10 times what they were in 1850.

The most significant changes affecting the overall agricultural picture are those taking place the past few decades due to rapid population growth. In the past 25 years the population of northeast Thailand has doubled, and the area of cultivated lands has correspondingly doubled, since an extensive type of farming is practised. The population is expected to double again during the next 25 years; however, of the total area of 17 million ha, eliminating deeply flooded areas, stream beds, communities, and topographically unsuitable lands, the total land suitable for cultivation is 6 million ha. Of this 5 million ha were already under cultivation in 1970. Also, a review of the distribution of paddy and upland fields shows that present paddy fields are located not only on alluvial soils suitable for paddy (recent and semi-recent alluvial soils) but that more than half are located on

more coarse-textured soils less suitable for rice than for upland crops. Also the extent of upland fields is spreading into forest zones as public roads are opened, hence increasing the extent of the total cropping on soils less suited to agriculture (because of their greater erosion potentials). Assuming this trend will continue, the total cultivated areas should use up all the potentially arable lands by 1980. For example, the chanwats where cultivated areas in 1970 exceeded 90 per cent of the arable lands included Nong Khai, Udon Thani, Roi Et, Buriram, and Chaiyaphum. To maintain the expected population growth will obviously require modifications in the existing pattern of agricultural development.

The analysis of the situation in northeast Thailand made in 1973 (Ref. 1, 2) developed the following findings:

(a) For upland farming, kenaf is the only dominant crop, with the yields more a function of soil fertility than rainfall. Before 1966, when every year large areas of virgin lands were exploited, yields were commonly 200 kg/rai or more, but since 1966 yields have declined as the percentage of virgin lands decreased and the percentage of lands repeatedly cultivated increased. Statistical analysis indicates depreciation of overall yields by 50 per cent in about 13.4 years.

(b) The current yield for the paddy areas is about 243 kg/rai. With increasing irrigation and with the increased labor power which will be available, the yield can be increased to 410 kg/rai by 1985 and ultimately to 462 kg/rai by 1995 assuming irrigation services are available to all paddy areas. These figures represent the numerical limitations of the present system of extensive paddy practices, i.e., even with maximum use of fertilizers the sustained yield levels to be expected with current rice varieties are of the order of 3 tons of paddy per hectare. In other words, the production ceiling to be expected from such a development strategy, under the monoculture paddy system, is very limited.

(c) Water will probably prove to be, ultimately, a limiting factor more serious than arable land. Rainfed paddies are erratic in performance and for sustained yields need supplemental water amounting to 280 mm in an average year and 800 mm in drought years occurring every 10 years. The total demand for supplemental water on irrigable paddies in drought years is about 14 billion $m^3$, almost equal to the total watershed

runoff in such years. The maximum water supply potential is about 15 billion $m^3$, assuming it is feasible to store and distribute this amount. Of this 15 billion $m^3$, some 4.5 billion $m^3$ was being stored in 1970, enough for use on about 380,000 ha in the rainy season and 250,000 ha in the dry season. Moreover, for diversified and/or double cropping, the total demand could be as high as 42 billion $m^3$ including the 14 billion $m^3$ for rainy season paddy. The deficit of 28 billion $m^3$ will have to come from another source, i.e., the Mekong river.

(d) By 1980 all of the arable lands in the northeast will have been taken up by agriculture, plus many marginal and sub-marginal areas. Kenaf production will have reached a plateau, and the same situation will likely occur with cassava, the new crop now extensively grown in the northeast. The monoculture paddy system, with extensive irrigation and ample use of fertilizers, will have a production potential of about twice the present level, i.e., about 6 millions tons/year.

The conclusion from these studies is that the resources of the northeast (and of some of the other regions in the lower basin) under present land use practices are quite limited, and that these practices must be modified to meet future needs. The entire agricultural programme of the Mekong Committee is designed to develop and demonstrate methods and technologies to change existing patterns of "accelerated traditional/ declining fertility" farming to sustained yield farming taking maximum advantage of irrigation potentials from projects like Pa Mong.

## 3. Agricultural research and experimentation

A major component of the Mekong Committee's agricultural development programme is a continuing programme of research and experimentation, to develop practicable means by which modern technology can be incorporated with traditional farming methods to result in maximum sustained yields. The research and experimental programme embodies two approaches, first a series of experimental farms located throughout the basin, plus a group of research investigations attacking specific problem areas to produce findings having regional or basinwide application.

### 3.1 Experimental farms

A system of experimental farms in the four riparian countries has been sponsored since 1962 by the Mekong Committee together with collaborating agencies especially the UNDP and FAO. The purpose of these farms is to evaluate,

under controlled conditions, the soil-plant relationships in the irrigated agriculture expected to result from water resource development, including yields, water requirements, costs of production, and farmer reactions. More specifically, the experimental farms are intended to promote crop improvement under conditions of irrigated agriculture both in the dry and the rainy season. For this purpose, these farms have a number of specific objectives, the most important of which are:

(a) Selection of plants for which the experimental farms will recommend cultivation techniques to the agencies in charge of agricultural extension;

(b) Selection of local varieties and improvement of their potential yields;

(c) Import and testing of new rice varieties, selected by the International Rice Research Institute, to test their adaptability and to determine the best growing conditions before proposing them to the extension services;

(d) With local and imported varieties, conducting of tests on requirements for irrigation water, fertilizers, herbicides, and pesticides;

(e) Once the tests have been carried out, proposing new varieties and irrigation methods to farmers operating in the demonstration areas of the experimental farms.

The results of the experimentation and demonstration should be most helpful in assisting the pioneer irrigation projects to progress from the study phases to stages of implementation.

At the present time the programme includes eight experimental farms, with locations as shown in Figure 1, including one in the Lao PDR, one in Thailand, four in the Democratic Kampuchea, and two in Viet-Nam. The selection of sites was made to include a wide range of soils and problems to be experienced in practicing irrigated agriculture in riverine areas, on lowland soils, levee soils, semi-impounded lowlands, upland soils, and seasonally flooded soils. The experimental farms generally have 10 to 20 ha allocated to research and about 300 ha for demonstration.

Table 1 summarizes information on the eight farms (Ref. 19), including some details on the types of research and experimentation involved.

### 3.1.1 Periodic reports

A detailed review of the findings of the experimental

farms programme is given in the Mekong Committee report series, "Periodique Agricole, Stations D'Experimentation et de Demonstration" (Ref. 19). Volume 1, prepared in 1972, presents a summary for each farm from the date of its establishment up to the 1970-1971 growing season. Volume 2, issued in 1974, covers the 1971-1972 period (both rainy seasons plus intervening dry season). A third volume is being prepared to present the results from the 1972-1973 dry season onward.

### 3.1.2 High-yielding rice varieties

One aspect of the experimental farms programme has been an assessment of the potentials of HYV (high-yielding varieties of rice) in the riparian countries (Ref. 5). The HYV were introduced in the basin more than seven years ago. Although they have had a spectacular development in the Vietnamese delta, where they occupy 28 per cent of the rice area and produce almost half the paddy, the role of HYV is still marginal in the other three countries. An analysis of the accumulated experience, both at the experimental farms and under actual farm conditions, indicates the following tentative conclusions:

(a) Even under controlled experimental conditions, the HYV behave irregularly, and do not always yield more than local varieties.

(b) The higher yields of HYV under actual farm conditions can be attained only with high fertilization, and most important with good water control. The HYV are seriously handicapped by their short height and insensitivity to photo-periodism in case of insufficient water control.

(c) Conditions favorable for HYV in the basin are at present more-or-less limited to the Mekong delta where the high population density necessitates higher yields. In other areas use of HYV will be limited to irrigated areas which, even with the projects sponsored by the Mekong Committee, will not exceed 2 million ha by the year 2,000 out of the total 10 million ha now under rice cultivation.

(d) Efforts should be made to increase production of lands where water control is insufficient for HYV, with research directed to improvement of cultural practices to increase soil fertility and obtain higher yields with local selections, and to breeding of new higher yielding varieties adapted to areas with limited irrigation potentials.

## 3.2 Livestock development

In order to develop practicable methods for mixed farming and utilization of irrigation for feed and pastures in relation to Mekong basin development, the Mekong Committee's programme of agricultural research has included some studies and surveys for evaluating the use of irrigation water in

developing forage and pasture land for livestock. The specific activities include (1) use of irrigation water for improving forage crop and pasture, (2) efficiency of different types of feed available in the basin, and (3) survey of livestock and feed enterprises in the basin for a prefeasibility study for a livestock development programme.

### 3.2.1 Cattle stocking rates in northeast Thailand

A modest livestock study, a five-year programme, was initiated in 1969 by means of field experiments at Nong Khai and Khon Kaen in northeast Thailand (Ref. 6). The experiments were designed to determine the cattle-stocking rate or carrying capacity of both irrigated and rainfed grass pasture. The tests included use of grasses alone and of mixed pasture of grass and legumes to determine the areas of irrigated grass and/or legume pasture needed for one grazing animal. The work also included surveys of commercial livestock raising enterprises and of the supply of animal feed in each province of northeast Thailand in connection with planning for local development of agro-industries. The experiments were completed in August 1974, after two two-year experimental cycles.

The main conclusion from the study is, for conditions in the northeast, the availability of irrigation will not offer significant advantages over rainfed livestock raising in most areas. Generally the rainy season will produce sufficient feed to meet year-around needs provided silos are used for storage of feed for use in the dry season.

### 3.2.2 Special studies

Two additional studies on livestock development have been sponsored by the Mekong Committee including an evaluation of the fodder situation throughout the basin completed in 1974 (Ref. 7), and an evaluation of livestock management in the riparian countries completed in 1975 (Ref. 8).

The study on fodder needs in the basin recommended that the Mekong Committee sponsor a programme for increasing livestock production in the basin because of the unsaturated demand for animal products and also for draught animals, based on the constraints imposed by forage quality and availability. The recommended programme would include (a) research grants to institutions in the basin for study of pasture species evaluation and breeding, seed production, and fertilizer needs, (b) training in pasture science at universities and extension training centers, and (c) institutional arrangements to assure availability of reasonably priced high quality pasture seed.

## 3.3 Heavy clay delta soils

The Mekong Committee has participated, together with the Government of Viet-Nam and the Universities of Can Tho, Hawaii, and Colorado State, in a pilot project started in 1974 for

achieving multiple cropping on heavy clay delta soils under conditions of water control. Various field crops are being raised on a 8-ha experimental farm at Can Tho with the application of experimental cropping practices, irrigation methods, and soil treatment. Project funding includes staff, housing, laboratories, equipment, and training of personnel for a period of six years.

A limited research programme was begun in 1974, while awaiting construction of the laboratories and other facilities. This included review of the existing agro-economic situation in selected delta provinces and experimental work on evaporation/transpiration rates applies to rice, percolation tests on heavy clay soils, and fertilizer applications (e.g. for sorghum planted in floating rice areas during the dry season). The 1974-75 dry season programme included testing of wheat production, higher yields of aromatic rice varieties, and production of drought-tolerant rice varieties.

3.4 Rock salt areas

A detailed study of the effects of year-around irrigation on the quality of ground water and return flows in the Lao PDR and northeast Thailand underlain by rock salt was completed in 1973 (Ref. 29). The findings of the study show that irrigation confined to the rainy season will not significantly affect ground water but year-around irrigation will result in significant effects, namely (1) ground water levels will rise from 1-2 metres in floodplains and as much as 3-5 metres in upland areas, hence drainage will be necessary to prevent waterlogging and soil salinization; (2) ground water discharge will increase 10-15 per cent, hence most streams will have a higher baseflow (some intermittent streams will flow perenially); (3) the irrigation will not lead to any dissolving of rocksalt; (4) surface salt seepages will not be increased (may be decreased in certain areas); (5) the irrigation will lead to no harmful effects on water quality in the Mekong or its tributaries, and (6) monitoring of the effects of irrigation is nevertheless desirable to check all possible consequences.

An additional follow-up study was made by the Mekong Committee in 1974 in collaboration with the Land Development Department of Thailand (Ref. 10). This study showed that the local seasonal salinization, which is a widely occurring phenomenon in northeast Thailand, originates from ground water emanating from leached salt-bearing strata which still contain some residual salt even close to the ground surface. Further observations will be made in representative test areas, by personnel of the Land Development Department, in order to make a quantitative evaluation of saline discharge and build-up in the soils of such areas.

## 3.5 Systems analysis of development alternatives

A micro-analysis of possible farm types, using simulation techniques and taking advantage of the large amount of basic data available from studies of the Pa Mong project and other sources, was started in 1973 with assistance from the ILO (Ref. 12). A study of rainfall frequency and local distribution, for determination of rainfall needs for farming and effects of consecutive drought periods in the rainy season, was also begun (Ref. 17). The potentials of irrigated agriculture were further evaluated by a systems analysis of development alternatives in the Lam Pao area in northeast Thailand in 1975 (Ref. 28). These quantitative analyses will form the basis for an assessment of alternative development strategies for irrigation vs. dry farming for the various zones of northeast Thailand.

### 3.5.1 Simulation model applications

This activity began following receipt of a system analysis model developed by TAMS and applied in Turkey, Venezuela, and Ecuador (Ref. 21). The model was further developed by the Mekong Committee and adapted for a computer programme called the Mekong Agricultural System Simulation (MASS), using as input data the extensive material collected for the Pa Mong Stage One feasibility study (Huai Mong division). This work required eight man-months of professional staff time and about 40 hours of a CDC 3600 computer.

The purpose of the MASS programme (Ref. 12) is to demonstate the effectiveness of an agricultural economic simulation model for analyzing agricultural alternatives and potentials under Mekong basin conditions, thus providing a highly effective means for assisting in planning for maximum beneficial use of irrigation potentials. Properly executed analysis precludes options that are impossible, impractical, unrealistic, or uneconomic. Specifically, the MASS programme has the purpose of providing an effective and rapid means for (1) analysing agricultural development alternatives under existing and possible future conditions of farm size, farming methods, soil productivity, mechanization, crops and cropping patterns, each separately for dry land, drained and irrigated production; and (2) analysing farm budgets in sufficient detail to enable the preparation of individual farm operation plans. For the initial MASS programme, the data stream was designed to permit analysis of various alternatives, namely irrigation and rainfed farming, four different farming methods (animal traction, limited mechanization, semi-mechanization, and full-mechanization), nine farm sizes representing the actual situation in the Huai Mong division, 16 soils of different productivity, and 20 crops arranged in three or six-crop rotation as controlled by the relevant farm method. The analysis was made for both market prices and accounting prices.

The model allows for analyzing a choice of various alternatives emphasizing (1) maximum employment, or (2) maximum net return, or (3) minimum capital investment, or (4) minimum credit requirements. The results of the 1974 work are encouraging but still experimental and not yet fully applicable to other areas of the basin without adaptation and further testing, which is in progress. The programme for 1975-76 includes analysis of project areas for which sufficient basic data are available, e.g., the delta and pioneer agricultural project areas, to test the model's output against practical results in the field and also to use the programme for simulating possible farm prices, based on the experience gained on the Kalasin experimental farm for the Lam Pao pioneer agricultural project.

### 3.5.2 Rainfall analysis

The rainfall analysis (Ref. 17) had the objective of determining whether the considerable differences in yields of rainfed paddy in the northeast are related primarily to the rainfall distribution pattern and quantifying irrigation requirements for year-around paddy production. The analysis indicates an average irrigation requirement of about 520 mm, i.e., an annual net water use of 13,000 $m^3$ per farm of 2.5 ha, or 17,000 $m^3$ allowing for 25 per cent farm losses, assuming all irrigation labor will be from the farm family without hired help. An evaluation of the relationship between rainfed crop yields and rainfall showed the relative rate of plant growth (hence plant yield) depends upon the mean soil moisture stress in the active root zone. An adaptation of the Hedges and Moore model incorporating this relationship appears applicable to conditions in the northeast.

### 3.5.3 Lam Pao irrigation alternatives

The systems analysis at Lam Pao included 19,000 ha in a new irrigation service area receiving water from Lam Pao reservoir which was completed in 1968 (Ref. 28). While the Kalasin Experimental Farm, in studying irrigated rice cultivation in the Lam Pao project area, had demonstrated the physical feasibility of significantly increasing crop yields and of double-cropping, little utilization of the Lam Pao irrigation system has been made because of farm distribution and management problems. The irrigation system is underutilized and little double cropping occurs for a number of reasons including the unsuitability of the local rice during the dry season for reasons of photoperiodicity; hence high-yielding non-photosensitive varieties must be used. However, these are sensitive to inundation depth, requiring careful control of irrigation which in turns required near-capacity operation of the system (water delivery to small and scattered areas is impractical). Also, the high-yielding varieties require more fertilizer thus more credit. Also, production techniques with the high-yielding rice varieties differ somewhat from traditional methods. Finally, the income

to accrue from irrigated rice production in this area (representative of northeast Thailand) is considered relatively small compared to the risks in undertaking a new type of cropping venture.

The study was aimed at demonstrating a feasible approach to irrigated rice cultivation by minimizing needs for capital investment and for credit, and maximization of employment and net return. Among the variables considered were 20 crops, 11 farm sizes, dryland and irrigated conditions, 18 irrigation units, market and accounting prices, 3 farming methods, and 11 soil bodies. The analysis was conducted using a simulation model and a CDC 3600 computer for processing about 30,000 data inputs (exclusive of soils information).

### 3.6 Soil stabilization

Another research activity, authorized in 1974, is experimentation on stabilization of soil structure on canal embankments and on arable lands, with the initial work to be limited to northeast Thailand and the Lao PDR (Ref. 22). This project will evaluate the feasibility of using bituminous compounds and other means for stabilizing canal embankments which commonly are left exposed because of the high cost of paving. The banks are rapidly eroded by rain, even for the flatter bank slopes, due to a lack of soil particle coherence characteristic of many soils in the basin especially in northeast Thailand. Hopefully the use of such compounds will be an affordable substitute for expensive paving.

### 3.7 Delta soil fertility

Because the Pa Mong dam will serve to trap silt, there is apprehension that Pa Mong might lessen delta fertility. An evaluation of this potential was made for the Mekong Committee by the University of Hawaii in a report submitted in January 1974, "The Composition of Mekong River Silt and Its Possible Role as a Source of Plant Nutrient in Delta Soils" (Ref. 15). The study included analyses of the mineralogical and chemical composition of Mekong river sediment and of soils of the Vietnamese portion of the Mekong delta. River sediment samples were collected at regular intervals from October 1972 to May 1973 at Long Xuyen, Cantho, and My Tho in Viet-Nam. Soils were collected along transects running perpendicular to the river at locations near the sediment sampling sites.

Small but significant difference in mineral, chemical, and acid extractable nutrient content were measured between sediment and soils. The sediment samples were higher in mica, hematite, kaolinite, feldspar, and chlorite-montmorillonite and lower in quartz contents. The sediment samples were also higher in magnesium, phosphorus, potassium, calcium, and manganese and lower in aluminum contents. The readily extractable phosphorus, potassium, and calcium contents were also higher in the sediment than in soil samples.

Based on these data, the quantity of phosphorus, potassium, magnesium and calcium added to a soil each year by sediment was computed assuming a yearly deposit of silt one millimeter thick with a bulk density of 1 g/cm$^3$. The readily soluble nutrients which would thus be added each year to a one hectare area amounted to 1.0 kg P, 3.2 kg K, 4 kg Mg, and 50 kg Ca. It was concluded that even if these computed values were doubled, the sediment deposit could not significantly increase the fertility of delta soils.

Examination of the soils data confirmed the above conclusion. It had been assumed that soils near the river bank would receive a larger quantity of sediment and therefore would contain more soluble nutrients than soils away from the river, but the data showed no significant difference. Soil texture and soil moisture release data also did not vary with distance from the river channel.

Based on mineralogical, chemical, and physical analyses of sediments and soils of the delta, it was concluded that the annual deposition of sediment does not measurably increase the fertility of Mekong delta soils and moreover that water control, not soil fertility, will be the dominant factor through which large increases in delta agricultural productivity can be realized.

### 3.8 Ad hoc panel of environmental consultants

The final report of the ad hoc panel of environmental consultants included a number of recommendations for additional research activities. These included (a) studies of the potentials of water control to reclaim large areas of soils both in northeast Thailand and in the delta which are now too saline for productive use, and similarly to reclaim extensive areas of acid sulfate soils (up to 1 million ha) in the delta, (b) studies of potential problems of pests (insects, fungi, bacteria, viruses, nematodes, rodents, and weeds) and of plant diseases which may result from the planned wide application of irrigated agriculture in the lower basin, and (c) evaluations of the potentials of waste recycling and of improved home gardening in rural villages to increase agricultural productivity and income.

All of these proposals are being considered as possible new research activities, including possible incorporation into the experimental farms of pioneer agricultural projects programmes. All represent worthwhile endeavors, but are presently considered to have a lower level of priority compared to the projects already underway or authorized, which deal with the primary problem areas as they may be discerned at this time.

## 4. Pioneer agricultural projects

Unlike the experimental farms, which are designed for

research to test new technologies under controlled conditions, the pioneer farms are intended to demonstrate how a successful farming community operation can be established as promptly as possible, so that the results can be progressively applied to implement major regional irrigation schemes. The concept of the pioneer project is to demonstrate at full working scale the feasibility of modern sustained yield farming practices under a variety of conditions, representing each of the major soil types and cropping patterns found in the basin, to realize maximum benefits from water resources development projects such as Pa Mong. The term "pioneer" was selected for these projects because their primary purpose is to develop a new system of farming practices, including appropriate forms of institutional organization, farmer assistance programmes, size of farm units, farmers' organizations, and related matters so that the desired new farming practices can be applied with confidence throughout the region.

All of the pioneer projects are intended to be full-scale models in which solutions can be found for both physical and human problems, hence must be of sufficient size to encompass the full array of physical and institutional problems likely to be encountered in the subsequent large undertakings. Also, in view of the close relationship between irrigation and dry farming, and to provide a basis for judging the increases in agricultural production that can be expected from irrigation, the programme includes two projects in the rainfed (dry farming) areas. These projects in total will provide a basis for planning efficient basinwide utilization of agricultural resources.

The pioneer projects included in the Mekong Committee's plans represent the largest such programme for water resource projects yet undertaken. The concept of the pioneer project is believed to have originated in the Sudan in the 1930's, for demonstrating methods for cotton cropping, and has also been used in the Euphrates river zone in Syria from 1953-66. It was first suggested for the lower Mekong basin by an FAO expert in 1967.

## 4.1 Projects included in programme

At present a total of 15 pioneer projects are included in the programme. They are listed in Table 2 with locations shown in Figure 1. A UNDP Plan of Operation, approved by the Mekong Committee, UNDP, World Bank, Asian Development Bank, and four donor nations in 1971, and extended in 1973, includes 12 of these projects. The other three projects, at Nong Wai, Lam Pao, and Manchai Kiri, all in Thailand, were established earlier hence are not included in the UNDP Plan of Operation.

The total area included for the UNDP projects (Ref. 4) is approximately 65,000 ha, with the expectation that findings will be applicable to some 2,400,000 ha in the basin. The estimated total programme cost is $65 million including

$ 7.5 million for design (farm systems and facilities for irrigation, drainage, roads, etc.): $40 million for construction including on-farm development; $ 12.4 for initial operation (5 years); and $ 5 million for supporting an advisory activity (monitoring of all the programmes, collection, collation, and publication of information).

The programme for implementing the UNDP projects includes several successive phases, namely preparation, construction, and operation. By preparation is meant preliminary design of the project including defining its nature, scope, and operating concepts as well as estimates of costs for construction and operation. After approval of the preparation report the project is ready for final design and construction.

4.2 Problems being investigated

The following is a summary of the major problems which other countries have experienced in attempting to establish irrigated agricultural systems, which are being considered in planning and implementing the pioneer projects:

(a) Irrigation water supply: The design of the distribution facilities must suit the particular crop/soil needs to provide adequate irrigation without erosion and excessive water loss. The water must be available to the farmer to protect his investment when he needs it (to prevent wilting): this means designing on the basis of "demand" as well as "rotation".

(b) Non-irrigable lands: Many projects have experienced serious problems with soils on project lands, including accumulations of salts and alkali, water logging, erosion, etc., hence selection of project lands must minimize inclusion of such soils. Also, improper leveling can expose subsoil, hardpan, or gravel. Sprinkler irrigation may be a feasible alternative to such leveling.

(c) Drainage: Drainage must be an integral part of the design, especially for multiple cropping. Possibilities for reuse of drainage water should be considered within the limits of acceptable water quality.

(d) Operation and maintenance: Common problems are loss of canal capacity because of silt deposition or weed growth and malfunctioning of diversion structures. Usually some type of community sponsored maintenance programme is needed to furnish maintenance services at affordable costs.

(e) Water control. Usually open ditch gravity conduits must be used, both for water supply and drainage. This means obtaining right-of-way to

assure access to all farm units. This may result in splitting of existing operating units to such an extent it may be advantageous to redelineate the operating units so they can be served more economically.

(f) Farm unit development: The fields must be prepared for irrigation with the land preparation compatible with the method of irrigation used (flood or furrow).

(g) Farm management practices: This means the choice of selection of crops, fertilizers, insect control measures, irrigation frequencies, etc.,all of which depend upon experience. Because few farmers can be expected to have irrigated agriculture experience, provision of good extension services will be very important.

(h) Farm supplies and equipment: Arrangements must be made for local merchants to stock the necessary supplies and equipment.

(i) Credit: Many farmers will need local sources of credit at reasonable interest rates including long-term credit to finance expenses for buying, clearing, leveling land, building homes, etc.; intermediate-term credit for livestock and equipment; and short-term credit for current production expenses.

(j) Public service: A reasonable minimum of community facilities (roads, water supply, schools, etc.) must be furnished to help establish the area as a satisfactory community. This means preplanning of villages or other types of community settlements.

## 4.3 Items included in project preparation

Based on the considerations noted above, each project plan includes or will include provision for the following:

(a) Physical organization

(1) Selection of project area and project lands.
(2) Prediction of farming system.
(3) Calculation of water requirements.
(4) Design of water supply and drainage facilities.
(5) Determination of methods of delivery of water.
(6) Design of infrastructure facilities (roads, storage, processing industries, etc.).
(7) Construction of all structures and facilities.

(b) Human organization

(1) Establishment of organization for operation and maintenance.

(2) Establishment of water users organization to manage the project affairs.

(3) Establishment of government mechanisms to assist farmers, issule land title deeds, assign water rights, provide community water supply, schools, and health facilities.

4.4 Monitoring

Because the major aim of the pioneer projects is learning how to do a better job of organizing physical and human resources for efficient farming under the new conditions, a monitoring system is essential to collect, collate, evaluate, and disseminate information based on the evolving experience at each project. The monitoring system, to be financed as part of the overall programme budget, will function both basinwide and within the projects. To maximize the dissemination of information, local institutions will be utilized to the extent feasible for data collection and analysis.

4.5 Financing of projects

The pioneer projects can hardly be expected to be profitable in themselves although some might be. Because they are learning experiences, some of their costs must be considered part of the overall expense of water resource development.

4.6 Current status

Table 2 presents a summary of pertinent information briefly describing each of the pioneer projects and its current status. The preparation plans for most of the projects were completed by the end of 1974 or in early 1975.

5. Irrigation planning

Another important aspect of the Mekong Committee's agricultural programme is application of the currently available technology for development of preliminary master plans or bases for master plans for agricultural development in selected regions of the basin.

5.1 Vientiane plain

A study identifying eight priority irrigation projects within the Vientiane plain, commissioned by the Asian Development Bank (ADB), was completed in 1969. A feasibility report on pump irrigation in the Vientiane plain was completed in 1970 by the U.S. Bureau of Reclamation (USBR), independently of the ADB study.

In 1974, the Vientiane Plain Development Authority continued work on construction and initial operation of one of the

priority irrigation projects identified in the 1969 study, Tha Ngone, with assistance from ADB and the Government of Japan. The Governments of India and France submitted feasibility reports to the Government of the Lao PDR on the Mak Nao and Thadeua projects, respectively. These three projects, Tha Ngone, Nak Nao, and Thadeua, are being prepared within the context of overall development planning for the Vientiane plain arising from the studies by the ADB's consultants in 1969 and the USBR in 1970. In addition, the development of the Casier Sud area of the Vientiane plain is included in the pioneer agricultural programme.

Another of the eight priority projects referred to above, Kao Liao, in 1974 was the subject of preliminary planning by the Mekong Secretariat and the Vientiane Plain Development Authority, in order that the first phase of the proposed Kao Liao pump irrigation project be prepared for early implementation. This would be a 1,000-hectare development within the 10,480-hectare project area, which is situated close to the western outskirts of Vientiane. The purpose of the project is to develop the initial 1,000 hectares for intensive irrigated agriculture, the water to be pumped from the Mekong river using low-cost electricity available from the Nam Ngum hydroelectric scheme. The proposed development will permit the integration of refugees - now in scattered settlements in the Kao Liao area - into an orgnized farming community. Both the ADB's consultants (1969) and the USBR (1970) concluded that the Kao Liao project would be economically one of the most attractive projects in the Vientiane plain development programme. An updated cost estimate for the 1,000 ha first phase gives a total overall cost of $ 1,387,000 made up of $ 940,000 in foreign currency and $ 447,000 in local currency.

## 5.2 Mekong delta

### 5.2.1 Dutch team report

The agricultural potentials of the Mekong delta which includes 1.6 million ha in Democratic Kampuchea and 3.9 million ha in Viet-Nam, can be considerably enhanced through opportunities stemming from water resource development. The Mekong Committee together with the Netherlands Government undertook a four-year programme in 1970 to provide a basis to be used by the riparian governments in preparing masterplans for agricultural development in the Mekong delta, including preliminary design of selected specific projects. This project was completed in April 1974 with submittal of the main report, "Recommendations Concerning Agricultural Development with Improved Water Control in the Mekong Delta", together with two appendices and several working papers, as follows (Ref. 9):

| | |
|---|---|
| Appendix A | Evaluation of possible development |
| Appendix B | Identification of further investigations |
| Working Paper I | Impact of rainfall and floods on paddy productiion |
| Working Paper II | Climate and analysis of evaporation and rainfall |
| Working Paper III | Flood demand for 1970-2000. |
| Working Paper IV | Hydrology |
| Working Paper VA | Land resources |
| Working Paper VB | Social and economic aspects |
| Working Paper VI | Irrigation and drainage |

The entire four-year study included a professional input by the Dutch team which carried out the study estimated at approximately 25 man-years.

A brief summary of the study is presented as follows:

(a) Evolution of farming in delta: Technical development of the delta was started in the first decades of this century, and since then a large number of canals have been dug to open up new areas and to improve drainage conditions. Little has since been done to develop agriculture by improvement of water control except for improving the main drainage canal systems and the recent introduction of pumps for irrigation used by individual farmers. Of the total area of 5.5 million ha in the Mekong delta, only 50-60 per cent is cultivated. The remaining land has been unsuitable because of flooding or unfavorable soil conditions (salinity, acidity, toxicity). About 90 per cent of the cultivated area grows one crop of rice per year. Floating rice is grown in areas with deep flooding and transplanted rice in areas less deeply flooded. High-yielding (HYV) rice cultivation is expanding rapidly in the Vietnamese part of the delta. Of the total delta cultivated area, about 5 per cent is double cropped and 5 per cent used for crops other than rice. Total rice production is 4.7 million tons/year in the Vietnamese delta and 1.1 million tons/year in that portion of the delta in Democratic Kampuchea.

(b) Present situation:

(1) Climate: Rainfall is a major constraint for year-around cropping. Without irrigation only one crop of rice per year can be grown, and yields are often reduced by dry or wet spells.

(2) Water resources: Water control measures, such as drainage, irrigation, protection against sea water intrusion, and flood protection will be the main features of agricultural development. The water entering the delta averages 14,300 $m^3$/sec, ranging from an average maximum in September of 41,500 $m^3$/sec, and an average minimum in April of 2,000 $m^3$/sec, and flows mainly to the South China Sea through a system of branching rivers. During the flood season large areas of the delta are flooded (up to 3-5 m in some places), while also large quantities are stored in the Great Lake which functions as a buffer reservoir. Some of the water flows overland towards the Gulf of Thailand and some is drained by the Western and Eastern Vaico. Upstream dam projects, including tributary and mainstream projects, can be expected to increase the average low flow by 1,000-2,500 $m^3$/sec within 20-30 years, and to reduce flood levels in the deeply flooded areas by about 1 m. As part of the study a mathematical model was constructed to study the discharges and water levels of the river branches downstream of Phnom Penh. This showed that distribution of the downstream flow among the river branches is a function of both the magnitude of the river discharges and of tidal conditions.

(3) Seawater intrusion: Seawater intrusion makes much of the water in the downstream parts of the river branches unsuitable for irrigation, with the extent of intrusion depending mainly on the river discharges and the depth of the bars in front of the estuaries. Seawater intrusion not only affects water quality in canals and creeks but at high tides can flood adjacent land areas. Extraction of fresh water for irrigation from the river branches or creeks and canals will increase the intrusion, and the increasing application of sampan pumping is having this effect. Direct seawater intrusion from the sea through canals and creeks can be prevented through use of small enclosures. Salinity of irrigation water should not exceed 1 g/l during rice transplanting nor 4 g/l during the end of the growing season. Four different salinity zones are delineated.

(4) Soils: More than 90 per cent of the delta land has heavy clay soils which are more

suitable for rice than other crops. Very acid soils are common in the Ha Tien Plain and Plain of Reeds, and acid to very acid soils are common in the central part of the Trans-Bassac. Most of the delta soils have a low to moderate fertility level, hence more fertilizers will be needed to maintain higher production levels.

(5) Irrigation and drainage: Drainage is generally poor due to the flat terrain throughout the delta. The recent trend for use of sampan pumps for irrigation has expanded double cropping of rice from a few thousand to 150,000 ha. The water duty is about 1.1 liter/sec/ha for two crops of rice per year, and less for other crops. Drainage criteria, based on a three-day rainfall with a return period of 10 years, vary from 1.7 to 4.4 litres/sec/ha for short stem rice and from 0 to 2.3 litres/sec/ha for long stem rice. Irrigation throughout the year is not possible by gravity alone in most areas but along the main rivers this can be achieved if supplemented by local farm pumping. Year-around drainage by gravity is possible in parts of the coastal area due to tidal fluctuations. The study divides the total delta area into "main land units" (See Figure 11 of Main Report) having more-or-less common characteristics with respect to soils, topography, flooding, drainage conditions, and current land use.

(6) Population vs. farming: Of the 6.7 million population in the Vietnamese delta, 60 per cent depend mainly on farming for their living. Availability of farm labor is not a constraint for agricultural development but there will likely be a growing problem of unemployment. Of the 3.0 million population in delta in Democratic Kampuchea, about 70 per cent are farmers (under normal conditions).

(7) Socio-economic conditions: While the Vietnamese may tend to resist farmers' mutual cooperation projects, they are very responsive to innovations and willing and able to take advantage of new opportunities. The present annual income from rice cultivation is about US$ 550 per farm family of 6 persons. The farmers in Democratic Kampuchea are more tradition oriented, hence educational means will be needed as the basis for introducing

new methodology. The present annual family income from rice cultivation is about US$ 250 per family of 5.2 persons.

(c) Scope for agricultural development: Agricultural development of the Vietnamese delta, without the undertaking of new water control projects, could meet the national domestic demands for rice for the coming decades. Accelerated development of the delta by means of water control projects will lead to a surplus of rice. However, even in the first case without control projects, part of the production should be exported in order to counterbalance import of commodities like fertilizers, mechanical equipment, fuel, etc. Farm income will likely remain at the same level assuming the agrarian population growth is 2 per cent per year.

(d) Development potentials:

(1) Improved agricultural practices: Four land suitability classes have been distinguished to indicate the relative suitability of different land units for improved crop cultivation. They assume adequate water control for at least one crop per year and a high level of farm management, including liming for reclamation of acid and very acid soils. The study presents estimates for present and obtainable rice yields with different degrees of water control and requirements for fertilizers, pesticides, and lime for each land unit of the delta. Under optimum conditions the yield of floating rice is set at 2 t/ha, of local transplanted rice at 3 t/ha, and of HYV rice at 5.5 t/ha.

(2) Improved water control: The existing network of major canals and creeks in the delta is characterized by large variation in the configuration of parcels and smaller creek and canal patterns. The study analyzes various alternative schemes for achieving irrigation and drainage, and low level vs. high level systems. For different areas of the Vietnamese delta the applicability of these alternatives are presented, along with possible sequences for the development of the irrigation and drainage systems. Potential limits for extraction of freshwater from each river branch by months were determined considering double cropping in the coastal area, year-around cropping more upstream, and seawater intrusion.

(e) Development possibilities: Without major improvements (the "without case" in water control) paddy production in the Vietnamese delta may increase in 20 years from the present 4.7 to 9.1 million tons/year. Development possibilities for rice cultivation with improved water control were delineated for a large number of "development units", a development unit being an area of more-or-less uniform conditions. A combination of a certain cropping pattern uniformly applied to the whole unit with a certain degree of water control is called a "development case". Development cases can be applied to a development unit more or less independently from developments in adjacent units. Development cases are considered both with and without irrigation during the low flow period. A total of nine development units were defined, with emphasis on rice cultivation, including the "without case" of no water control. A combination low level irrigation and drainage system was chosen for the first stage of delta development, wherein farmers pump for irrigation and drain by gravity. For each unit the costs for constructing the needed facilities were estimated including inlet and outlet structures. The anticipated economic returns, based on present worth and internal rate of return, were computed for each unit (Appendix A of report, Ref. 9b).

(f) Development planning: The development units were arranged in groups, each forming a region with similar agricultural potential as affected by seawater intrusion, floods, gravity conveyance of irrigation and drainage water, and soil acidity. Recommended priorities were indicated for development of water control projects by regions, beginning with the areas between and along the main river branches.

(1) Ultimate development: Without any increase in low flow, a maximum of 1,220 $m^3$/sec of water will be needed in February for irrigating 1,122,000 ha, which equals almost the allowable extraction, and a maximum of 530 $m^3$/sec in April for irrigating 480,000 ha. For development with an increase in low flow, only a limited increase and no reduction in flooding was assumed. The irrigation requirements in April will reach 1,125 $m^3$/sec, which means an increase in minimum low flow discharge from 1,200 to 3,200 $m^3$/sec, totaling 6.5 to 27.1 billion $m^3$ dry season upstream storage release. The investment in facilities (pumping, canals) is about $ 45 million.

(2) Economic aspects: The economic evaluation indicates that development of many of the regions with increase in low flow will be very attractive. Also, through such development carrying capacities will generally be increased considerably compared to "without case" projections. With reference to crop diversification, many regions are poorly suited for crops other than rice because of saline groundwater or other factors; however, some regions are well suited for fruit trees and upland field crops. Details of the economic analyses are presented in Appendix A of the report. This describes the relative economics of rice production in the delta for each of 97 units in the delta (having similar topography, soil characteristics, and cultivation practices), grouped into 13 regions, for 9 different "development cases" (DC's) including DC1 (the present situation), DC2 (without project improvements), and DC3 to 9 for the variety of levels of improved water control considered. The expected benefits and costs were computed for each unit to get the present worth and also the yearly income to the farmers for each unit for each case. The factors considered in the analysis include net arable area, cropping intensities and yields, gross production value, non-factor inputs (costs other than rent or family labor), and net production value (NPV). Project benefits are defined as NPV "with project" minus the NPV "without project".

(g) Socio-economic aspects: Attemps to establish water users associations might be difficult in the Vietnamese delta, hence the alternative strategy is to use the existing village organization, together with establishment of governmental organizations at different levels (projects, regional and delta) to establish and implement water policies. Attention should be paid to marketing and credit facilities with adequate sales potentials for farm produce and supply of farm inputs at reasonable prices. The extension programmes should be kept in pace with the needs of the farmers. Facilities for health, education, and service centres also need to be provided. A masterplan for agricultural development of the delta should be incorporated into an integrated regional plan which in turn must fit into the national plan. A possible institutional structure for development administration is included in the report.

(h) Further surveys and investigations: The report of April 1974 was based on the then available data including limited field observations. For completion of a master plan for delta agriculture further surveys and investigations will be needed (Ref. 9c) as follows:

(1) Land resources and crops: Experimental testing is needed for selecting and cross-breeding of transplanted local and other varieties of rice, for the selection and cross-breeding of floating rice (especially in acid soils), for investigating promising rice varieties for varied soil or hydro-meteorological conditions, for experiments with rice on very acid soils, and for studies for other crops suited to the delta. More detailed field surveys are needed for evaluation of soils (including suitability for different crops) in areas where little soils information is now available, and for rice sampling for determining on an annual basis the productivity of different main land units. Extension services including field demonstrations and publicity are needed for reliable promulgation of the developing information.

(2) Water resources: Primary, secondary, and tertiary benchmark systems should be installed for topographic surveys needed for project design. Irrigation and drainage studies are needed for evaluating evapotranspiration rates, effective rainfall, and percolation and conveyance losses, for evaluating soil physical properties, for delineation of present configurations of land parcels and waterways, for evaluating economical low lift pumping methods, and for studying erosion of embankments. A hydrologic basic data programme should be established, sufficient to permit operation of the delta tidal model to quantify relationships between freshwater extraction and seawater intrusion, including measurements of discharge, salinity, acidity, rainfall, sediment, and water quality.

(3) Socio-economic aspects: Reliable demographic data are needed including information on job mobility, job preference, migration and urbanization trends, social structures, potentials for farmers' associations, price mechanisms, land fragmentation, land tenure legislation, and land consolidation. Institutional studies are needed on

the capacities of the government agencies to manage agricultural development.

### 5.2.2 Follow-up action

In 1974 the Netherlands team was requested to identify and formulate projects suitable for early implementation in the Vietnamese delta. The team selected five such projects mainly on the basis that they should be easy to implement, require only a modest investment, be economically and socially attractive, and be compatible with any long-range delta development plan that may be put into effect later. The five projects are:

(1) Ke Sach, near Soc Trang (irrigation: 13,000 ha first phase, later increased to 25,000 ha).
(2) Can Tho (irrigation: 12,000 ha first phase).
(3) Huong My, in Kien Hoa (irrigation: 12,200 ha first phase).
(4) Kien An, SE of Rach Gia (irrigation: 12,200 ha first phase).
(5) Quan Long, in the Cau Mau peninsula (salinity protection without irrigation: 20,000 ha first phase).

Ke Sach has been selected for the first priority project. The Netherlands has been asked to assist in preparing an overall plan for this development (60,000 ha), including designs and tender documents for the 25,000 ha first phase, and implementing at least part of the project.

## 5.3 Flood control effects on downstream agriculture

Because of concern about the effects of flood control at Pa Mong on downstream agriculture, especially in Democratic Kampuchea, detailed studies to quantify these effects have been carried out by the Mekong Committee resulting in a preliminary report in 1975 (Ref. 24). As shown by this study, the agricultural lands of Democratic Kampuchea may be classified into two general categories, upland and lowland, the uplands being drainage areas subject to water deficiencies reflecting the poor rainfall of the area and the lowlands being subject to prolonged flooding. Whereas the uplands are generally subject to drought and would require large investments in irrigation facilities to become very productive, the lowlands are fertile and could become very productive if the traditionally severe flooding could be brought under control. The extent of arable lands which might be relieved by flood control, while not significant in the Vietnamese delta, are very sizeable in Democratic Kampuchea. This includes 184,000 ha in the Great Lake area; 1[illegible]7,[illegible] ha on the left bank of the Mekong; and 53,000 ha in Grans Bassac.

The SOGREAH mathematical model of the Mekong delta, developed in earlier studies by the Mekong Committee, was

utilized in this study to obtain the stage hydrographs. A detailed contour map (interval of 1 m) was prepared using the available 1:50,000 scale maps. Also, use was made of ERTS-1 satellite imagery for investigating macro-topographical characteristics of the region. Four years with different magnitudes of flood were selected as test-years, namely 1940, 1957, 1961, and 1963, representing two of the highest and two of the lower floods occurring in the available 36 years of records. From the hydrographs for each unit area considered estimates were made, for conditions with an without Pa Mong, of the peak sustained water level, increment of flood-free acreages resulting from flood control, maximum depth of water, maximum rate of water rise, duration of inundation, and duration of peak water level.

The study also took into account the characteristics of the types of rice, the predominant crop in the region except on levees and on the upper parts of levee backslopes ("chamcars") where dry-foot crops are usually grown. Six varieties of rice were considered, with respect to the water conditions, topography, and soils to which they are adapted as shown in Table 5. Another table (Table 6) was prepared to show relationships between hydrologic conditions and productivity of floating and ordinary rice varieties. For the dry-foot crops, similarly, the decisive factors influencing productivity were taken into account, namely the extent of flood-free periods and the soil fertility which is believed to be replenished by silt deposited by floodwaters. Chamcar lands are farmed either in the pre-flood or post-flood seasons, or both, to avoid submersion.

(a) Effects on present cropping practices

The results of the analysis, in terms of impact on agricultural practices due to flood regulation, assuming a maximum release of 2,000 $m^3$/sec from Pa Mong during the flood season, may be summarized as follows:

(1) The primary causes of rice crop damage (other than pests and diseases) are floods in the low-medium elevation parts of the lowlands, and drought in the medium elevation-higher parts of the lowlands and in all terrace areas.

(2) With Pa Mong, the total area cultivatable with floating rice in Democratic Kampuchea will increase from approximately 4,950 $km^2$ by 2,600 $km^2$ (about 52 per cent); also, of the total area useable for floating rice some 2,670 $km^2$ will become suitable for ordinary rice varieties (which have yields higher in amount and quality). This means

extending the ordinary rice growing farmlands forward into the lowlands.

(3) With Pa Mong, flood damage on transplanted rice grown in medium elevation-high lands would be virtually eliminated.

(4) Chamcar lands suitable for agriculture will be markedly expanded with Pa Mong, the increase ranging from 1.7 to 3.2 times, averaging about double (from 38,600 ha to 72,600 ha). This will increase the farmable areas in Kandal Island and Muk Kompul floodplain (two of the most important chamcar areas) from approximately 20 to 40 per cent of the gross area. On the average, with Pa Mong the flood will reach the chamcar about two weeks later and recede about two weeks earlier, hence there will be (a) less risk of total crop failure due to submersion by "unseasonal" floods, (b) opportunity for later planting (or sowing) of pre-monsoon crops, so pre-monsoon rainfall may be more efficiently utilized, (c) opportunity for earlier planting of post-monsoon crops, allowing more time for land preparation and for crop growth, and (d) more flexibility in crop diversification and scheduling.

(b) Effects on colmatage silt deposition

An analysis was also made (Ref. 24, Annex 2)of silt deposition in delta in Democratic Kampuchea as affected by Pa Mong, as an extension of the study noted above, especially of deposition on the chamcars where the soils are believed to be replenished by fresh silt brought in by flood flows. In Democratic Kampuchea in particular there is concern that mainstream flood control would reduce sediment deposits in the delta and, for the chamcars, if the soils are not refreshed by minerals supplied by flooding, the soil physical and chemical properties might deteriorate. This study established the silt concentration in the Mekong as a function of the magnitude of flow at various points along the river, and assuming storage at Pa Mong will remove all incoming silt, then it is assumed the downstream river will resuspend silt to some portion of its without-Pa Mong value, namely 50, 75, and 100 per cent. The results of the analysis have been summarized as follows:

(1) With respect to amounts of silt deposited in the delta in Democratic Kampuchea, the affected area can be divided into three

zones, namely the upstream zone, the Phnom Penh zone, and the downstream zone. The caluclated amounts of sediment being received by each zone, without Pa Mong, are shown in Table 7. As shown in the table, the downstream data correspond roughly with the University of Hawaii study's estimation of 1 mm deposition per year in the Vietnamese delta. Also, the upstream deposition is far more than downstream, especially in flood years. The table also shows the expected deposition in Democratic Kampuchea with an efficient system of colmatage (a canal system designed for conveying turbid flood waters onto the chamcar so silt will be deposited at the canal system outlets thus replenishing the land or creating new arable land). The silt deposition varies greatly with the flood magnitude, hence in the Phnom Penh zone significant silt deposition occurs only in high flood years. In the downstream zone sedimentation is insignificant even in high flood years.

(2) The expected depths of sediment with Pa Mong are also shown in Table 7. Thus, in high flood years the total silt deposit with Pa Mong is reduced to 25-30 per cent of the without-Pa Mong values for the upstream zone, to 40-50 per cent in the Phnom Penh zone, and to 20-30 per cent in the downstream zone. In normal flood years the percentages are 10, 10, and 30 per cent respectively. With Pa Mong the normal flood year's silt deposition is almost negligible except with efficient colmatage. Without Pa Mong the amount of deposition in normal years (every two years) is about the same as the amount with Pa Mong in flood years (once every 10 years). The reduction in siltation is primarily due to the reduced flood volume caused by the dam, much moreso than the reduced concentration of silt because of silt-trapping in the reservoir.

(3) With an efficient colmatage system, siltation is about 20 mm in normal years and 25 mm in flood years under without-Pa Mong conditions, whereas with inefficient colmatage the amount of siltation is relatively low. With efficient colmatage the sediment depth fluctuates less from low to high flood years and the effects of Pa Mong are much less as compared to areas

with inefficient colmatage. In normal flood years the deposition with efficient colmatage will be about 5 to 6 mm.

(4) Inspection of satellite imagery shows that engineered colmatage systems designed to end where silt deposition is desired are far more efficient than natural colmatage systems ("preks" or small creeks) which tend to carry out much of the silt that comes in.

(c) Future studies

The studies noted above will be further developed and strengthened when it is possible to conduct field observations to reinforce the office studies already made. Also, additional possibilities of benefits from flood control are to be investigated, for example, possible control of "black water" which seasonally develops around the periphery of the Great Lake due to anaerobic decomposition in the shallow marshes remaining during the dry season. These black waters spread onto paddy areas as the lake level rises when rains begin, causing extensive damage both to plant life and fish.

The studies described above, as previously noted, assume the maximum release from Pa Mong during the flood season (1 July - 31 October) will be held to 2,000 $m^3$/sec, which is achievable with a Pa Mong high pool level of 260 m MSL. For lower high pool levels the extent of flood regulation would be decreased, resulting in lesser levels of effects on agriculture in Democratic Kampuchea. Further studies are underway for quantifying these effects for maximum pool levels of 250, 240, and 230 m.

## 5.4 Additional projects

### 5.4.1 North Phnom Penh polder

In 1972 the Government of Democratic Kampuchea constructed a polder with 13 km of diking northwest of Phnom Penh, to protect about 11,100 hectares of land from flooding (Ref. 13). In 1973 the Mekong Secretariat, assisted by an urban planning consultant from the Netherlands, made field investigations and prepared a draft pre-feasibility report containing an organized land development plan. The proposed short-term development includes consolidation of 700 hectares, irrigation and drainage for intensive agriculture including livestock, a model village, and a 100 ha fish breeding farm. Land consolidation of about 800 ha for urban settlement is to follow later. In 1974 the Government of Democratic Kampuchea carried out a limited amount of construction work in the 700 ha area destined for intensive

development and built the livestock experimental station and fish ponds.

5.4.2 Northeast Thailand

In 1973 the Mekong Committee made a review of topography, population, and actual agricultural land use in northeast Thailand in relation to present and future land capability, based on ERTS satellite imagery interpretation, ground surveys, and existing statistical data (Ref. 1). The results show that the agricultural productivity of the northeast, under present conditions of exploitation, is rather limited. Means of rationalizing and improving land use emerging from the review are:

(1) For the mountains and hill slopes, a new approach to forestry management in line with the watershed management proposal for Lam Takong (see discussion on watershed management).

(2) For the uplands, raising of livestock and growing of fodder crops in rotation with other upland crops, as proposed for the Mancha Kiri pioneer project.

(3) For the lowland areas, intensive water control and diversified agriculture, based on the findings at the Kalasin experimental farm and as proposed for the Nong Wai pioneer agricultural project.

A systematic analysis of rainfall in northeast Thailand was made in 1974, resulting in a geographical classification of the region into areas either suitable, marginal, or unsuitable for growing lowland and upland crops under rainfed conditions (Ref. 17).

5.5 Basinwide mapping programmes

To facilitate agricultural planning throughout the basin, to take advantage to potentials from irrigation, the Mekong Committee's agricultural programme includes ongoing programmes for preparing basinwide maps presenting basic data, as follows:

(a) Satellite mapping: Using the information made available from the Mekong Committee's LANDSAT programme, the Agriculture Division has under preparation three comprehensive basic data maps showing vegetative cover, hydromorphology, and land use. The vegetation map has been essentially completed and the remaining projects are underway.

(b) Ecological zone mapping: Another current basinwide mapping project, also making use of LANDSAT information plus all other available physical data, is a delineation of ecological zones and land systems representing areas having common ecological (and hence common agricultural production) characteristics, based on consideration of climate, rainfall,

evapotranspiration, hydrology, and soil types. This map should be very useful in indicating the extent to which findings from the experimental farms and pioneer agricultural projects may be extended throughout the basin and also for assisting in many other aspects of development planning in the basin.

6. Summary of probable environmental effects

(a) Specific effects: A number of specific environmental effects of the agricultural programme for the lower basin, expected to result from the Pa Mong project, have been evaluated as follows:

(1) Agricultural chemicals: Pollution of natural waters with pesticides, herbicides, and other residual chemicals is a universal problem and very large-scale research programmes are underway on a continuing basis in the industrialized nations to develop the best practicable control procedures. These findings should be most helpful in solving problems in the Mekong basin. Studies for developing and using control procedures to suit local conditions should be undertaken as these needs become defined as the planned system of irrigation is progressively developed.

(2) Crop pests and plant diseases: Crop pests and plant diseases which may result from the new irrigation/agricultural regimes are potential problems for the future, and probably will similarly develop in other tropical zones where irrigated agriculture is being introduced. The matter can be handled as it becomes definitive and more subject to analysis and correction. Again, research findings and control procedures developed elsewhere will help solve Mekong basin problems.

(3) Irrigation and soil fertility: There is no evidence to indicate that the proposed irrigation will result in impairment of the qualities of productive soils. There are soil problem areas (acid, sulfate, and saline soils) but these exist already, and in time it should be possible to reclaim considerable portions of these lands for agriculture through improved water control methods. Also, evaluations of lands overlying rock salt deposits indicate little hazard of problems of salinity will result from irrigation.

(4) Silt trapping at Pa Mong: Although Pa Mong will trap large amounts of silt and associated

nutrients, it is anticipated the river will, through downstream erosion, soon reestablish a normal silt/nutrient loading corresponding to flow velocities. Hence, downstream silt deposition patterns, and associated nutrients, should not be impaired except for effects of flood reductions in reducing deposition induced by colmatage (Item 5). Evaluation of sediment deposition in the Vietnamese delta indicates such deposition amounts to about 1 mm per year and does not measureably increase soil fertility in the delta, and moreover confirms the fact that the single most important factor in bringing about large increases in delta agricultural productivity will be water control.

(5) Flood reduction and downstream agriculture: Investigation of effects of flood control at Pa Mong on downstream agricultural practices, based on hydrograph analysis, indicates that such flood control (1) will significantly improve present rice growing practices both in lowlands in Democratic Kampuchea, by extending the land area available for cropping and by permitting replacement of floating rice with ordinary rice of higher quality and yields, and in the middle elevation zones and higher terraces because of reduction in flood damage; (2) will significantly increase the extent of chamcar areas available for dry-foot cropping and permit more flexible and efficient use of these areas; (3) will result in some reduction in colmatage silt deposition in chamcar areas; however, with efficient colmatage systems, designed to result in deposition at desired places (rather than depending upon natural small streams), the amount of reduction in deposition and accompanying adverse effects can be minimized and compensated for, and (4) will result in significant overall gains in agriculture productivity throughout the delta.

(b) Food production: While the Pa Mong project would be financed essentially from power revenues, the Pa Mong project is critically needed as the most feasible approach to increasing agricultural productivity to meet the projected food needs of the lower basin. The increased productivity would be mostly in rice and upland crops and also in fish (both from the reservoir fishery and from fish farming) to help meet protein needs. The necessary water for enabling this increase, by permitting

cropping during the dry season, by improving cropping during the wet season, and by permitting fish farming on a continuing basis, must come essentially from mainstream storage projects. More specifically, the Pa Mong project will make it possible (a) virtually to eliminate flooding along the middle course of the Mekong river from Pa Mong to Khone Falls, which are densely populated riverine lands, and to develop these lands by low lift pump irrigation on both sides, particularly on the Democratic Kampuchea side of the Vientiane and Savannakhet plains, (b) to irrigate up to 1,000,000 ha in northeast Thailand and the Lao PDR, and through the irrigation system to supply thousands of villages with domestic water, (c) to transfer 5,000 million $m^3$ or more of surplus water in the irrigation season to the central plain of Thailand, (d) to reclaim up to 200,000 ha in Democratic Kampuchea through flood control, thus utilizing lands not now usable, and to convert up to 200,000 ha from floating rice culture to other rice varieties of higher yields and quality, (e) to make available for use in the dry season in the Mekong delta about 30,000 million $m^3$ of fresh water, and (f) to engage in year-around fish farming throughout the lower basin.

Using the general rule of thumb that a cubic metre of irrigation water will yield about 0.5 kg of rice (and even more of upland crops), the potential extra rice yields from the improvements noted above could support at least 25 million people in northeast Thailand and Lao PDR alone. The additional benefits in extra for supply further downstream would also be very considerable because of the very large land areas which would become subject to cropping or extra cropping either through flood control or irrigation. Depending on the amount of water made available to the delta during the dry season, the increase in agricultural productivity in the delta could be even more than in northeast Thailand and the Lao PDR.

(c) Socio-economic impact: Because the Mekong Committee's agricultural programme can be expected to assist materially in achieving maximum food production, which is expected to be critically needed, and at the same time lend to development of farming communities offering higher standards of living than current conditions, the entire agricultural programme may be said to be a most positive one in terms of effects on environment,

in that the welfare of the participating farmers should be significantly improved in both material and cultural ways. Also, another important contribution of the agricultural programme is that this type of research and development is badly needed, even without water resource development, to assist the riparian countries to change some of their present farming methods (the "accelerated traditional" methods) which are soil fertility depleting and thus hazardous to continue to use in the long run, to methods which are higher yielding on a sustained basis.

The Pa Mong project will present the opportunity to demonstrate on a mass scale, especially in the irrigation service areas in northeast Thailand and the Lao PDR, how to transform existing agricultural practices into new concepts and methodologies which take full advantage not only of continuing improvements in agricultural technology but of the unique combination of the year-around sunshine, year-around water available through water control, and a highly competent people. This combination is believed to be unique to southeast Asia, and if these resources can be mobilized in the lower Mekong basin to take advantage of continuing technological improvements in agriculture, which can be expected to increase exponentially, it is realistic to believe that the lower basin cannot only meet its own food needs but can realize major export revenues. This would mean the lower basin would have a far greater carrying capacity than now envisaged.

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| (a) | Main Report | |
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| (c) | Appendix B: | Identification of Further Surveys and Investigations |
| (d) | Working Paper I: | Impact of Rainfall and Flood on Paddy Production |
| (e) | Working Paper II: | Climate, An Analysis of Evaporation and Rainfall for Agricultural Purposes |
| (f) | Working Paper III: | Food Demand 1970-2000, Khmer Republic and Republic of Viet-Nam |
| (g) | Working Paper IV: | Hydrology |
| (h) | Working Paper VA: | Agriculture, Land Resources |
| (i) | Working Paper VB: | Agriculture, Social & Economic Aspects |
| (j) | Working Paper VI: | Irrigation and Drainage |

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TABLE 1

[illegible]OLOGY OF [illegible]TION OF [illegible] FARM.

Agriculture

| Name of Farm | Goal | History | Descriptions/Notes on Station | Details of Tests and Work Progress (1973-75) | Technical Support to Pioneer Projects | Annual Budget US$ (Current) |
|---|---|---|---|---|---|---|
| Mat Dok Keo (Lao PDR) | Irrigated agriculture under riverine conditions. | From 1962-5 was UNDP/FAO project. Israel has provided technical assistance since 1965. | 17 ha research plus 300 ha experimentation. 275 resident families. Twice severely damaged by Mekong floods (in 1966, 71) with high rehabilitation costs. | Dry season tests included fertilisers and varietal comparison tests on maize, groundnuts, and market garden produce. New varieties of corn and barley tested. Seed multiplication in demonstration area. Experiments with colmatage (incremental levee soils). | Casier Sud | 122,000 |
| Kalasin (Thailand) | Irrigated agriculture on lowland soils of NE Thailand. | Since 1965 has been UNDP/FAO project. | 13/300 ha for research/experimentation. 75 farm families. 1974 program included training of 40 extension agents plus courses for Kasetsart students. | Dry season tests 1973-74 on irrigated crops (cotton, groundnuts, maize, rice). Varietal tests for vegetables, soybeans, groundnuts, sun flower, plus varietal tests on jute between main dry and rainy season growing periods. Year around tests on fertility maintenance, crop rotation systems, and economic evaluation. Varietal tests on dates for planting and fertilisations requirements for local varieties and hybrids. | Lam Pao | 140,000 |
| Prek Thnot (Democratic Kampuchea) | Irrigated agriculture on lowland soils of central plain of Democratic Kampuchea. | Technical assistance from Israel since 1965. Station was moved in 1973 to temporary site at North Phnom Penh polder. | 15/270 ha for research/experimentation. Three pumps installed for supplying water from Prek Thnot river to 10 villages. | Tests (prior to moving of station) on selection of paddy varieties and other crops such as groundnuts, soybeans, and vegetables, including fertiliser needs, cultivation practices, and control of pests and diseases. Tests on diversification of irrigated crops especially maize, groundnuts, jute, kenaf, and market garden crops. Establishment of farmers associations in demonstration zone for credit, mechanisation, and marketing. | Prek Thnot | 144,000 |
| Banan (Democratic Kampuchea) | Irrigated agriculture on lowland soils of NW plain of Democratic Kampuchea. | UNDP/FAO project since 1967. | 15/300 ha for research/experimentation. | Dry season tests on rice cultivation (varietal comparisons, triple cropping nursery management), crop diversification (fertilisers, sowing dates, varietal tests), and introduction of forage crops (maize, sorghum, seed multiplication). Rainy season tests with rice (fertiliser applications, nurseries), fertiliser and variety comparisons for various crops, and research on cropping techniques for forage crops. | Banan | 240,000 |
| Prek Leap (Democratic Kampuchea) | Irrigated crops on levee soils in Democratic Kampuchea. | Sponsored by Mekong Committee since 1972. | Farm covers 30 ha with old facilities for pumped irrigation with underground ducts in poor condition. Most of area flooded 4-5 times per year which excludes rainfed cropping; however 2 crops/year possible after flood season over provided adequate machinery available. | Cultivation of levee crops such as maize, cassava, soybean, mungbean, groundnuts, sorghum. Adaptation tests on high-yield rice varieties, plus varietal tests of levee crops. Launching in 1974 of IRRI program on high protein crops and IRI program on maize and sorghum. Program in 1975 includes study of fertility and irrigation problems with levee crops. | Muk Kompoul | Data unavailable |
| Tuol Samrong (Democratic Kampuchea) | Irrigated crops and rice mechanisation on semi-inundated lowlands in Democratic Kampuchea. | Originally established in 1962 with Japanese assistance. Sponsored by Mekong Committee since 1972. | Has specious building and well equipped laboratory. Total acreage of 300 ha of which 240 ha reserved for experimentation and seed production. | Tests on rice genetics and cultivation methods. Seed multiplications, fertiliser applications, and cropping techniques for selected rice varieties cultivated during rainy season. | Bovel | Data unavailable |
| Eat Mat (Viet-Nam) | Irrigated agriculture in central highlands of Viet-Nam. | Field preparations and training in 1972 to prepare for start of operations in 1973. | Irrigated research area of 16.4 ha. Construction of irrigation system completed in 1972. Plans for additional improvements include construction of dam on nearby stream plus establishment of experimental area to be irrigated from dam. | Irrigation experiments (water requirements and irrigation techniques) and comparative tests (crop suitability for different cropping seasons) on upland rice, groundnuts, soybeans, corn, wheat, sweet potatoes, and rape seed, with economic evaluation of each crop to achieve profitable cropping pattern (3 crops per year for upper Ire Pok area). Economic tests of crop rotation systems. | | About 200,000 |
| An Giang (Viet-Nam) | Floating rice and irrigation of seasonally flooded soils. | Came under sponsorship of Mekong Committee in 1973. | Farm includes 6.4 ha for crops plus 15 adjacent ha for extension work. Area is regularly flooded from 2-2.5 m. Consulting assistance from International Rice Research Institute. | Testing of varieties of floating rice during wet season and of irrigated crops in dry season including soybean, groundnuts. Use of fertilisers for soybeans and sorghum. 1975 program included soybeans and other oil producing crops and seed multiplication for rice varieties. | Caisan | Data unavailable |

TABLE 2

SUMMARY OF AGRICULTURAL RESEARCH PROJECTS

| | Topic of Research | References | Year Started | Year Completed | Location | Nature of Research |
|---|---|---|---|---|---|---|
| 1 | Experimental Farms | 5, 19 | 1962 | On-going | Basinwide | Series of eight experimental farms exploring variety of new techniques and crops applicable to lower basin. |
| 2 | Livestock Development | | | | | |
| | (a) Cattle stocking rates | 6 | 1969 | 1975 | NE Thailand | Evaluation of cattle stocking rate for both irrigated and rainfed agriculture. |
| | (b) Fodder Appraisal | 7 | | 1974 | Basinwide | Quantity and quality of fodder in basin. |
| | (c) Livestock Management | 8 | | 1975 | Basinwide | Appraisal of existing livestock management practices in basin. |
| 3 | Heavy Clay Delta Soils | 10,2 | 1974 | On-going | Viet-Nam delta | Multiple cropping potentials on heavy clay delta soils under conditions of controlled water supply. |
| 4 | Rock Salt Areas | | 1973 | 1974 and On-going | NE Thailand | Evaluation of effects of rock salt strata on quality of groundwater and return irrigation flows. |
| 5 | Systems Analysis (Farm Types and Rainfall Analysis) | 17,21 | 1973 | On-going | N E Thailand | Evaluation of rainfall needs for farming including effects of droughts in basin for planning agricultural development strategies for lowland irrigation. |
| 6 | Simulation Model Applications | 12,21 | 1974 | On-going | Basinwide | Analysis of agricultural development alternatives for basinwide planning for both rainfed and irrigated conditions including all pertinent variables affecting cropping. |
| 7 | Soil Stabilization | 22 | 1975 | On-going | NE. Thailand | Stabilization of irrigation canal embankments using bituminous compounds (prevention of bank sloughing). |
| 8 | Delta Soil Fertility | 15 | 1972 | 1974 and on-going | Vietnamese delta | Evaluation of weather silt trapping at La Ron will affect fertility of delta. |

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TABLE 3

SUMMARY OF INFORMATION ON LOWER AGRICULTURAL PROJECT

Agriculture

| PROJECT NAME | AREA (ha) (Total / Farm) | POTENTIAL APPLICATION AREA (ha) | POPULATION (Families) | BUDGET (US $ millions) (Total / foreign) | PREPARATION PHASE (Completed) | CONSTRUCTION PHASE | PERIOD OF PROJECT (years) | OBJECTIVE AND DESCRIPTION | References (3,4,14,18) |
|---|---|---|---|---|---|---|---|---|---|
| Democratic Kampuchea | | | | | | | | | |
| Prek Kampul | 4,600 / 2,200 | 10,300 | 14,000 / 2,700 | 2.6 / 1.3 | Jan. 1975 | Pending | 16 | Pump irrigation for levee areas 3 km wide extending 17 km along west bank of Mekong river north of Phnom Penh, with improved agricultural supporting services including credit. Average 1.5 ha in family farm. | 16a |
| Lovel | 46,000 / 4,300 | | 50,500 / 8,500 | 8.5 / 4.2 | Jan. 1975 | Pending | 7 | Rehabilitation project to restore gravity irrigation scheme using unregulated flow of Great Lake tributary for wet season rice irrigation for 24,000 ha plus more intense cultivation of 4,000 ha. | 16b |
| Trea Thnot | 5,000 / 3,000 | 70,000 | | 10.45 / 7.0 | July 1975 | Pending | 3 to 5 | First stage of storage irrigation project for transition from rainfed subsistence to intensive diversified land use with year around irrigation including use of higher yielding rice varieties, with support from farmers organization. | |
| Lao PDR | | | | | | | | | |
| Cassier Lai | 5,130 / 3,200 | | | 7.4 / 5.3 | 1974 | Pending | 7 | Pump irrigation for river bank areas and improvement of rainfed crops for river levee and flood plain soils, including construction of flood control dike, river pumping plant, and integrated irrigation and drainage system. | |
| Vientiane Plain | | | | 7 | July 1975 | Pending | - | Improvement of agriculture with flood protection and pump irrigation (rural development). | |
| Northeast Thailand | | | | | | | | | |
| Pump Irrigation | 3,000 / 1,500 | | | 3.1 / 1.7 | Jan. 1975 | To start in 1975 | 7 | Pump irrigation for river bank areas, rehabilitation of five pump station systems built in 1960's, plus completion of irrigation distribution, with objective of determining degree of water control and drainage needed. To be funded by PTO. | |
| Tank Irrigation | 4,000 / 3,400 | | | 4.0 / 1.9 | Jan. 1975 | Pending | 10 | Development of best methodology for gravity irrigation from clusters of small reservoirs or tanks, including completion of irrigation distribution and of service roads. | |
| Rainfed Rice | | 1,000,000 | | | 1974 | $1.4 million allocated in 1974 | - | Systematic study of rainfed rice cultivation, including of imported varieties, and improved seed multiplication, with improved extension services and training. | |
| Rainfed Upland Crops | | | | | July 1975 | Pending | - | Testing of viable farm systems for sustained cropping of upland soils including use of 10 agricultural stations in northeast, and final land clearing, with improved extension services. | |
| Viet-Nam | | | | | | | | | |
| Do Cong | 2,400 / 6,300 | 250,000 | | 7.1 / 2.1 | 1973 | 2.3 million approved by ADB Dec. 1973. Construction to begin 1975 | - | Development of gravity irrigation schemes adapted to delta topography and land tenure ownership patterns including control of salinity intrusion. | |
| Tiep Shut | 20,300 / 15,000 | 1,000,000 | | 15.2 / 7.7 | Jan. 1975 | Pending | - | Integrated salinity control program including improvement of drainage and extension of period of use of fresh water from canals using low-lift pumps. | 16d |
| Cai Dan | 50,000 / 19,350 | 300,000 | | 10.9 / 5.2 | Jan. 1975 | Pending | 6 | Transition of low-lift pumping from drainage and irrigation canals to introduce dry-season cropping to areas in delta flood zone now limited to floating rice. | 16e |
| Others (Thailand) | | | | | | | | | |
| Mong Wai | 11,000 | 100,000 | | 7.6 | 1972 | .5 million IFC loan approved Jan. 1975 | 5 | Demonstration of diversified cropping with rice during wet season and with variety of crops in dry season through improvement in design and operation of existing irrigation schemes including use of cooperative associations on marketing and credit. | |
| Lam Pao | 5,000 | | | | 1973 | 1.75 million IFC loan approved 1974 | 5 | Crop diversification with year-around irrigation including supplemental rice irrigation in wet season. | |

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TABLE 4

SUMMARY OF INFORMATION ON AGRICULTURAL WATER PLANNING

| Region | Date of Completion | References | Co-sponsors | Description of Planning Activities |
|---|---|---|---|---|
| Vientiane Plain | 1969 | AR 1/ | UNDP | Study identifying eight priority projects within Vientiane Plain. |
| (Elements of overall development planning for Vientiane Plain by Vientiane Plain Development Authority). | 1970 | AR | U.NR | Feasibility report on pump irrigation potentials. |
| | 1974 | AR | ADB, Japan | Construction and initial operation of first priority project at Tha Ngone. |
| | 1974 | AR | India, France | Feasibility reports on Nam Ngum and Thalerm projects. Nasier Nu project qualified as pioneer agricultural project. |
| | 1974 | AR | | Preliminary planning on Nam Ngum for implementing first phase of pump irrigation project (1,000 ha of total 10,400 ha) using Nam Ngum power including organization of refugees into integrated farming community, at total first phase cost of about $1.4 million. |
| Mekong Delta (Comprehensive programme to establish bases to be used by riparian governments in preparing master plans for delta agricultural development). | 1974 | 9 | Netherlands | Comprehensive studies undertaken by Dutch Delta Team in 1970, involving 15 man-years professional effort, leading to main report plus 9 appendices completed in April 1974. Elements of report evaluated in detail include (a) history of evolution of farming in delta, (b) the present agricultural situation (climate, water resources, seawater intrusion, soils, irrigation and drainage, population, socio-economics), (c) scope for agricultural development and development potentials (improved agricultural practices and improved water control), (d) development planning (ultimate development, economics), (e) socio-economics, and (f) needed further investigations. |
| | 1975 | AR | Netherlands | Identification and formulation of five projects suitable for early implementation, namely irrigation projects at Ke Sach (25,000 ha first phase), Can Tho (12,[illegible] ha), Hoang Ly (11,[illegible]0 ha), and Plain (12,[illegible] ha), and a salinity protection project at Quan Long (20,000 ha). Detailed planning proceeding for Ke Sach as the first priority project. |
| Democratic Kampuchea | | | | |
| (a) North Prek Tonle Polder | 1972 | 13 | | Construction of polder including 13 km dikes Ke of Prek Tonle. |
| (Planning for development of 11,[illegible] ha polder of Government of Democratic Kampuchea) | 1973 | 13 | | Field investigations and pre-feasibility report for [illegible] ha consolidated area with irrigation and drainage for intensive agriculture including livestock, model villages, and fish farm. |
| (b) Flood Control Projects | 1974 | 13 | | Construction of portion of [illegible] ha project including livestock experimental station and fish farm. |
| | 1975 | 24 | | Hydrologic analysis using [illegible] and model for evaluating effects of Ke Mong flood control on agricultural productivity in lowlands in Democratic Kampuchea including effects on rice cropping, extent of chamkar dry foot cropping areas, and silt deposition by colmatage. |
| Northeast Thailand (Preliminary evaluations and planning for increasing regional agricultural productivity) | 1973 | 21 | | Review of topography, population, and present land use using satellite imagery, ground surveys, and existing statistical data to evaluate future land use capabilities in N. Thailand. Results show agricultural productivity of NE is limited under present conditions of exploitation. Means for improvement include watershed management for mountains and hill slopes, raising of livestock and growing of fodder crops in the uplands, and intensive water control and diversified agriculture in the lowlands. |
| | 1974 | 17 | | Systems analysis of rainfall in region, resulting in zoomorphical classification of region into areas suitable for lowland and upland crops under rainfed conditions. |
| | 1975 | 28 | | Systems analysis of development alternatives in Lam Pao irrigation service area to develop approach requiring minimum capital and credit with maximum employment and returns. |
| Basinwide Mapping Programmes (Portrayal of resources of lower basin pertinent to agricultural development) | Underway | AR | | Preparation of basinwide maps on vegetation, hydromorphology, and land use, based on satellite imagery and other data. |
| | Underway | AR | | Delineation of ecological zones of lower basin representing areas having common ecological/agricultural characteristics based on consideration of climate, rainfall, evapotranspiration, hydrology, and soil types. |

Notes: 1/ Annual Reports of Mekong Committee

TABLE 5

ENVIRONMENTAL CONDITIONS AFFECTING FARMING OF RICE 1/

| Varieties | Water Conditions | | Topography (altitude) | Soils |
|---|---|---|---|---|
| | Water Depth | Period of Inundation | | |
| Early maturing | Intermittent submersion | Very short | Terrace (high) | Coarse grained |
| Semi-seasonal | Shallow | Fairly short | Terrace, Floodplain | Fairly coarse |
| Seasonal | Shallow-medium | Medium | Floodplain (medium altitude) | Medium |
| Late maturing | Medium--deep | Medium-long | Floodplain (low) | Fine |
| Floating | Very deep | Long-very long | Floodplain (low) | Fine |
| Dry season | Dry season irrigation available | Irrigation | Floodplain (low) | Fine |

1/ Modified from: Kata, Y., "Rice and Field Crops in Cambodia", Water Resource Utilization in Southeast Asia, SEAS of Kyoto University, 1966.

TABLE 6

CRITERIA FOR FLOATING RICE CULTIVATION AND NON-FLOATING RICE CROP FAILURE (Ref. 24)

| Factor | Floating rice | | Non-floating rice | |
|---|---|---|---|---|
| I. Rate of rising water level | 0 - 100 mm/day<br>Over 100 | Favourable<br>Impossible | | |
| II. Period of sustained peak | Less than 10 days<br>Over 10 | Unfavourable<br>Favourable | | |
| III. Depth of water | 0 - 50 cm<br>50 - 100<br>100 - 300<br>Over 300 | Unfavourable<br>Marginal<br>Favourable<br>Impossible | 0 - 50 cm<br>50-100<br>Over 100 | Favourable<br>Marginal<br>Failure |
| IV. Period of inundation a/ | 0<br>30 - 90<br>Over 90 | Impossible<br>Marginal<br>Favourable | 0-7 days | Tolerable<br>Possible<br>Failure<br>" |

NOTES: Floating rice production is successful when all four factors are met.

Non-floating rice; crop failure is probable when factors III and IV are unfavourable simultaneously.

a/ For non-floating rice, the period of inundation should be read as "the period in which whole plant is submerged under water".

TABLE 7

ESTIMATED SILT DEPOSITION IN DELTA IN DEMOCRATIC KAMPUCHEA

(Reference 24)

| Zones | Without Pa Mong | | | With Pa Mong | |
|---|---|---|---|---|---|
| | Depth of Deposition (mm) | | Ratio of high to normal flood | Depth of Deposition (mm) | |
| | Normal Flood | 1/10 Year Flood | | Normal flood | 1/10 Year flood |
| Upstream | 5-10 | 20-30 | 3-4 | 0.5-1 | 5-10 |
| Phnom Penh | 2-3 | 5-9 | 2-3 | 0 -0.5 | 3-5 |
| Downstream | 0.3 | 1. | 3 | 0 -0.1 | 0.2 |
| Efficient Colmatage | 20. | 25. | 1.25 | 5. | 10. |

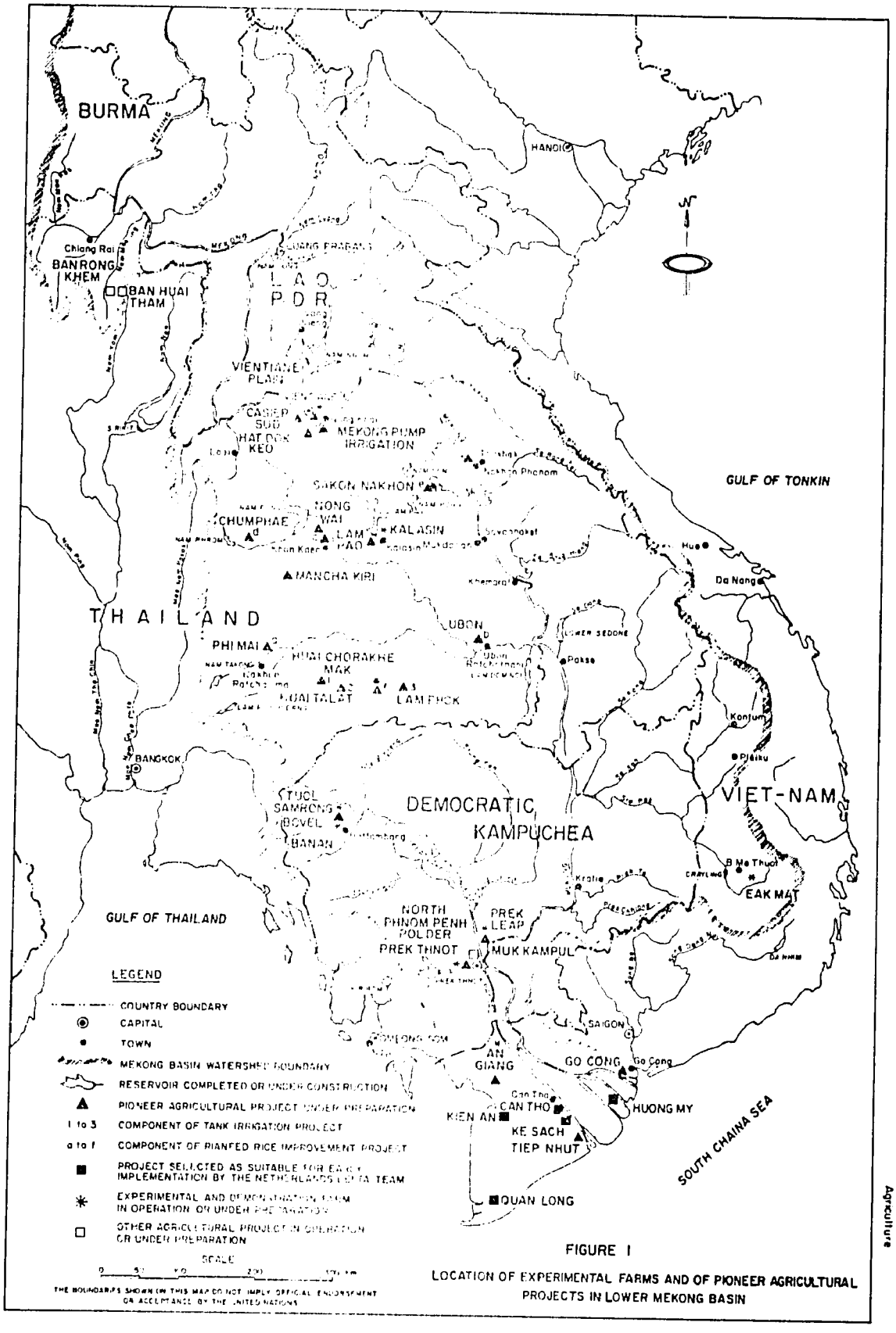


FIGURE I

LOCATION OF EXPERIMENTAL FARMS AND OF PIONEER AGRICULTURAL PROJECTS IN LOWER MEKONG BASIN

Agriculture

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## AGRO-INDUSTRIES

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# PA MONG ENVIRONMENTAL ASSESSMENT

## AGRO-INDUSTRIES

### 1. Introduction

In keeping with the Mekong Committee's basic policy that water resource project development must contribute effectively to advancement of human welfare in the lower basin, the Committee has carried out a programme for promoting industrial development throughout the region wherever the project products (plentiful power, plentiful water, improved navigation, etc.) might favor the establishment of such industries. Numerous investigations have been made to explore the feasibility of such ventures, which may be organized into three general categories, namely (a) agro-industries, (b) mineral resources development, and (c) power oriented industries. All such investigations have involved the co-operation of the riparian countries and many of them have been jointly sponsored by UN affiliates, especially the UNDP, UNIDO, and FAO, and by several donor nations. This discussion is concerned with the category of agro-industrial development.

### 2. Existing situation in lower basin

Present trends in industrial development in the riparian countries indicate most industries, including a large number of agro-related industrial activities, tend to concentrate in a few major cities, in particular in and around metropolitan centres, e.g., Bangkok, Saigon, and Phnom Penh. Industry is attracted to these centres because of their large and rapidly growing markets, their well developed infrastructure, and facility for contacts with interested government agencies. Such highly centralized industrial development progressively reinforces itself as industry expands and develops, thus tending to contribute to an ever-widening income gap between the urban and rural sectors. This trend in industrial development is common, although in varying degrees, to all the riparian countries.

Modern agro-industries that currently operate in rural areas in northeast Thailand are mainly engaged in processing activities carried out in conjunction with trading operations, such as rice milling, cotton and kapok ginning and kenaf baling. In recent years, a few plants engaged in more advanced processing of agricultural produce have developed, including gunnybag manufacture and cotton spinning. There are, however, in addition, a wide range of other processing activities which have development potentials when located near the raw material producing areas. Such activities include fruit and vegetable processing, industries associated

with modern livestock production (animal feed preparation, and the recycling of slaughterhouse waste such as offal processing for stockfeed, and fat recovery for industrial use), corn and tapioca processing, utilization of rice by-products (pulp and hardboard, rice bran oil extraction), processing of oil bearing seeds and nuts (groundnut, soyabean, castor bean, cotton and kapok seed) and associated soap manufacture, and seri-culture, silk reeling, and textile manufacture.

In summary, under present conditions, there is need for the public authorities to formulate and implement new policies by which the present trend of over-concentration of agro-industries in a few centres can be reoriented to promote distribution of these industries throughout the countries. This is needed to promote equitable sharing of agro-industrial economic opportunities including increased rural employment.

A listing of agro-industrial projects included in the public development programmes of the lower basin countries is included as Annex II of Reference 1 ("Agro-Industrial Development Programme", Mekong Committee, 11 Aug. 1972). Also included in Reference 1, as Annex 1, is a listing of major agro-industries in the lower basin.

3. Impact of irrigated agriculture

The advent of widespread irrigated agriculture from a mainstream project like Pa Mong can be expected to intensify the problem of over-concentration of agro-industries as described above, and likewise the need for remedial measures. As has been noted in discussion of effects of Pa Mong on agriculture, if the potentials of irrigated agriculture are to be realized, the farming communities in the riparian countries must shift from rainfed paddy cultivation practices to an entirely new concept of farming including not only new cropping technologies but changes in socio-economic institutions needed to assure proper marketing of saleable products. In a similar manner, if agro-industries are to be part of the new agriculture complexes in the irrigated areas, public action will be essential for assisting all of the participants in agro-industrial endeavors - the farmers, industrialists, traders - in the development of the new industries.

In order to help guide agro-industrial development in the riparian countries to realize increased benefits from both tributary and mainstream projects, the Mekong Committee has sponsored a continuing programme, in co-operation with the riparian governments, for the promotion of both agro-input and agro-output industries which relate to the development of irrigated agriculture. Special considerations which could enhance agro-industrial development in the lower basin will be the availability of plentiful power and the improved transportation facilities to result from mainstream developments such as Pa Mong and the navigation improvements along the river envisioned in the Mekong Committee's basinwide plans.

The Mekong Committee's programme for agro-industrial development has two main objectives, first, studies to identify and describe promising agro-industrial investment opportunities, and second, co-operation with the riparian governments in formulating and implementing plans and policies for establishing such industries, together with provisions for training in technical specialties and in management. The various studies may be classified as project studies (evaluations of specific industry potentials), regional reviews for identifying input and output potentials for specific agro-industries, and master planning for agro-industrial complexes. The results of the agro-industrial studies are intended to indicate whether a particular crop, or group of related crops, could be profitably processed in or near the areas of cultivation. Such studies can contribute to a better understanding of the interaction between agriculture and derivative industries. They have been designed to focus initially on evaluating the agro-processing potentials of the pioneer agricultural projects and the larger areas to which the pioneer projects pertain. Most of the studies have been carried out within the past five years.

In summary, the rationale of agro-industrial development planning for the lower basin is based essentially on the contribution that appropriate agro-industries will make to a more intensive utilization by agriculture of newly available irrigation facilities. A well-developed network of processing industries in or near irrigated areas would substantially increase the value of agricultural production. The resulting incremental benefits would in turn raise the benefit-cost ratio of the original investment in engineering works. As such, the proposed programme will directly support the Committee's primary effort in developing the water resources of the lower Mekong basin.

Details regarding the elements of the Mekong Committee's programme for preparing for agro-industrial development are presented below.

## 4. Preparatory programme for agro-industrial development

The programme has included essentially three categories of activities, namely feasibility studies for exploring and confirming the potentials of attractive industries, promotional measures to help implement promising new industries, and training of key government and industrial officials involved.

### 4.1 Feasibility studies

(a) Objectives: The studies relating to agro-output industries have four main objectives, as follows:

(1) To determine whether processing in or near the areas of cultivation of a particular crop or a group of related crops would

promote agricultural development, particularly by providing the farmer a ready nearby market for his produce. The location of processing facilities in close proximity to areas of cultivation would facilitate speedy transfer of information and technical know-how and skills in the interest of both agriculture and industry.

(2) To identify constraints and bottlenecks in the agro-industrial development process that require government intervention.

(3) To indicate for public or private investors whether there is a promising situation for establishment of the industry. The studies are not intended as blueprints for enterpreneurial action but aim at providing a basic frame of reference for arriving at intelligent investment decisions. It is hoped, in this way, the studies will induce the private sector in particular to take a more active interest in the largely neglected areas of modern rural industrialization.

(4) To examine the industrial potential of the agricultural pioneer project areas and the larger areas to which they pertain, so these projects can contribute to a more intensive utilization of the facilities that become available through water resources development.

The studies of agro-input industries have been mostly concerned with potentials for local production of nitrogen and phosphate fertilizers. These involve establishing the availability of suitable local raw products, but otherwise follow the format noted above for the output industries.

(b) Presentation of findings: The specific agro-industrial opportunities studied thus far include both nitrogen and phosphoric acid as input industries, and a number of output industries, namely pineapple, poultry, pulp and paper, sugar, vegetable oil, sericulture, kenaf, and fruit and vegetable canning. A summary of these studies and the findings from them is given in Table 1.

## 4.2 Investment promotion

The goal of this programme, initiated in 1973, is attraction of public and private investment for viable agro-industrial projects. The work includes analysis of the

prevailing investment situation (including institutional arrangements, incentive schemes, promotional facilities, and restrictive practices) in co-operation with the government officials concerned, and assistance in attracting domestic investors, within the framework of government policies concerning foreign investment, and in obtaining co-operation from international financing agencies and from the international business community.

This programme amounts to a continuing array of efforts to bring about effective communications which could help promote agro-industries. In 1974, for example, consultations were continued with the Co-operative Programme of Agro-Allied Industries in collaboration with FAO and other specialized agencies of the United Nations. Efforts were made to organize the visit of an exploratory mission to consider possible contributions by the international business community. Following an FAO proposal, arrangements have been made to carry out, jointly with FAO, a survey in the riparian countries on practical possibilities for international co-operative ("twining") arrangements whereby selected agricultural processing enterprises in industrialized countries would render technological, managerial, and marketing assistance to parallel enterprises in the riparian countries.

4.3 Executive development

The goal of this programme is improvement of riparian country skills in planning and implementing agro-industrial development policies, programmes, and projects. In particular there is need for joint training of officials concerned with agriculture, industry, trade and national planning, together with representatives of the private sector.

(a) Elements of programme: The programme has included both (a) staff development, comprising seminars, technical meetings and fellowships both for training abroad and for in-service training in the Mekong Secretariat, and (b) training of riparian government officials through participation in international courses on industrial development, through field study tours, and through participation in an agro-industrial workshop sponsored by the Mekong Committee in 1973, attended by 19 riparian officials, as described below.

(b) Workshop: The "Workshop on Agro-Industrial Development Planning in the Lower Mekong Basin", held at Bangkok/Hua Hin in Thailand from 27 November to 15 December (Ref. 23), featured problem-solving and decision-making exercises to analyse the technical, economic, social and institutional characteristics of selected

agro-industries and to find solutions for constraints in the production chain from crop cultivation to industrial processing and marketing operations. The agro-industries selected for special study included agricultural machinery manufacture, animal feeds, fertilizer manufacture, food processing (including fish, fruit and vegetables, rice products and meat), pulp and paper manufacture, and vegetable oil extraction.

The main conclusions of the workshop, on issues of public policies, are summarized briefly as follows: (a) to facilitate agro-industrial development as an entity per se, the riparian country governments might consider creation of interministerial mechanics dedicated to such service, (b) representatives of agricultural co-operatives and of agro-industrial industries should be involved in policy formulation and development planning, and (c) contract farming offers valuable potentials for supporting agro-industrial development, and this approach should be evaluated in detail.

The report of the workshop includes reviews of a number of proposals for further study of specific agro-industrial project potentials.

4.4 Impact of preparatory programme

The programme of studies related to agro-industries carried out by the Mekong Committee over the past decade, to help in the promotion of a diversified industry taking full advantage of water resource development projects, has included an impressive number and range of activities. Most of these have been in areas where tributary dam and reservoir projects and associated irrigation systems are already in operation.

The programme has served to identify and characterize many of the numerous complexities involved in establishing agro-industries in agricultural areas traditionally oriented to rainfed paddy. These include the problems of motivating and training the participating farmers, of adapting local and imported fruit and vegetable species so their cultivation will suit processing needs (considering matters of protection against spoiling, storage, and transportation), of scheduling cropping to co-ordinate with and not interfere with rice cultivation, of mechanics by which the farmer can receive a guaranteed fair price for his crops and likewise the buyer be protected on matters of delivery and of repayment for advances to the farmers for fertilizer, etc., and many other related problems.

The impact of Mekong Committee's programme, being limited to assisting the responsible riparian country governments, cannot be assessed in quantitative terms. However,

there has been an encouraging growth of decentralized agro-industries in Thailand over the past several years, especially in north Thailand, which is providing experience in solving the numerous problems involved in establishing successful new ventures located in agricultural zones. It is believed the total experience being gradually accumulated, including the contributions from the Mekong Committee, represents a significant achievement and essential first step in preparing for the major impact of a mainstream project like Pa Mong. This effort needs to be continued and expanded as the next step, especially to focus attention on implementing specific industries with the most promising potentials.

5. Pa Mong pool levels

The selection of the design pool level for Pa Mong will indirectly influence agro-industrial development in that the greater the volume of water to be available and used for irrigation, the greater will be opportunities for producing crops of the types needed for agro-industrial processing.

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TABLE 1

SUMMARY OF AGRO-INDUSTRIAL STUDY

| Industry | Period of Study | Reference No. | Area Studied | Summary of Findings of Preliminary/Feasibility Studies | Follow-up Activities |
|---|---|---|---|---|---|
| **Agro-Input Industries** | | | | | |
| Agricultural Machinery | 1965-74 | 60, 61, 62, 74 | Lower Basin | Local manufacture of farm machinery should be encouraged by government support of selected entrepreneurs already capable of manufacture, including low interest loans and setting of local standards. Regional financial support of national institutes preferred to fostering of new riparian research institute. | |
| Nitrogen Fertiliser | 1965-74 | 60, 61, 62, 74 | Lower Basin | Only Thailand and Democratic Kampuchea now produce chemical fertilisers which meet only part of their requirements, the former producing ammonium sulphate and urea from lignite and the latter producing rock phosphate. Widescale use is still made of compost and nightsoil for vegetable and fruit growing. Thailand's short-term programme involves establishing a complex fertiliser plant using both imported and local ingredients, with local packaging, but in the long-range nitrogenous fertiliser must be produced locally probably from naptha. In Viet-Nam both the short-range and long-range plans are based on producing urea from naptha. Also, studies completed in 1966 indicate good potentials for local manufacture of nitrogenous fertiliser using electric power provided such power would be available at no more than two mills per kWh. Another study completed in 1967 indicates low-cost power would favor establishing a calcium carbide industry as a basis for manufacturing many other chemicals including urea. | There appears to be good potential for a regional fertiliser industry for meeting the needs of mechanized and irrigated agriculture but such a project would be capital intensive and be a large scale undertaking and would probably have to be pursued by the Mekong Committee in collaboration with ECAFE. |
| Phosphoric Acid | 1967-74 | 63, 64, 65 | Lower Basin | Availability of electric power and local raw materials at reasonable cost make this potential industry attractive for lower basin. A plant at a coastal location, comprising phosphorus smelting and acid production, producing 200,000 tons $P_2O_5$ annually (80 % acid), with two 70 MW smelting furnaces, would require total fixed investment of 42.5 million. | Report being evaluated by private sector. Further studies needed based on detailed estimates of costs for raw materials and power. |
| **Agro-Output Industries** | | | | | |
| Animal Feed Industry | 1974-75 | 74 | | This industry is central to the development of the agro-industrial sector; industry integrates raw material producer, farmer, feed mill, and meat processing plants. Introduces byproduct possibilities. Desire to develop feedstock and livestock industries tied to need to provide low priced protein and to increase higher value exports. All riparian countries interested in development of the industry. Problems: quality control, price controls currently hurting industry. Integration of feed and livestock industries key approach. Ex. private sector in Thailand (1) Charoen Pokphand (chickens), (2) Kasetchai Issuri (swine), and (3) Chokchai (cattle). | Lao animal feedstock/livestock plan under development. Construction of slaughter house by New Zealand Government is integral part of plan. Development is integral part of plan. Development of integrated pig farm/fish farm complex by Kasetchai Issuri, private sector, Bangkok. |
| Fruit and Vegetable Processing | 1974-75 | 74 | Lower Basin | Experience in establishing new fruit and vegetable processing factories in north Thailand indicates very good potentials in lower basin because of steadily increasing world demands, suitability of soils and climate, and increasing availability of soils and climate, and increasing availability of irrigation. Such operations should start at limited scale and expand as experience demonstrates how to handle many difficult problems including modified cultivation practices and coordination of farmers and processing activities. The best potentials are in freezing/dehydration which reduce packaging and shipping costs much more than canning. | A number of new industries are now being established in northern Thailand which should assist in developing similar projects in lower basin. |
| Kenaf | 1975-76 | 78 | Lower Basin | Study results indicate it would be feasible to establish series of pulp/paper mills in lower basin using locally grown kenaf as raw material, each with capacity of 70,000 tons pulp/year and supporting about 20,000 families. Six mill sites were selected in the lower basin area, for which adequate quantities of kenaf whole stock, chopped stalk, and bast ribbon can readily be made available within economic haul distances. One or more pilot kenaf demonstration farms are recommended for extension training purposes. A mill for pulping kenaf would be almost identical in design to a bagasse or straw pulp mill. | |
| Pineapple | 1974-75 | 66, 67, 74 | Lao PDR | Good prospects for pineapple production and canning in the Lao PDR, because of favorable soils and climate and increasing world market; major question is whether export is feasible because of underdeveloped infrastructure and high transport costs to shipping points. Operations should begin at small scale (3 million investment) using 1 500 ha cultivation to produce 500,000 cases annually to develop experience before expanding at location near port of exit, e.g. Pakse. | In-depth feasibility study recommended especially for projecting progressive steps taking into account the considerable time needed for establishing the industry. |

TABLE 1 (Cont'd)

SUMMARY OF AGRO-INDUSTRIAL STUDY (Cont'd)

| Industry | Period of Study | Reference No. | Area Studied | Summary of Findings of Preliminary/Feasibility Studies | Follow-up Activities |
|---|---|---|---|---|---|
| Agro-Output Industries<br>Poultry | 1974-75 | 68, 74 | Lao PDR | Accelerated development of poultry raising appears very attractive in the Lao PDR because there is large local need for protein, and soil and climate are favorable for soybeans/groundnuts needed to produce feed cake (as byproduct of vegetable oil industry) which will be equally valuable for pork as well as chickens. Establishment of industry will require coordination of financing feed milling, meat processing, breeding and hatching, and marketing with training in feed and poultry technology. | This programme is to be incorporated into the Lao plan for integrated feedstock/livestock programme. |
| Pulp and Paper | 1964-75 | 69, 74 | Lower Basin | Although the market for paper products will become large in the lower basin, there are insufficient wood resources (except possibility Lao PDR) to support a large industry even with low cost power. A medium-sized industry is feasible using existing raw materials which could become a large industry with forest plantations of conifers operating on sustained yield basis. Also, medium scale industries may be feasible based on use of rubber wood, bamboo, rice straw, and bagasse. Best potentials appear to be for use of kenaf for long fiber pulp in Thailand, for use of bagasse and rice straw in Vietnam for making panel boards, for hardwood pulp mill and pressed board industry in the Lao PDR, and for rehabilitation of bamboo pulp mill in Democratic Kampuchea. | Further studies recommended as pulp and paper situation further evolves. Thailand has approved kenaf plant in northeast and bamboo/bagasse plant near Kanchanaburi. |
| Sericulture | 1972-75 | 73 | Lower Basin | The countries of the lower Mekong basin have been showing increasing interest in reviving, developing, and expanding the sericulture industry to produce domestic raw silk, because of increasing world demand, intensive labor requirements, and low capital investment requirements. The key factors are mulberry leaf cultivation and silk-worm rearing operations. Irrigation should enhance mulberry leaf production (sustained yields throughout the year) which together with improved silk-worm rearing can increase raw silk production from about 20 kg/ha (under rainfed conditions) to as much as 120 kg/ha. | The Mekong Committee with assistance from the Japanese Government proposes to establish a research centre at Khorat for detailed study of "irrigated sericulture" including development of plans for implementing these methods at the pioneer sericulture projects. |
| Sugar | 1972-73 | 70 | Lao PDR, Democratic Kampuchea | Potentials very promising for cane sugar production and processing in the Lao PDR and Democratic Kampuchea because of favorable soil and climate and growing local market. The recommended programme for the Lao PDR starts with plant processing 1,000 tons cane/day (producing 11,000 tons sugar in 120 dry season), then expanding to 2,000 tons cane/day to 1985 together with 10,000 litres/day alcohol distillation. In Democratic Kampuchea the need is for 45,000 tons sugar/year for first phase and 55,000 tons/day by 1985, to supplement current palm sugar production. | |
| Vegetable Oil | 1973-74 | 71, 72, 74 | NE Thailand<br>Lao PDR | In northeast Thailand, with irrigation oil nut cultivation (soybeans, groundnuts) can be increased sufficiently for vegetable oil plant large enough to be economical utilizing contract farming, e.g., at Khon Kaen, with oil used both locally and exported, and with concurrent development of livestock industry to furnish market for oil cake and meal. For Lao PDR a pilot oil mill of 100 kg/hour capacity is recommended to gain experience in integrating oil seed cultivation, oil milling, animal feed mixing, and livestock raising. Raw material procurement is main problem hindering development of this industry (small-scale operations are uneconomic). | Further studies in order for industry at Khon Kaen because of favorable transportation and banking facilities, labour availability, and proximity to Nong Wai/Lam Pao raw materials areas. |

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## AQUATIC BIOLOGY

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CHAPTER III

# PA MONG ENVIRONMENTAL ASSESSMENT

## AQUATIC BIOLOGY

### 1. Introduction

The Mekong Committee's programme in aquatic biology, in addition to fisheries and wildlife (which are discussed separately), includes (a) continuing collection, collation, and evaluation of basic data throughout the basin, to provide an increasing fund of scientific facts to permit assessment of effects of water resource development on a variety of possible environmental values including fisheries, recreation, aesthetics, eutrophication, and water quality, and (b) studies for evaluating anticipated possible adverse effects of development on environmental biological values and for controlling and correcting these effects. At this time the primary areas of interest are in reservoir hydrobiology and limnology and in weed control. A number of additional studies are under consideration including a study on mangrove swamps.

### 2. Basic data programme

Relationships between aquatic biology and environmental values, especially with respect to fish-food chains, are often extremely complex but in the continuing development of the water control . systemsin the lower basin, it will be desirable to understand these relationships to the extent possible as guides both for further system design and for system operation.

The basic data programme now includes many sources of information, primarily (a) information collected as part of the fisheries programme including the basinwide fisheries study (Ref.1), the Great Lake study (Ref.14), tributary reservoir studies at Nam Pong and Nam Ngum (Ref.2, 3, 4, 10, 11), Pa Mong pre-impoundment studies (Ref.15), and the hydrobiological and socio-economic survey of Mekong reservoirs (Ref.8), (b) information collected through the basic hydrologic data programme relating to water quality, and (c) limnological surveys at Nam Ngum (Ref.12). Much of the interest in aquatic biology is just getting underway. It appears that the Mekong Committee's programme of research and studies in aquatic biology will be a continuing one for many years if not decades, thus building up a progressively better data base, and with the programme being continually reoriented to suit specific problem areas as they become identified.

## 3. Water quality monitoring

The Mekong Committee's existing basic data programme includes water quality observations both in the mainstream and main tributaries (See discussion on water quality). While limited mostly to physical and chemical parameters since regular monitoring was initiated in 1972, it is planned gradually to expand the scope of this work (within the limitations of available funds) to include basic biological parameters, both for the water column and for bottom sediments. Thus a limited but valuable fund of basic biological data will be accumulated over the years, by which any significant changes in the biological characteristics of the water may be detected including changes due to buildup of pollution.

## 4. Impoundment limnology

A project for conducting a hydrobiological (and also socio-economic) survey in Mekong tributary reservoirs was initiated by the Mekong Committee in 1971, primarily for the purpose of guiding reservoir management to achieve maximum yields of desirable fish species. Thus far this work has been mostly limited to Nam Pong reservoir in Thailand and to Nam Ngum in the Lao PDR.

### 4.1 Nam Pong reservoir

Some limited but valuable observations on the limnology at Nam Pong were made as part of a study of the fishery in the reservoir in 1965-66 by the Thai Department of Fisheries (Ref.2). This included observations both of pre-impoundment and post-impoundment conditions made just before and immediately following impoundment. The post-impoundment programme included fish catches together with sampling of plankton (types and weight), benthic biota (weight and types), and of the water's physical and chemical characteristics (DO, $CO_2$, $H_2S$, alkalinity, temperature, pH, and transparency), plus observations on commercial fishing. The pre-impoundment survey included only fish fauna catches. The post-impoundment study showed low dissolved oxygen and high carbon dioxide conditions below 10 m, indicating the probable presence of a thermocline during the hotter months of the year. In the monsoon months no stratification was evident. Both plankton and benthos were abundant. Also, an explosive growth of aquatic weeds occurred shortly after the reservoir was formed (but the situation stabilized later on).

### 4.2 Nam Ngum reservoir

The first phase of construction of Nam Ngum reservoir was completed in 1972, with impoundment beginning in 1971. The resulting reservoir flooded an area of 324 $km^2$. Phase II of the project (now underway) will increase the maximum water level to 212 m and flood about seven per cent more area, beginning in 1976.

### 4.2.1 Initial survey

An initial limnological survey of 12 months duration was made in 1972-73 (Ref.3, 10). The report of the study gives details of observations at 17 sampling stations in different parts of the reservoir, at different seasons, on water levels, colour, transparency, temperature, dissolved oxygen, pH, and plankton for both the water column and the bottom sediments. The detailed information is presented in a series of 19 charts and 12 tables.

The study findings showed that (a) water temperatures ranged from 20.0 to 32.2° C and the pH from 5.2 to 8.5, (b) the primary microscopic organisms, other than algal, were the genus Volvax limnaeus, a protozoa which imparts a green colour to the water; the genera Brachionus pallas and Asplanchna gosse of the trocheiminthes, and the genera Cyclops, Daphnia Muller, and Bosmina Sars of the Arthropoda, which are considered important as food for fingerlings; and the genus Chroococcus Naegeli of the Cyanophyta, which propagates in large quantities and collects in the cooling water intake pipe causing some difficulties in clogging; and (c) approximately 60 species of planktonic algae were found but in relatively low quantity, presumably because the reservoir had been filled for only a short period.

### 4.2.2 Smithsonian study

A much more detailed ecological survey at Nam Ngum was carried out for the Mekong Committee in 1974-75 by the Smithsonian Institution (Ref.11). This included evaluations of vegetation (terrestial and aquatic), limnology, wildlife, drawdown agriculture, and human disease hazards, and use of remote sensing (ERTS imagery) for mapping of the reservoir area. The field observations were made in the period June - December 1974.

The findings and conclusions of the study, presented in a 156-page report (Ref.12), may be summarized as follows:

(a) Terrestial vegetation: The bioclimatic conditions of the Nam Ngum area favour dense climax evergreen forests, occurring in three types, evergreen forests on sandstone terrain, bamboo forests which develop where the evergreens have been cleared, and limestone area vegetation. The climax forest is dominated by an upper story of Dipterocarpaceae (about 400 trees/ha), a substory of various species (750 to 1,600/ha), and various lianas (350 to 450/ha). Five bamboos are present (for which a key was developed). The The total biomass (from 1,595 to 2,578 tons/ha) is higher than previously reported for tropical Asia.

(b) Reservoir vegetation: Submerged trees at depths greater than 6 m (in the anaerobic zone) tend to remain intact, but trunks and branches near the surface decay rapidly. Foliar biomass and litter decay rapidly during flooding. Aquatic weeds are present but were not a problem. Conditions along most of the reservoir shore are not favourable for development of extensive drawdown agriculture, primarily because of the steepness of the zone as well as the poor soils (which are deficient in both phosphates and nitrates).

(c) Limnology:

(1) Mixing and flushing: Insolation and wind are major factors determining the thermal structure and stability of stratification in the reservoir, whereas rainfall patterns and amounts affect the rate of flushing. The large number of submerged trees and islands reduce the extent of wind induced mixing. Flooded vegetation restricts vertical mixing, which has resulted in a shallow mixed layer near the surface and a lower large mass of cool, stagnant, and anoxic water (devoid of oxygen). The lake appears to be anoxic below 10 m, and sometimes below 5 m (during the driest part of the year due to lesser wind mixing action). During the wettest part of the year there is some penetration of oxygen to 20 or 30 m depth.

(2) Water column: The water column during most of the year is divided into three zones with transition layers between: (1) the uppermost zone, which circulates in response to wind and is 6-10 m thick; (2) the middle zone, which lies between 10-25 m, is much cooler (near 23° C) and receives the bulk of river flow during the rainy season, (3) the bottom layer, which is found below 30 m and is considerably cooler than the middle layer (18° C). This distribution changes briefly during the coolest months, probably by mixing of layers 1 and 2 and possibly by some rise in the level of layer 3.

(3) Water quality: The reservoir waters are moderately transparent; discoloration from decaying vegetation is not significant; and turbidity at lower levels indicates siltation. Anoxia in the deeper waters has resulted in accumulation of solids at the bottom and in buildup of ferrous iron and of hydrogen sulfide. The major nutrients,

nitrogen and phosphorus, were not plentiful in the upper layers but have accumulated at lower depths. The pH was routinely between 7 and 8 in the upper aerobic layer, but was significantly lower in the lower depths.

(4) Plankton: The plankton of the Nam Ngum reservoir, shown in Table 1, are typical for lowland tropical lakes. The bluegreen algae dominated the biomass, but the standing crops were not particularly heavy. The species composition, especially the presence of Lyngbya limnetica and Anabaenopsis raciborskii, is quite typical of tropical lakes of this salinity (Table 1). The green algae were present in remarkably low variety and included a number of small desmids. Few diatoms were found, despite quite high silica levels (about 9.0 mg/l). Factors that could be responsible for these peculiarities include the low turbulence of the euphotic zone, which may be adverse to some larger species, and the riverine water inoculum that continually reaches the lake. A number of larger algae turned up in net samples, including a number of filamentaous greens and some large desmids. The zooplankton were not especially abundant at the times of sampling. The most common organisms were two cyclopoid copepods, Thermocyclops sp. and Tropocyclops prasinus. Various rotifers were present such as Keratella hexarthra and Conochiloides spp.

(5) Growth on flooded vegetation: Similar size pieces of bark and branches of submerged trees and bamboo were collected to obtain some estimate of the numbers and kinds of organisms living on them as compared to those living on aquatic plants or on the bottom (Table 2). The same numbers of organisms occurred on trees, bamboo, and in a mat of Spirogyra associated with Silvinia in the open water area. Tree branches had significantly more organisms than bamboo, probably because the rough bark provided more surface area and habitat diversity. The Nitella had the greatest number of organisms per net weight of macrophytes, also the greatest total number of organisms.

(6) Benthic organisms: The benthic samples had a low diversity of organisms and about the same number of organisms per surface area as the trees and bamboo of the open water. It appears that submerged trees and macrophytes in near-shore areas provide habitat for a great diversity

and abundance of invertebrates. The abundance of the conchostracan, Cyclestheria hislopi, was of interest since this organism is usually associated with small aquatic environments. Several hemipterans were identified including Bellostomalida, Corixidae, and Cicadellidae. Both damselfly and dragonfly nymphs of several species made up the Odonata. Some of the Coleoptera were identified as being Hydrophidae, Anthicidae, and Ptinidae. Most of the Diptera were Chironomid larvae of a number of species.

(7) Fisheries aspects: The flooded vegetation provides a large surface area for growth of plants and animals which may be a major source of food for fishes. The flooded vegetation prevents overexploitation of fish populations (by impeding navigation). Adequate information is not yet available and the reservoir is too new to estimate future fish yields.

## 5. Aquatic weeds

### 5.1 Control of aquatic weeds

Proliferation of aquatic weeds is a serious problem for virtually all tropical reservoirs, lakes, canals, and other water bodies, and could seriously hamper operation of Pa Mong and tributary reservoirs and irrigation canals included in the Pa Mong project. Some minor adverse effects of weed growth have already been experienced in the existing tributary reservoirs. The weed mainly of concern is the water hyacinth (Eichornia crassipes), and to a lesser extent also water-lettuce (Pistia stratiotes) and water fern (Salvinia cucullata).

Infestation of water weeds, and also dense algal blooms, are due to nutrient enrichment by decomposing terrestial vegetation and occur throughout tropical climate areas (Ref. 10). The floating water weeds have adverse effects by (a) forming dense mats which are physical obstructions to navigation and fishing, (b) interfering with surface reaeration of the water often causing heavy fish mortality, (c) entrapping water in axils and forming numerious small pools thereby providing breeding habitats for mosquitoes (including Anophelines), and (d) increasing transpiration losses, perhaps as much as six fold.

An assessment of the extent of this problem was made for the Mekong Committee by the U.S. Corps of Engineers in 1970 (Ref.5). This study indicates that the only known feasible control methods are mechanical and chemical methods, which are too expensive to be generally applied in the lower Mekong basin. Also the chemical methods which are most effective (using 2, 4D or esters and amines) may pose prohibitive environmental hazards.

The Mekong Committee is presently considering studies of several alternative methods of control (Ref. 6, 9), including (a) processing the weeds to produce valuable products such as pelletized cattle feed, liquid extract for growing yeast, chlorophyl for food coloring, and pressed fibre as raw material for paper, and (b) using organisms which eat or attack the weeds including aquatic mammals (manatees from the Guianas) who consume the weeds for food, insects and mites which attack the weeds, plant pathogens, and exotic fish herbivores. These various alternatives are under evaluation with the objective of selecting the most promising approaches. The problem is recognized as serious and will be pursued.

5.2 Evaporation studies

Because of the sizeable evapotranspiration losses which may result from growth of aquatic weeds in reservoirs and irrigation systems, especially the water hyacinth, and the need for quantifying this factor for planning of lower basin projects like Pa Mong, the Mekong Committee in 1975 contracted with the Thai Meteorological Department to conduct field experiments for measuring these losses under a variety of climatic conditions (Ref. 16). The tests are being conducted using a series of seven ponds (each 4 m x 3 m x 1 m) covered with water hyacinth in varying amounts, equipped with instrumentation for measuring all components of water losses thus permitting evaluation of losses due specifically to evapotranspiration. The studies are scheduled for completion in 1976.

6. Mangrove ecosystems

Mangrove swamps extend over an estimated 200,000 ha of the Mekong delta. They are important for the materials obtained from the mangrove per se (e.g., charcoal and resins) but it is also believed the mangrove swamp environment of shallow brackish waters may be very important for the high fish productivity in the delta for purposes of reproduction and for serving as nurseries. Also, it is believed the mangrove ecology might be affected significantly by changes in salinity, water depths, etc., resulting from upstream impoundment and related local salinity control and other agricultural improvement works. Attention to the role of mangroves will need to be included in implementing detailed improvement systems in the Mekong delta. At present delta planning is still in the beginning stage.

7. Effects of Pa Mong on aquatic biology

Impoundment at Pa Mong and the associated irrigation works to be built downstream will have a variety of effects on the aquatic biological resources of the lower basin. These effects (in addition to those on fisheries and wildlife, which are discussed separately) may be summarized as follows:

(a) Pa Mong reservoir: A rich flora and fauna is expected to become established in the new reservoir, stemming primarily from the nutrients derived from the submerged vegetation. There will be a high level of primary biological productivity which will support a high level of fish production, but not sufficient to detract from the colour, transparency, or other aesthetic factors relating to the beauty of the lake and its value for recreation and tourism. The extent of scientific knowledge now available about the biological behaviour of lower basin lakes is not sufficient to permit precise projections of the limnological conditions to be expected at Pa Mong, but it is anticipated a typical thermocline will exist with an aerobic layer (about 10 m during the dry season) above and anaerobic layer below, with the upper layer being thicker (up to 20 m or more) during the rainy season. A continuing research programme is underway, working with tributary reservoirs, to obtain a progressively increasing fund of scientific knowledge about the limnology of lakes in northeast Thailand and the Lao PDR, in the general vicinity of Pa Mong, with the primary objective of establishing guidelines to assist in establishing the best possible fishery at Pa Mong with maximum sustained yield of desirable species. Specific subjects to be investigated include the extent to which trees and other vegetation to be submerged should be removed prior to impoundnentment, and the best depths for withdrawals for reservoir releases (whether from aerobic or anaerobic zones).

The only anticipated negative aspect would be explosive blooms of nuisance water weeds (both in the reservoir and in the irrigation system), and a programme of research is planned to produce effective methods of control which are economically affordable.

(b) Downstream effects: Except for the river stretch immediately below the dam, little impact is expected on the existing aquatic biology of the river downstream. Resuspension of suspended soil materials and associated nutrients should occur fairly promptly so that the biological environmental pattern should become reestablished similar to the without-project conditions. The changes in the hydrological flow patterns caused by Pa Mong will be well within the natural range of variation.

In the delta zone there should be little effect from Pa Mong per se except that maintenance of a higher minimum flow level during the dry season should be beneficial to aquatic biological resources because of the more stable condition. However, the presence of an assured supply of irrigation water the year around will lead to a great number and variety of new local works and systems (ditches), barriers, canals, etc.) which will significantly alter the present pattern of flows, drainage, and salinity intrusion. Also, the intensified agricultural operations, especially use of agricultural chemicals, could create real hazards to aquatic biological resources unless properly controlled. As noted in the discussion on fisheries, in the evolution and development of the delta agricultural plan, careful attention must be given to effects on biological values including fisheries to be sure that adverse effects will be minimized and that advantage is taken of opportunities for enhancing these values.

(c) Pa Mong pool level: The choice of pool level for Pa Mong will have little effect on the environmental considerations noted above except that higher levels of storage will mean a larger reservoir and greater release of irrigation water to the delta.

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## TABLE 1

### MAJOR PHYTOPLANKTON SPECIES OF NAM NGUM RESERVOIR

(from "Post-Impoundment Assessment of the Ecological Effects of the Nam Ngum Dam and Reservoir, Laos", Smithsonian Institution, 1 April 1975)

Cyanophyta

- *Aphanothece microsphaera*
- *Aphanocapsa delicatissima*
- *Dactylococcopsis fascicularis* fa. *solitaris*
- *Romeria gracilis*
- *Lyngbya limnetica*
- *L. limnetica* fa. *minor*
- *Anabaenopsis raciborskii*
- *Anabaena* sp. 1

Chlorophyta

- *Tetrahaedron minimum* var. *apiculato-scrobiculatum*
- *Actinastrum hantzschii*
- *Ankistrodesmus falcatus* var. *acicularis*
- *Staurastrum* sp. 1
- *Staurastrum* sp. 2
- *Cosmarium* sp. 1
- *Botryococcus braunii*

Chrysophyceae

- *Dinobryon sertularia*

Cryptophyceae

- *Cryptomonas marssonii*
- *C.* sp. 1

TABLE 2

NUMBERS OF ORGANISMS COLLECTED FROM SUBMERGED AND FLOATING VEGETATION AND FROM BOTTOM SEDIMENTS AT NAM NGUM RESERVOIR

(from "Post-Impoundment Assessment of the Ecological Effects of the Nam Ngum Dam and Reservoir, Lao PDR, Smithsonian Institution, 1 April 1975)

| Sampling Location | Hydra | Oligochaeta | Polychaeta | Ostracoda | Copepoda | Cladocera | Conchostraca | Gastropoda | Amphipoda | Hydrachnarina | Hemiptera | Odonata | Hymenoptera | Ephemeroptera | Plecoptera | Trichoptera | Neuroptera | Lepidoptera | Coleoptera | Diptera | Unident. Insect | Unknown | Total | # /gm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Near shore | | | | | | | | | | | | | | | | | | | | | | | | |
| Near Huai Nam Yen | | | | | | | | | | | | | | | | | | | | | | | | |
| Tree branches | | | | | | | | | | 1 | 1 | | | | | | | | | | | | 2 | |
| Salvinia | 1 | | | 39 | 19 | 1 | | 1 | | 17 | 10 | 4 | | | 1 | 2 | | | 1 | 14 | 2 | | 105 | 0.15 |
| Open water | | | | | | | | | | | | | | | | | | | | | | | | |
| Near Huai Nam Yen | | | | | | | | | | | | | | | | | | | | | | | | |
| Bamboo | | 1 | | 2 | | 2 | 3 | 2 | | | | | | | | 1 | | | | 4 | | | 15 | |
| Tree branches | | 1 | | 4 | | | 2 | | | | | | | | | | | | | 3 | 1 | | 10 | |
| Tree bark | | | | 2 | | | 4 | 1 | 3 | | | | | | | | | | | | 6 | | 16 | |
| Salvinia-Spirogyra | | | | 4 | | | 1 | | 1 | | 2 | 1 | | | | 2 | | | 2 | 1 | 2 | 2 | 18 | 0.10 |
| Near island | | | | | | | | | | | | | | | | | | | | | | | | |
| Near Huai Nam Yen | | | | | | | | | | | | | | | | | | | | | | | | |
| Tubifilla | | 2 | | 1[illegible] | | 12 | | | | | 12 | | | 1 | | | | 1 | 1 | 66 | | | 1[illegible]9 | 0.87 |
| Potella (n[illegible]) | | 100 | | 66 | 4 | 27 | [illegible] | 1 | | | | 4 | | | | 8 | 1 | | 4 | 31 | | | 2[illegible]0 | 1.2[illegible] |
| Survey Sta. 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Tree branches | | 1 | 31 | 25 | 1 | 24 | 104 | 9 | 1 | | 13 | | 1 | 1 | 1 | 2 | | | 4 | 8 | 2 | | 226 | |
| Bamboo | | 12 | | 25 | | | 4 | | | | 1 | | | | | 1[illegible] | | | | | 3 | | 55 | |
| Benthos | | | | | | | | | | | | | | | | | | | | | | | | |
| Near Huai Nam Yen | | | 1 | 1 | | | | | | | 1 | | | 2 | | | | | | 16 | | | 21 | |
| Near Nam [illegible] | | | | | | | 9 | | | | | | | | | | | | | 19 | | | 28 | |

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## ARCHAEOLOGY

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# PA MONG ENVIRONMENTAL ASSESSMENT

## ARCHAEOLOGY

### 1. Introduction

The need for an archaeological survey of the Pa Mong and other reservoir areas included in the Mekong Committee's Indicative Basin Plan has been recognized for many years (Ref. 2, 3). Pa Mong reservoir would flood several hundred kilometers of the Mekong valley thereby covering possible archaeological sites. In addition, the Mekong Committee is interested in archaeological findings as background for the Committee's development planning programme (Ref. 1). This phase of archaeology, known as environmental archaeology, yields information on key environmental factors such as changes in climate, rainfall, flooding patterns, and river courses which may have influenced patterns of vegetation, soil formation, land use, settlement, and migrations of earlier civilizations.

The first preliminary archaeological surveys for Pa Mong were made by F.K. Marsh in 1969, as part of the Pa Mong Phase II project, in the Nam Mong drainage area portion of Pa Mong reservoir (See Figure 1), located in Amphoe Na Klang, Changwat Udon Thani (Ref. 4, 5), and by the Thai Fine Arts Department (for the Thai National Energy Authority) in 1972-73, which included village-by-village canvassing of most of the Thai portion of the reservoir (Ref. 6). This earlier work furnished the background for a more detailed two-year programme initiated by the Mekong Committee in 1973, with assistance from the Ford Foundation, by a team (headed by Dr. B.T. Bayard) of the Department of Anthropology of the University of Otago in New Zealand (Ref. 7). The work by Marsh, including tentative location of some 22 archaeological sites, two of which were tested by excavation of one-metre pits, represented the only archaeological excavation done in the entire reservoir area prior to 1973.

The detailed 'Otago Survey' is needed not only because Pa Mong reservoir will cover a large area of possible archaeological importance but also because of the recent surprising archaeological discoveries in the adjacent regions of northeast Thailand. The site of Non Nok Tha, some 50 km south of the Na Klang lobe of the reservoir, has provided firm evidence for bronze metallurgy in the area prior to 2,000 B.C., domestic rice prior to 3,500 B.C., and domestic cattle and possibly pigs at an equally early date. The even more spectacular site of Ban Chiang, 40 km east of Na Klang, has yielded bronze tools and ornaments as early or earlier than those at Non Nok Tha, as well as hundreds of the now-famous red-on-white vessels decorated with remarkable sophistication.

These discoveries are only two of the results of the last decade of archaeological research in Thailand, research which has replaced the view of mainland southeast Asia as a backwater of cultural development with one emphasising its importance as one of the progressive development centres of east Asia.

2. Picture of previous land uses

Although environmental archaeology is still in its infancy, enough work has been done in the lower basin to indicate a general picture of the successive phases of exploitation of the land (Ref. 1). By reconstructing the original landscape, through study of relics of natural vegetation, and study of soils and drainage patterns, it becomes possible to visualise the settlement pattern that evolved (See Figure 2).

About 2,000 years ago two main areas in the lower basin, in the Mekong delta and in the Mun-Chi river basin in northeast Thailand (plus another area in the Chao Phya delta in Thailand), became settled by farmers growing broadcast rice watered by natural flooding. Two factors led to choice of these sites, namely availability of water throughout the year and the ease of reclaiming the land. Hence the early settlements in the delta zones were located on the grassy plains lying between dense riverine forests and the deep forests of the higher grounds, including brackish areas notorious for their presumably 'infertile' soils, and in the Mun-Chi area on erosion terraces which flooded to a shallow depth in the wet season. In other words, flat lands with sparse vegetation and natural flooding were the choice lands (and still are for growing floating rice). The population was centered in city-states which were essentially self-supporting agricultural communities with no significant trade with the outside. During this early period the area was first exposed to Indian culture and religions, and produced masterpieces of religious art in stone and clay that have never since been equalled. These early farmers dug canals and moats of very large size, the canals being used mostly for communications and the moats as reservoirs to supply domestic water during the dry season. This civilization reached its peak in the seventh century and then was replaced by the medieval civilisation of mainland southeast Asia dominated by Angkor.

A gradual change in settlement pattern occurred in the centuries that followed. Large areas of open dipterocarp forest in the lower terraces around the Great Lake and in the Mun-Chi basin were reclaimed into bunded fields. Remnants of these medieval farming sites are readily recognized from their checker-board pattern and bushy overgrown bunds. Water for domestic use was obtained from ponds supplied by groundwater, resulting in a change in social organization from the large agglomerations of the early rice farmers to

small groups around individual ponds. Medieval agriculture sites can be traced from aerial photos and topographic maps even in areas which were long ago abandoned. Because of the absence of natural flooding on the reclaimed low terraces, and the more permeable soils, transplanted rice was grown instead of broadcast rice along with fruits and vegetables, much the same as is practised today. Water for crops was supplied mostly by bucket irrigation along the river banks. The medieval populations were much larger than in the previous periods and large towns came into being, not as centers of commerce but of religious activity. By the tenth century the lowland settlements of the early rice farmerss has been almost entirely abandoned, perhaps due to changes in the climate and flood patterns of the major streams.

In the following centuries wars and unrest adversely affected agricultural development. Medieval agriculture continued but gradually deteriorated and many areas reverted to forests. Reclamation of the floodlands had to wait until the second half of the nineteenth century when the international rice trade became profitable. The deltas of the Mekong and Chao Phya again became the centers of agricultural production. In northeast Thailand, however, only recently has agriculture again become important.

3. Otago survey

The work programme for the present survey, authorized in October 1973 (Ref. 7), includes field visits and test excavations covering as much of the Pa Mong reservoir area as possible during the field study periods in December 1973 - April 1974 and December 1974 - April 1975. A central laboratory for processing of finds was established at the Khon Kaen National Museum. In addition to the survey itself the programme devoted considerable effort to training of personnel from the riparian countries, to establish a source of local expertise for continuing the studies.

(a) Survey area: To supplement the earlier field studies in the Nam Mong drainage area, the new field investigations were concentrated on the large lobe of the Pa Mong reservoir area in Amphoe Chiang Khan, with supplementary work in the vicinity of Pak Chom and along the Lao bank of the Mekong near Muang Sanakham (Figure 1). In these areas 3[illegible] sites were selected for study (in Loei province and the adjacent areas of Muong Sanakham), of which two-thirds appeared to be largely historic in date (contained shreds of stoneware and porcelain plus traces of brick, tiles, and pipes) and one-third prehistoric (no contact with any Indianized cultures). The locations of the 3[illegible] sites, shown in Map 2 of Reference 7, include places in the relatively

wide Loei valley and adjacent hills, in the narrower valley and more rugged hills of the Chom drainage areas, and on the hills and narrow plain of the Lao side of the Mekong.

Geographically the area surveyed is intermediate between northeast and north Thailand. However, from the standpoint of overall environment the area surveyed has much more in common with the forested hills, karst outcrops, and narrow river valleys of northern Thailand and upper Lao PDR than it does with the rolling lowlands and wide, seasonally swampy alluvial plains of northeast Thailand. This similarity includes landforms, elevation, and geological features.

(b) Preliminary survey findings: While the report on the 1975 field studies is not yet available, the findings from 1974 (Ref.7) and preliminary findings for 1975 (Ref. 8) indicate, in the Pa Mong reservoir vicinity, the Loei-Vientiane and nearby areas to the north were characterized by an essentially Hoabinhian technology and economy until early historic times, while conditions outside the reservoir vicinity, on the Khorat plateau to the east, encouraged an early development of rice cultivation, cattle breeding, and sophisticated bronze technology. These very striking differences in human occupation and in cultural stagnation, as contrasted to cultural development, can be explained by differences in environment, the former area being characterized by dense forests and the latter by the open diptherocarp savannas.

(c) Suggested additional studies: The Ortago survey results, while still very preliminary, suggest the following additional studies should be considered:

(1) Detailed survey of both banks of the Mekong river along the reach in the reservoir area, extending about 1 km inland, to check for evidence of movements of population and diffusion of technology along the river.

(2) Detailed clearing, mapping, and photographing of notable historic sites (such as Vat Si Phum and Pa Chao Pho), together with recording of inscriptions and of local traditions about the sites.

## 4. Summary and conclusion

Although not exhaustive, the archaeological studies undertaken by the Mekong Committee indicate that, while significant archaeological remains do exist in the Khorat plateau east of the Pa Mong reservoir area, the reservoir itself is part of an area which has always been heavily forested hence not likely to contain valuable remains except perhaps along the immediate vicinity of the river. The continuing Mekong Committee programme includes plans for detailed field explorations along the river strip.

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# Map I : PA MONG RESERVOIR

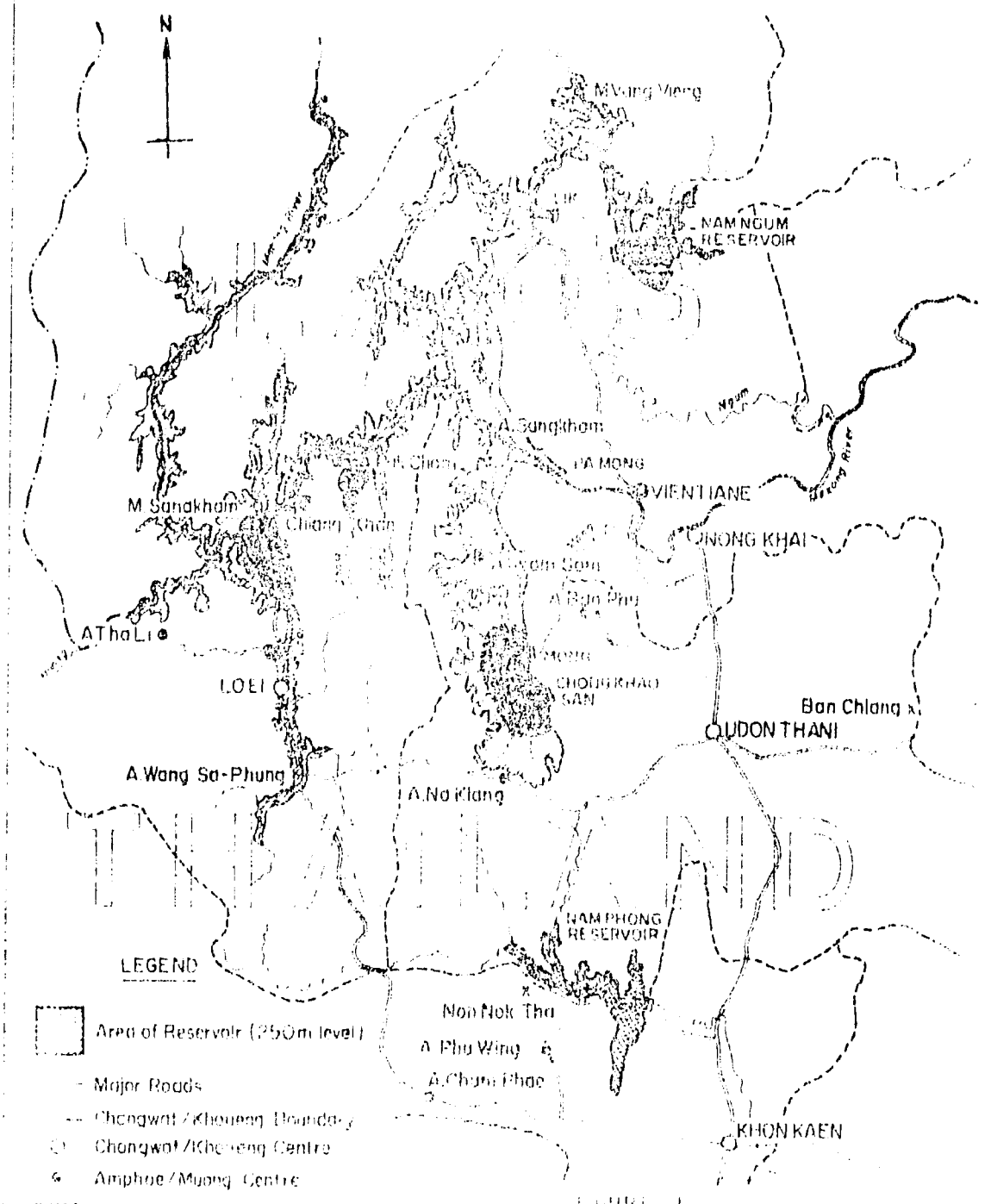


FIGURE 1

PA MONG RESERVOIR AND LOCATIONS OF AREAS SELECTED FOR ARCHAEOLOGICAL FIELD SURVEYS (From Reference 7)

Scale 1:1,500,000

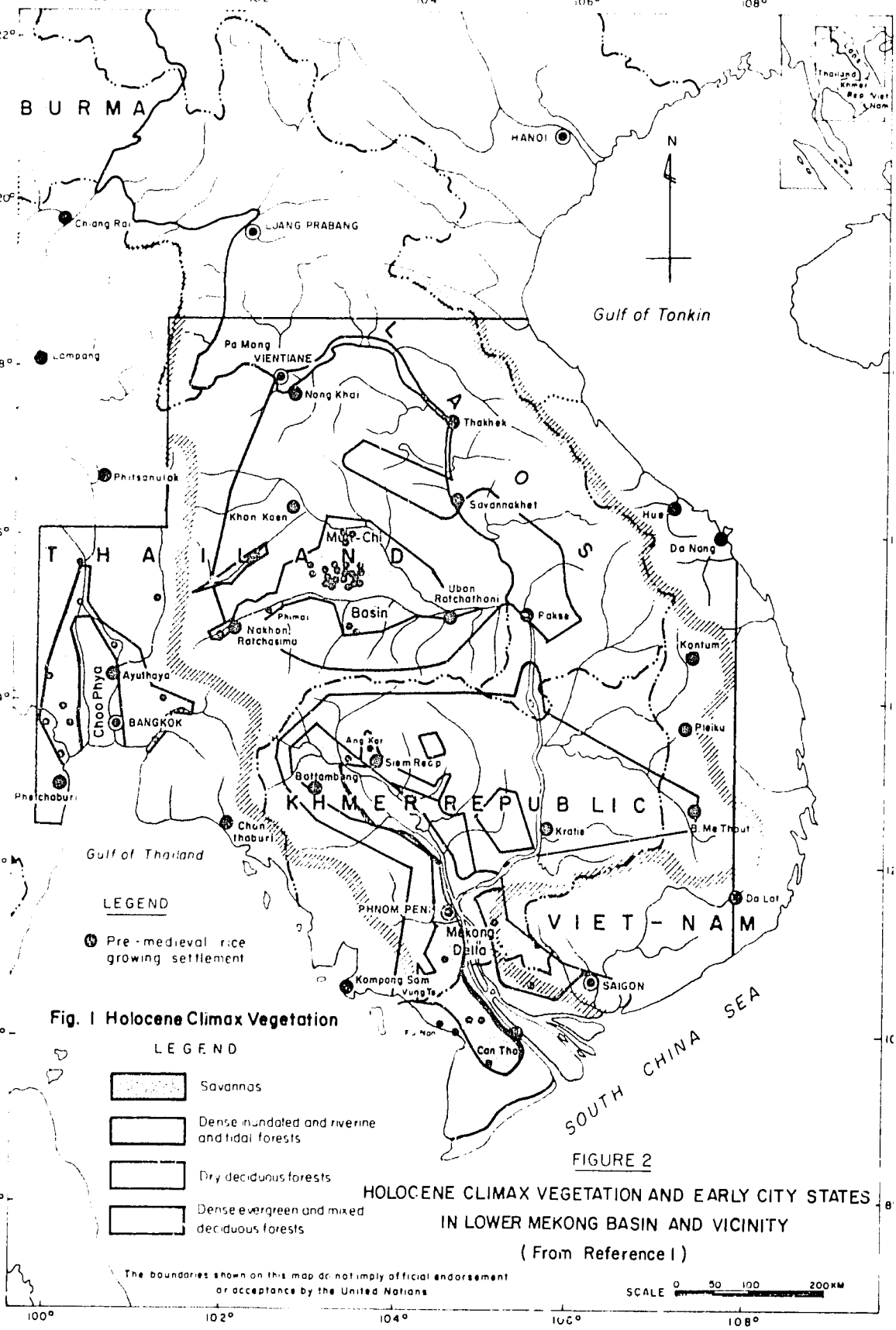


Fig. 1 Holocene Climax Vegetation

FIGURE 2

HOLOCENE CLIMAX VEGETATION AND EARLY CITY STATES IN LOWER MEKONG BASIN AND VICINITY

(From Reference 1)

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## BASINWIDE PLANNING DATA AND TOOLS

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# PA MONG ENVIRONMENTAL ASSESSMENT

## BASINWIDE PLANNING DATA AND TOOLS

### 1. Basic data programmes

For purposes of comprehensive planning of water resource projects in the lower Mekong basin, including Pa Mong, the Mekong Committee has established and operated a number of basinwide programmes for the collection and utilization of basic data pertinent to the many purposes of water resources projects including power generation, irrigation and agriculture, flood control, navigation, socio-economic development, etc.

Basic hydrologic data are of course essential for water resource project development, and in view of this importance the Mekong Committee has established and operates a comprehensive hydrologic data collection programme (See discussion on surface water). While the main thrust of this programme on hydrology on of quantity of flow in the Mekong river and tributaries, supplementary programmes of sampling and analysis are conducted using the same river gauging stations for determinations of sediments and bed load and of water quality, and also of salinity in the Mekong delta areas affected by seawater intrusion (See discussions on sedimentation and erosion, on water quality, and on salinity).

Additional basic data programmes have been developed by the Mekong Committee relating to agricultural practices throughout the basin including preparation of basinwide maps showing vegetative cover, hydromorphology, land use, and ecological zones (See discussion on agriculture); the Annual Statistical Bulletin (See discussion on socio-economics); and a number of special publications.

Some of the basic data noted above are derived by the Mekong Committee's remote sensing programme including use of satellite imagery (Item 2 below). Because of the vast extent of the lower basin, satellite imagery appears increasingly valuable for a wide variety of purposes.

For efficient application and use of the basic data, the Mekong Committee has developed programmes in system analysis utilizing electronic computers and a number of mathematical models tailored to various specific needs (Item 3).

## 2. Resources mapping with satellite imagery

### 2.1 Development of programme

Aerial photographic mapping (U.S. Army Map Service series) covering the entire lower basin have been available at scales of 1 : 1,000,000; 1 : 250,000; and 1 : 50,000; plus partial coverage at scales of 1 : 40,000; 1 : 10,000; and 1 : 2,500. However, considering the vast size of the lower basin, the complex nature of the Mekong Committee's planning activities and the continuing need for up-to-date data, the Mekong Committee has been especially interested in the potentials of satellite imagery both as an economical means for obtaining the large amounts of data needed and also for obtaining information on inaccessible areas. Accordingly, the Mekong Committee has participated in the experimental earth resources satellite imaginery programme, as an investigator for NASA, from the initiation of the programme in July 1972 with the launching of the ERTS-1 (now renamed the LANDSAT-1) satellite. The Mekong Committee's work, carried out by a mapping unit established within the Mekong Secretariat, includes responsibilities both for processing the data and for sponsoring training courses in the uses of satellite imagery for participants from the riparian countries.

Multispectral imagery received by the Secretariat from NASA covers the entire lower basin, including imagery taken by LANDSAT-1 between July 1972 and August 1973 (at which time the recording mechanism of the satellite became inoperative). Since July 1975 imagery from LANDSAT-2 has been received. About 45 frames of 185 km x 185 km are necessary to cover the 60 million hectares of the lower Mekong basin. These frames are taken every 18 days, with 7 consecutive days required to cover the entire lower Mekong basin (see Fig. 1).

The LANDSAT-1 data outputs made available to the Secretariat for analysis were in the form of bulk black and white multispectral scanner (MSS) transparencies in both positives (9.5 inch x 9.5 inch or 240 mm nominal size) and negatives (70 mm x 70 mm in size). The scales of these products were 1 : 1,000,000 and 1 : 3,369,000 respectively. These bulk MSS products (also called system corrected MSS images or SYCI) have been delivered also in the form of 7-track computer compatible tapes for a few selected frames.

An overall first-look assessment of the imagery with respect to its potential applications to geology, forestry, hydrology, and pedology (soil mapping and archaeology) was made by a Satellite Imagery Task Force established in the Secretariat in 1972. Preliminary results were reported at the "Symposium on Significant Results Obtained from Earth Resources Technology Satellite-1", organised by NASA from 5 to 9 March 1973 and published by NASA as part of the symposium proceedings.

This first assessment and later analytical work based on colour enhancement techniques, such as use of diazochrome colour films, and on use of computer compatible tape processing led to the conclusion that LANDSAT-1 multispectral imagery analysis reveals a wealth of information and details, many of these being not detectable through the classicle survey approach, in the areas of soils, forests, land use, flood areas, and geomorphology. To analyze the imagery, false-colour composite techniques are used with the help of a projector-viewer for colour-composite reconstruction, and with colour transparencies processed from diazochrome proofing films.

## 2.2 Thematic mapping

LANDSAT imagery has made it possible for the first time to observe the entire lower Mekong basin from a set of photographs that are homogeneous. Furthermore, sequential coverage makes it possible to study cyclical characteristics of certain phenomena, such as the repartition of evergreen and decideous forest, areas under crop, and the mechanism of flooding and drainage of the lowlands. The LANDSAT data has proven to be of such quality that these phenomena can be represented cartographically in the form of thematic maps.

Since early 1974 the Mekong Committee has received assistance from France in funding a two-year programme of thematic mapping using the satellite imagery available at the Secretariat. This programme includes preparation and printing of three kinds of thematic maps of the lower Mekong basin, (a) maps showing vegetation cover, including forestry, (b) maps showing land systems which combine physiographic, geologic, soils and hydrological characteristics as recurring units, and (c) maps showing flood and drainage conditions during consecutive periods. The programme, carried out in collaboration with the riparian countries, is proceeding largely on schedule. It is expected that the first set of thematic maps, at a scale of 1 : 500,000, with accompanying explicative notes, will be published in 1976.

As example of an early version of a thematic map produced by the programme showing types of ground cover is shown in Figure 2. Also, Figure 3, taken from the Mekong Committee's Annual Report for 1974, illustrates a colour composite type of thematic map at the scale of 1 : 1,000,000, which presents an overview of the Great Lake region in Democratic Kampuchea, taken on August 1973. This clearly illustrates several key environmental characteristics of the region as explained in the caption on the figure. A third illustration of the Mekong Committee's thematic mapping programme is given in Figure 4, which shows the extent of flood inundation in the lower basin during the period of 22-28 October 1972 (believed to represent about a one-in-ten-year storm). Eventually this type of mapping should be of

great value in relating hydrologic data during flood seasons to effects on environment including estimates of damages to crops and other values.

## 2.3 Computer programmes

Three computer programmes have been developed by the Secretariat computer and systems analysis unit for preliminary analysis of the system corrected (SYCI) LANDSAT-1 computer compatible tape data, namely, a histogramme programme, a pattern classification programme, and a positioning programme. Using the first two programmes, automatic mapping of the Vientiane flood plain has been accomplished which accurately recognizes at least six categories of land use at an approximate scale of 1 : 25,000.

A detailed programme of ground truth data collection was started in 1975 by the Secretariat in co-operation with AIT (Asian Institute of Technology) and ASRCT (Applied Scientific Research Corporation of Thailand). This is designed to be synchronized with LANDSAT-2 passes over the Chao Phya delta. This ground truth is used as input to a prototype computer programme obtained from Colorado State University or Purdue University using the new IBM 370 computer installed at AIT.

## 2.4 Rainfall forecasting

In co-operation with the Thai Meteorological Department and United States National Weather Service, the Secretariat has been receiving "APT" pictures from the ESSA 9 weather satellite and other weather satellite series operated by NOAA/NASA since 1979. Data from weather satellite, as well as radar stations throughout the region, are needed because there are few reporting meteorologic ground stations located on the left bank of the Mekong. A great volume of data is necessary to support the basinwide flood forecasting programme (See discussion on flood control), and, following construction of Pa Mong, will be needed to ensure proper operation of the reservoir for flood protection in conjunction with other purposes.

## 3. Mathematical modelling

Water resource development planning in the lower Mekong involves analysis of numerous alternative schemes for water resource control on the Mekong mainstem and its tributaries, for such purposes as hydroelectric power generation, irrigation, flood control, and navigation improvement. Detailed analysis of these numerous alternatives by manual methods is time consuming and expensive, and in planning projects such as Pa Mong in the past the detailed investigations were limited to relatively few of the promising alternatives. Water resources planning depends, essentially, on

evaluation of alternative schemes or combinations of physical systems subjected to stochastic inputs of hydrology and meteorology in order to obtain the outputs which serve the desired numerous purposes.

Adoption of a plan of development for the river system follows the comparative assessment of all feasible alternatives to obtain the one which optimally serves the criteria selected for development; hence investigation of a large number of alternative plans of development must be carried out if the really optimum scheme of development is to be identified. A major new tool developed in recent years for water resources system simulation is the mathematical modelling technique, which enables expeditious investigations of various alternatives subjected to long-term stochastically varied hydrologic inputs.

## 3.1 Evolution of Mekong modelling programme

Modelling efforts of the Mekong Committee began in 1961 (four years after the formation of the Committee) by arranging through the United Nations Development Programme (UNDP) for the development of a mathematical model representing the hydraulics of the Mekong delta (the river system downstream from Kratie, Democratic Kampuchea, to the mouth of the river in Viet-Nam, and including the Great Lake and Tonle Sap in Democratic Kampuchea). This led to development of the DELTA model by SOGREAH (Ref. 14).

A second major step leading to extensive application of modelling techniques for lower basin analyses was initiated in January 1962 (Ref. 2) with the assistance of the U.S. Corps of Engineers. This included a training programme of 18 months for 10 engineers from the riparian countries at the North Pacific Division Office of the Corps of Engineers in Portland, Oregon, which provided opportunity for these engineers to be familiarized with the basic concepts and operation of the SSARR and HYSSR models developed for use in the Columbia river basin investigations, and to develop applications of these models to the lower Mekong basin (Ref. 1). Much of the Mekong Secretariat's activities for application of modelling technique to water resources planning and flood forecasting has stemmed from this training programme.

The current applications of modelling techniques by the Mekong Secretariat are summarized as follows:

(a) Project evaluations and flood forecasting using the SSARR model.

(b) Planning of water control development projects in the lower basin, including the Pa Mong optimization and downstream effects study and tributary projects, using the HYSSR, SSARR, DELTA, and HIGHHEAD models.

(c) Evaluation of various proposed water control development schemes in the Mekong delta areas, using the DELTA and TIDAL models, including analysis of dredging.

(d) Application of the MASS model to the Lam Pao irrigation project in Thailand.

(e) Application of the CSHFLO model for economic evaluation of power system alternatives in the lower Mekong basin.

(f) Application of the WASP package of models for evaluating nuclear power alternatives.

A detailed description of these models is presented in Section 3.3.

Through 1974 the IBM 360/40 computer at the National Statistical Office of Thailand, and the CDC 3100/3300 computer system at the Bangkok Data Centre were used for most of the Secretariat's modelling work. Since then the CDC 3600 computer system at the Asian Institute of Technology with larger core storage, has been used to improve efficiency of the existing models. Also, since March 1976 an IBM 370/145 computer installed at AIT has been used.

## 3.2 Continuing development in modelling applications

At this time the state-of-the-art of mathematical modelling involves modification and adjustment of model parameters based on additional information gathered and on experience in working with the models. Hence the modelling applications of the Mekong Secretariat are in continuing evolution and improvement, for example in application of the SSARR model to flood forecasting in order to improve the accuracy of the forecasts (Ref.10). This includes efforts to develop the LSSARR model, which is essentially an extension of the SSARR model, to the delta (Ref. 10, 12). This is attempted by applying the backwater mode of routing to the channel reaches, and using three variable relationships in the estimation of over-bank flow and interflow between the Mekong and the Bassac river. Also, the HYSSR model has been modified to use a larger core storage computer resulting in reduction of computer time to one-sixth of former requirements for an average run (Ref. 6). In addition, arrangements are underway with SOGREAH for modification and recalibration of the DELTA model for the purpose of computer time reduction

and for better performance of the model for low flows. A reduction of approximately 24 per cent has already been achieved and SOGREAH has estimated an eventual reduction for the pending high flow/low flow version of the model to about 60 per cent of its present requirements.

Efforts are currently underway by the Secretariat for considering alternative models for supplementing currently used models (Ref. 11). The HEC-3 model developed by the Hydrologic Engineering Centre of the Corps of Engineer has been modified for application at the AIT computer centre. The potential applications are similar to those of the HYSSR model, but it is designed for broader applications where other purposes (such as irrigation and flood control) can be more conveniently handled, particularly for tributary basin projects. The HYSSR model is more suitable for mainstem projects for essentially hydropower development analyses. Also, the REGUL II models, which contain internal optimisation features, were developed as supplements for the SSARR in flood regulation studies where several constraints have to be taken into account. Similarly, as alternatives for the time-consuming DELTA model, the CHANNEL and THLSAP models are being used as trial models for simulating flows in the main channels of the Tonle Sap, Mekong (below Kratie), and Bassac rivers in Democratic Kampuchea (Ref. 7).

### 3.2.1 Flood forecasting programme

Evolution of the flood forecasting programme in the lower Mekong basin since its initiation in 1970 has been described in some detail in the discussion on flood control. Essentially the programme is based on the application of the calibrated SSARR model of the basin using as input data observed rainfall at key locations and quantitative rainfall forecasts from radar and satellite observations. Actual computation in the forecast consists of two parts: A back-up period of four days prior to the current morning and a forecast period over the next ten days. Rainfall data during the back-up period are adjusted so that the resulting stream flow from the model match the observed values on the forecast morning. Then the computatin is made for the forecast period using rainfall input as previously discussed.

At the present time forecasts for locations in the delta area have to be made manually based on correlation of their flows with upstream discharge, local rainfall and the tidal cycle. Such manual forecasts will be made until development of the LOSSARR model, now underway, is satisfactorily completed (Ref. 10, 12). The application of the DELTA model, which is the most theoretically promising model for forecasts for the delta area, is currently not feasible due to its large computer time requirement and the unavailability of its extensive data input requirements (Ref. 13).

Although still in its experimental phase the flood forecasting programme has shown signficant improvement each year. This is due both to the better refinement of the model parameters resulting from more field data for its calibration, and to the expected improvement of skills of the forecasters. In general, the degree of accuracy of the forecasts depends very much upon the shape of the hydrograph. Sharply rising hydrographs resulting from very heavy local rainfall usually results in low accuracy. This indicates the need of better definition of basin rainfall input, which is in the process of improvement using low cost tele-automatic rain gauges specially designed for Mekong conditions (Ref. 7). Ranges of deviation from observed peak heights of all 13 forecast locations except Chieng Saen were 0 to 0.29 m for 1 day forecasts, and from 0.01 to 0.03 m for 3 day forecasts. Median deviation in 1974 ranged from 0.01 to 0.08 m, 0.02 to 0.20 m, 0.02 to 0.32 m, 0.02 to 0.45 m, and 0.03 to 0.57 m for 1, 2, 3, 4, and 5 day forecasts respectively.

## 3.3 Description of models in current use

### 3.3.1 DELTA model

The DELTA model was developed for the Mekong Committee by SOGREAH, a French consulting firm, as a tool to simulate with reasonable accuracy the hydraulic regime of the Mekong delta. The motivating purpose was for use in conjunction with studies of a possible dam across the Tonle Sap for control of flow between the Great Lake and the Mekong river. It has since been used in various investigations of the Mekong delta area including (a) delta reclamation investigations, (b) hydraulic feasibility studies of structures (dikes, roads, canals), (c) studies to establish optimum size of structures, and (d) planning of flood protection schemes.

In the DELTA model, river channels and inundated plains of the delta covering about 50,000 $km^2$ are represented by 293 topological units, or meshes, of approximately 100 to 120 $km^2$ each, plus the Great Lake. For each mesh, two basic assumptions are made: (a) that volume of water is a function of water level alone, and (b) that discharge between meshes at any given time is a function only of the water levels in adjacent meshes and hydraulic exchange relationships that exist - i.e., whether open channel flow, or overflowing weir type as would be the case where roads or dikes form a boundary. Based on a set of initial boundary conditions and surface water inflow and rainfall as input data, water levels and flows between meshes are computed using the equations of continuity and dynamics of flow. Thus the model can predict water stages and flows in the meshes under the influence of varying conditions of rainfall and inflows into the delta. The model calibration involved some 2,400 parameters and was made by trial and error using mainly

1963 and 1964 flood data. However, model calibration for analysing low flow periods is considered inadequate as this has to take into account more complicated situations caused by tidal effects, and a new version of the DELTA model, suited to examine low flow conditions, is under development.

### 3.3.2 SSARR model

The SSARR (Streamflow Synthesis and Reservoir Regulation) model was developed by the North Pacific Division of the U.S. Corps of Engineers to provide mathematical hydrologic simulations for system analyses as required for the planning, design, and operation of water control works, and has been applied extensively in the Columbia river basin. It is being used for the lower Mekong basin in design flood studies, reservoir regulation studies, examination of flood characteristics, streamflow routing, streamflow forecasting, and streamflow reconstitution.

The SSARR model is a mathematical hydrologic model of a river basin system comprising three basic components, namely (a) a generalised watershed model for synthesizing runoff from rainfall and snowmelt, (b) a river system model for routing streamflows through channel reaches and storages using classical storage routing procedures, and (c) a reservoir regulation model whereby reservoir outflows and contents may be analysed in accordance with predetermined or synthesized inflow and free flow or any of several modes of operation. The watershed model estimates runoff excess based on soil moisture index values, which are computed from rainfall and evapotranspiration relationships. The runoff excess is further divided into baseflow and direct runoff, using an empirically established baseflow infiltration index. The direct runoff is separated into surface and subsurface flow using an empirical surface-subsurface separation curve. These three components of runoff so estimated (baseflow, subsurface flow and surface flow) are then routed through their respective conceptual storage, each with a different number of storages and time of storage. The routed components are finally combined to obtain runoff hydrographs at desired locations.

Similar to other hydrologic models, the key to success in practical application is the model calibration. The parameters have to be estimated by trial-and-error until acceptable agreement between the model outputs and their respective observed values is obtained.

### 3.3.3 HYSSR model

The HYSSR (Hydro System Seasonal Regulation) model was developed by the North Pacific Division of the U.S. Corps of Engineers for simulating power generation and flood control

characteristics of a system of water control projects within a river basin under varying conditions of power loads and streamflows over an extended period of time. Although it is essentially a model for computing power and regulated flow, it recognizes and stays within constraints placed on the system by other water uses such as irrigation requirements, navigation, water quality, or others. Results of model simulations provide data for economic studies of system long-term performance capabilities.

The HYSSR model determines the amount of water that should be put into, or released from, each storage reservoir in the system during each increment of time. When the system is regulated for maximum power subjected to a set of constraints imposed by other water requirements, the result is a sub-optimized solution. Trial and error runs using different sets of constraints result in other suboptimized solutions. A combination of logic, analysis, and judgement is used to obtain the optimized solution for the system (the one that maximizes the sum of net economic benefit from all water uses).

As developed, the HYSSR model is particularly suitable for application in water resource development systems where hydropower production is the prime objective of multipurpose operation, as in the case of the potential system of Mekong mainstream projects.

### 3.3.4 HIGHHEAD programme

The HIGHHEAD computer programme was developed by the Mekong Secretariat as a tool for analyzing water resources projects on the Mekong river tributaries. Programme components are: The module to systhesize streamflow data, the module to compute usable flow versus net storage, the module to compute usable firm flow for irrigation purposes versus net storage, and the module for computing surcharge storage versus spill. The HIGHHEAD programme attempts to work out the optimum scale of a project with reservoir characteristics and economic factors as input data. For each high water level (HWL) a primary objective is to minimize spill in order to obtain maximum power generation. The project configuration yielding the highest benefit/cost ratio is considered the optimum solution. The output from this programme is printed in the form of tables presenting the salient features of all project alternatives considered.

### 3.3.5 TIDAL model

The TIDAL model was used by the Netherlands Delta Development Team to predict the tidal effects on river discharges through the main channels of the Mekong estuarine system. This is a one-dimensional hydrodynamic model in which the equation of a continuity and the dynamic equation are expressed in terms of finite differences. The difference

equations form a system of linear equations which are simultaneously solved to determine water levels and discharges at each river section. To portray the estuarine system, three types of functional relationships are introduced to cover the range of river behaviour as follows: (a) water level is a known function at one end of a branch, (b) river discharge is a known function at one end of a branch, and (c) each end of a branch is connected with another branch. For the Mekong estuarine system, sounding charts were used as a guide for dividing the system into 44 branches with 23 river junctions. The basic input data are river discharge downstream of Phnom Penh and tidal fluctuation at the river mouths of the Mekong. The computed results have been found to be in good agreement with those obtained from salinity analysis studies.

### 3.3.6 WASP package

The WASP package (Wien Automatic System Planning Package) was developed for the International Atomic Energy Agency (IAEA) for conducting power planning studies for individual IAEA member states, especially the developing countries. It is a second generation version of an earlier power system planning programme developed for use by the Tennessee Valley Authority in the United States. The WASP package is designed to find the optimum power system expansion plan within user specified constraints, using nuclear and any and all other sources of power. The Mekong Secretariat acquired the package through arrangements with the IAEA.

The WASP package consists of a group of six interrelated programme modules which may be operated sequentially in a single run, or may be operated individually. The six modules are:

(a) LOADSY module: a programme to describe forecast peak loads, energy requirements, and the corresponding load duration curves for the system.

(b) FIXSYS module: a programme to describe the characteristics of the existing power system and all future additions which are firmly scheduled.

(c) VARSYS module: a programme to describe the alternative plants which could be used for expanding the power system over the study period.

(d) CONGEN module: a programme to generate alternative expansion configurations of the power system within user-imposed constraints. The maximum number of configurations that can be generated for each year is 200.

(e) MERSIM module: a programme to simulate system operation for each period in the year and for each hydrological condition for each acceptable configuration generated by the CONGEN module. The MERSIM module uses a probabalistic simulation model to calculate energy generated by each plant, and the corresponding domestic and foreign exchange operating costs for each configuration for each period in the year. The reliability of the generating system is also estimated by calculating the loss-of-load probability in association with maintenance scheduling.

(f) DYNPRO module: a programme to determine the optimum schedule for adding new units to the system over the expansion period. The module, using a dynamic programming mode, carries out the economic evaluation of alternative expansion plans and recommends the best plan to be developed.

The Mekong Secretariat has utilized the WASP package for evaluating the power benefits of the proposed Pa Mong project for four different pool elevation alternatives and for developing the optimum installation schedule for the Pa Mong powerplant. It will be further used as a tool in evaluation of other products and in conducting power planning studies for the Mekong basin countries.

### 3.3.7 CSHFLO model

The CSHFLO (Discounted Cashflow) model was originally developed by the Mekong Secretariat as a tool for economic evaluation of power system development alternatives.

The computer model generates streams of cashflow expenditures for any given system over any desired length of study period and discounts them to present value at different discount rates. The capital investment of each alternative system may comprise hydroelectric projects, thermal plants (nuclear or stream), and a transmission system for which investment may be made at different periods of time. The scheduled in service date for each of these is included in the variable input data and will differ for each alternative. The project unit costs, the operating costs, and the distribution of the total investment cost over the construction period are included in the fixed data. With this information the model will compute the total investment and operating cost for each year over the period being studied. The combination of these cost components constitutes the cashflow streams which can be discounted to the present time with as many as ten different discount rates. Each component of cashflow, such as investment cost of dam, hydropower plant and thermal plant, or operating expenses, is discounted

separately so that the relationship of each component can be identified and its relative importance to the total discounted cashflow can be observed.

One significant feature of this model is that every item of estimated cost, including unit operating cost, can be varied by changing only the cost index which is associated with that cost. Therefore, the sensitivity of the model to changes in project cost can be easily determined. The model, though first designed for analysis of power system alternatives, may also be used for analysis of other projects such as irrigation and flood control.

### 3.3.8 MASS model

The MASS model (Mekong Agriculture System Simulation) was originally developed by Tippets-Abbet-McCarthy-Straton, a U.S. consulting firm, for application in Turkey, Venezuela, and Ecuador. The model provides the means for rapid analysis of agricultural development alternatives under existing and possible future conditions of farm size, farming methods, soil productivity, mechanization, crops and cropping patterns for both dry farm and irrigated farm production. It will permit farm budget analysis in sufficient detail to enable the preparation of individual farm operation plans. The model provides the ability to analyse various alternative approaches to farm development, emphasizing either (a)maximum employment, (b) maximum net return, (c) minimum capital investment, or (d) minimum credit requirements.

The MASS model identifies crop productivity potential for any given area based on soil log data. Various crop rotation alternatives can be examined, utilizing in each case a combination of up to three crops using their rooting depths and relative fertilizer requirements as selection criteria. The selected crop rotations are analyzed according to farming method, farm size, soil body, and rotation type. Farm production potential corresponding to crop rotation alternatives considered are then analyzed for economic performance according to different optimization objectives, per farm or hectare labour requirements, capital investment needs, net return, or credit requirements. These outputs are then used in evaluating development alternatives.

Specific application in the lower Mekong basin includes an analysis of the Huai Mong division of the proposed Pa Mong project and a recently completed investigation of the Lam Pao irrigation project in Thailand.

## 3.4 Assessment of modelling applications

The Mekong Committee has made substantial applications of mathematical modelling in water resources system planning in the lower basin. In fact it is among leading international

agencies applying this powerful tool in analyzing complex water resources problems. Modifications and refinements necessary for the application of the models in their state-of-the-art are underway. Minor reprogramming of models originally developed for large core storage computers (such as the SSARR and HYSSR) for use on the smaller core storage computers available in Bangkok have in the past resulted in longer computer time requirements. This problem is being resolved as larger computer capacities become available. Continuing efforts are being made by the Mekong Secretariat to improve the efficiency of the models.

The models used at the present time have limitations but are adequate to serve the Committee's needs within present resources, including available computers. However, considering the increasing need for modelling applications for future phases of water resources system planning by the Mekong Committee (and also the operation phase), it may be appropriate now to make a preliminary evaluation of the models which are currently in use as well as other promising models which might find valuable application. Models currently being used by the Committee may be categorized for assessment purpose into hydrologic models (SSARR, DELTA), and planning models (HYSSR, MASS, CSHFLO).

### 3.4.1 Hydrologic models

The hydrologic models used are based on established hydrologic and hydraulic principles. The SSARR in particular has been tested for its applicability in the Columbia river basin. In addition to ability to simulate outputs compatible to their respective observed values using model parameters obtained from different set of hydrologic data (split sample test), many other factors must be considered. These include such criteria as model simplicity, input data, computer size, computer time and analysis of time requirement, parameter optimization technique, sensitivity of parameter, etc.

While it is beyond the scope of this assessment to discuss these criteria in detail, it may be appropriate to note that the Hydrologic Research and Development Laboratory of the National Weather Service of the United States had conducted an evaluation of three hydrologic models including the SSARR to select the model most appropriate for river forecast centres throughout the United States. Results based on data from six different basins of varying sizes and characteristics indicated the Stanford Watershed Model IV may be generally preferable to the SSARR model (Ref. 18). Although this evaluation is not necessarily applicable to the lower Mekong basin, due to different basin and hydrologic conditions, it indicates the need for comparison of the SSARR with other models as previously discussed. Similarly, with DELTA model has found many applications in the Mekong

Committee investigations, but it has limitations in certain areas, especially because of the large number of simulations required. Arrangements to minimize the large amount of input data and computer time required for the DELTA model, currently being made by the Mekong Committee, are necessary if the model is to have wide applications for flood forecasting and system simulation in the future.

### 3.4.2 Planning models

Application of planning models by the Mekong Committee in its simulation of water resources systems represents a major step forward from classical water resources planning. However, all simulations using the HYSSR model have thus far used observed or reconstituted streamflow data as inputs. It has been realized in recent years that use of such historical data alone may not be sufficient to evaluate future performance of the water resources system, because the possibilities for recurrence of the historic data are very slim. Synthetic streamflow data are used to cope with this problem in modern water resources planning. In this technique sets of streamflow data are generated such that certain stochastic characteristics of the observed streamflow data are preserved. These sets of stochastically similar streamflow data are then used as inputs of the simulations. In this way performance of the system can be better evaluated, because its sensitivity to the uncertainty of future hydrologic conditions can be assessed. At this stage of planning in the lower basin, investigation should be made of the feasibility of applying synthetic streamflow data, especially for use with the HYSSR model.

The MASS model appears to be a very powerful tool in assisting decision makers in evaluating irrigation development schemes using different criteria which can reflect policies of the administrations of the riparian countries.

Discussions with the Mekong Secretariat staff indicate the CSHFLO model is a straight-forward computer programme, which has proved to be convenient for economic analysis of water resource systems.

### 3.4.3 Flood forecasting

As noted previously, the flood forecasting programme of the Mekong Committee is still in its experimental phase, yet produces worthwhile information for alerting downstream populations to the immediate flood hazards. Continuing improved accuracy of forecasts has been observed. This improvement should continue as more data become available for refinement of model parameters, and especially when the needed rainfall input data become available as a result of the current programme of application of tele-automatic rain gauges in the lower basin.

### 3.4.4 Ecological modelling

Public concern on environmental integrity of aquatic ecosystems, that is, the water and its residing biota, in recent years has introduced another dimension, environmental quality, into the already complex water resource system planning problem. In the process of planning much more consideration must now be given to effects on the quality of the water, impact on aquatic ecosystems, and other environmental consequences and associated economic and social impacts. The approach in current use, such as used in this study, is the qualitative approach with quantification limited to individual effects under consideration.

The increasing complexity of the problems being faced in water resource planning, including the need for more details and for quantification of environmental effects, has stimulated development of new methodologies for ecological modelling. Very recent development in this area are attempting to bring together in the form of mathematical models all parameters for planning decisions, including biological as well as physical factors, and also socio-economic and related cultural and aesthetic factors relating to human uses of water resources and effects on human values, so that impact of water resources development on all environmental values can be conveniently evaluated. Essentially such ecological models are expected to follow the "tier" concept for considering environmental effects as previously discussed in Chapter II. Although such modelling is only in the beginning stages of development, enough progress has been made to demonstrate the feasibility of this approach. Hence it may be appropriate to explore this potential for future use in the Secretariat's continuing and evolving modelling programme.

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TABLE 1

APPLICATIONS OF MODELLING FOR LOWER MEKONG BASIN PLANNING

| Model | Purposes | Original Development | References | Notes |
|---|---|---|---|---|
| SSARR | Hydrologic model used for (a) planning/design and operation of water control projects, and (b) flood forecasting. | By U.S. Corps of Engineers for Columbia River Basin (USA). | 1, 3, 4 | Considers basin to comprise 3 sets of conceptual storages (surface, subsurface, ground water), estimates inflows (considering rainfall, evaporation, evapotranspiration, soil moisture), routes these through basin to obtain combined flow as basin runoff. |
| DELTA | Hydrologic model used for evaluating proposed delta development schemes including analysis of dredging. | By SOGREAH for hydrologic studies of Mekong delta. | 8 | Delta divided into 293 small geographic units or meshes with hydraulic links. Predicts delta water stages and flows under influence of upstream inflows and of local rainfall. Calibration considered sufficient for all but low flows. |
| HYSIM | Evaluation of Pa Mong project and downstream effects, and of other projects, including simulation of multipurpose operations. | By U.S. Corps of Engineers for simulating river basin power generation and flood control characteristics together with other purposes. | 5, 6, 7, 17 | Determines storage to be put into or released from each reservoir in system to obtain maximum net economic benefits, where hydroelectric power generation is prime objective. For tributary projects the HEC-3 model may be more useful (where other purposes are equally important). |
| MASS | Systematic analysis of irrigated agricultural projects in lower basin including Lam Pao (Thailand). | By TAMU for application in other countries, now being tailored to lower basin conditions. | 7, 9 | Model input includes all variables affecting rainfed and irrigated agriculture (technical and economic). Basic assumption in project analyses is to optimize economic benefits as well as farmer's benefits for the given constraints in land, labor, and capital. |
| CSHPLO | Economic evaluation of power system alternatives in lower basin. | By Mekong Committee for power evaluations using wide range of discount rates. | 5 | For given size of power plant and completion schedule, cash flow expenditures are computed from different power system alternatives. Expenditure is then discounted to present value using different internal rates of return. |
| HIGHHEAD | Development of optimum scale of project with reservoir characteristics and economic factors as input data, so as to maximize power and minimize spill for each selected high water level. | Mekong Secretariat as tool for analyzing water resources projects on Mekong river tributaries | 19 | Programme components include modules to synthesize streamflow data, to compute usable flow versus net storage, to compute usable firm flow for irrigation versus net storage, and to compute surcharge storage versus spill. |
| TIDAL | Prediction of tidal effects on river discharges through main channels of Mekong estuary. Results check with those obtained from salinity studies. | Netherlands Delta Development Team for the Mekong Committee. | 19 | One-dimensional hydrodynamic model in which equation of continuity and dynamic equation are expressed in terms of finite differences. The equations for differences form a system of linear equations which are simultaneously solved to determine water levels and discharges at each river section. |
| WASP | Determination of optimum power system with user specified constraints, considering nuclear and all other possible power sources. Used for analysis of Pa Mong alternatives. | International Atomic Energy Agency for conducting nuclear power planning studies for IAEA member countries. This is advanced version of programme originally developed by TVA in United States. | 19 | WASP package consists of group of six interrelated programme modules which may be operated sequentially in single runs or individually. These are the LOADSY module (peak loads, energy requirements, load duration), FIXSYS module (system characteristics), VARSYS module (expansion alternatives), CONGEN module (expansion configurations), MERSIM module (system operation), and DYNPRO module (schedule for new units). |

Note 1 Computers used by the Mekong Secretariat include the IBM 360/40 computer at National Statistical Office of Thailand, the CDC 3100/3300 computer system at the Bangkok Data Centre, and the CDC 3600 computer system at the Asian Institute of Technology.

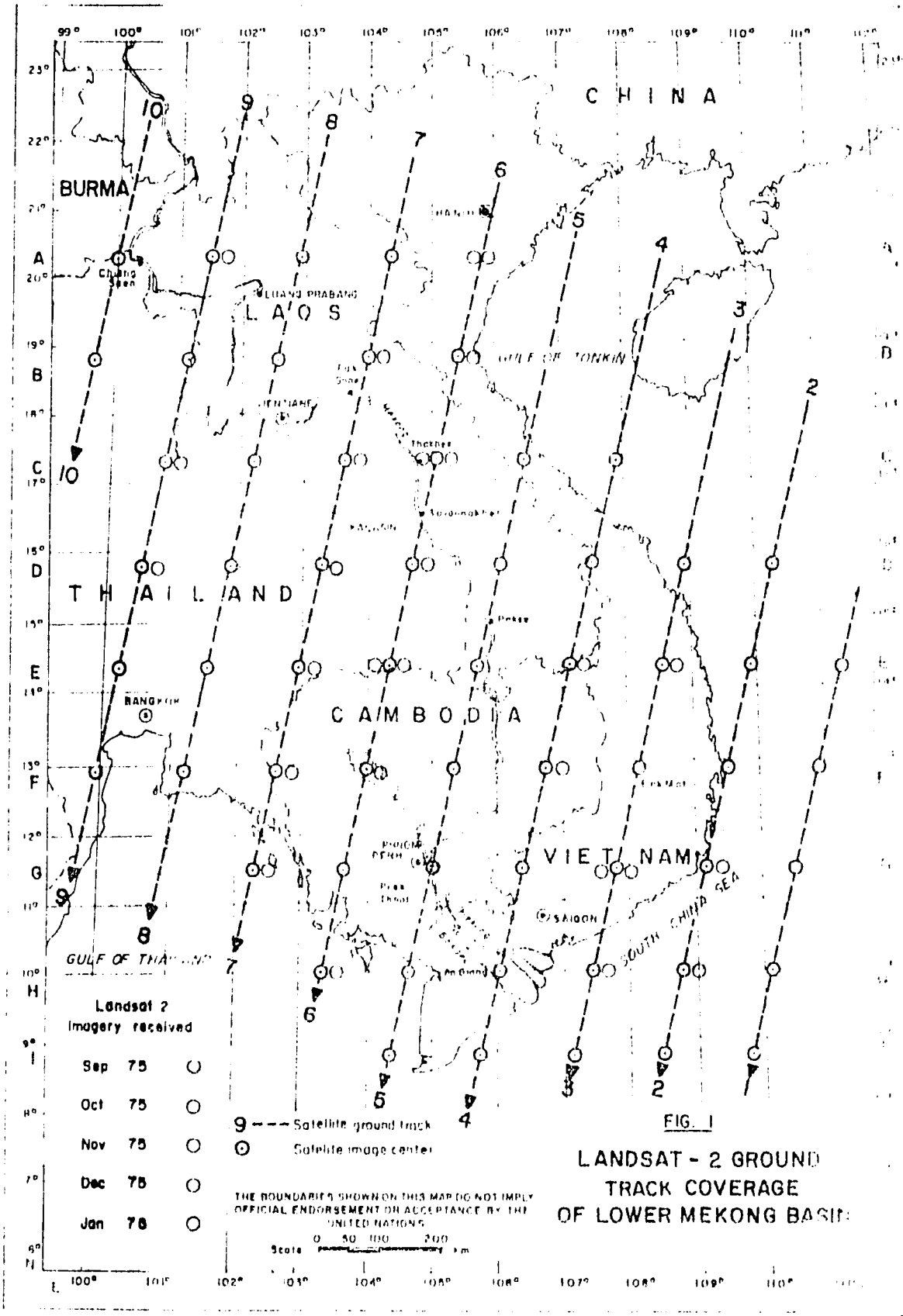



FIG. 1

LANDSAT - 2 GROUND TRACK COVERAGE OF LOWER MEKONG BASIN

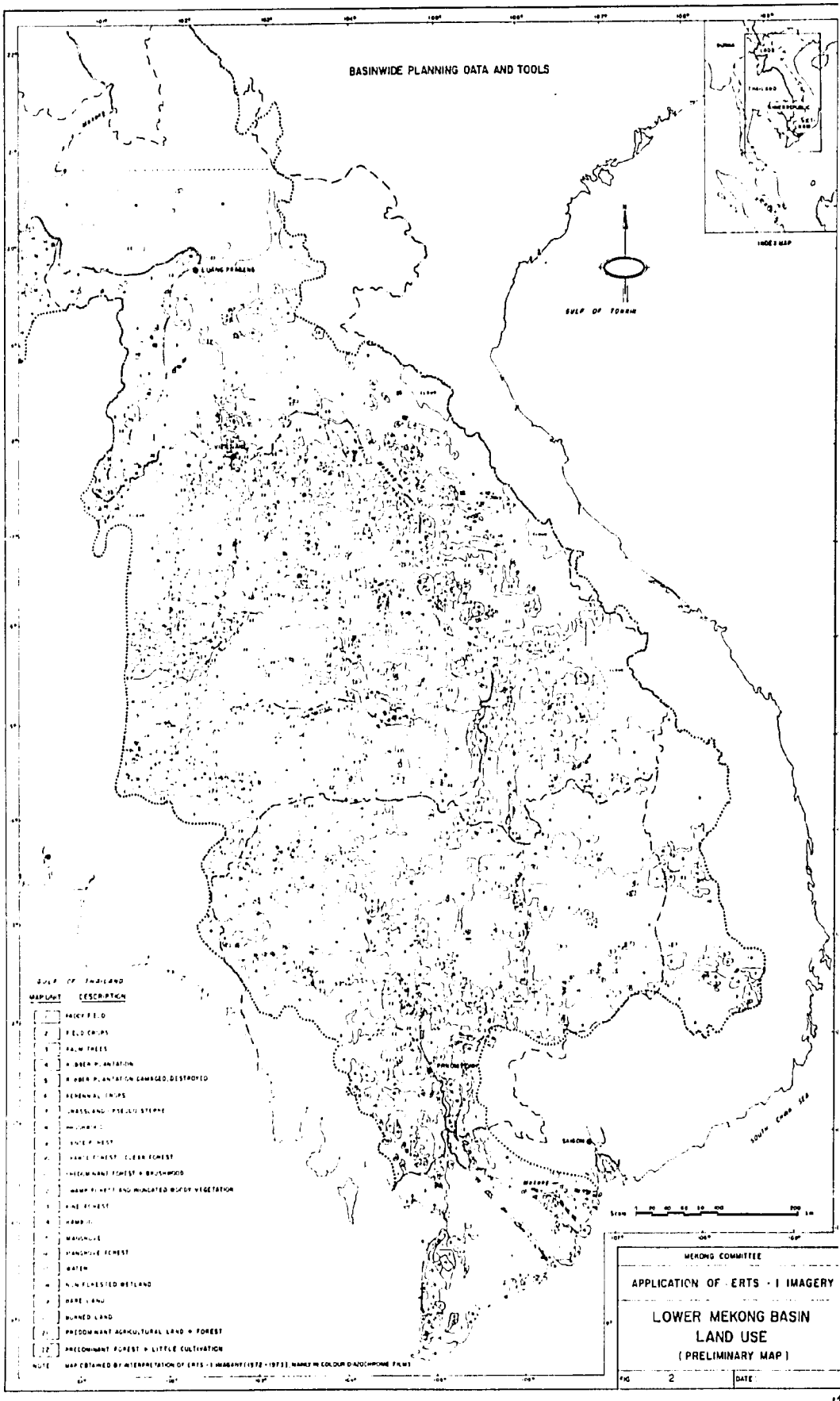
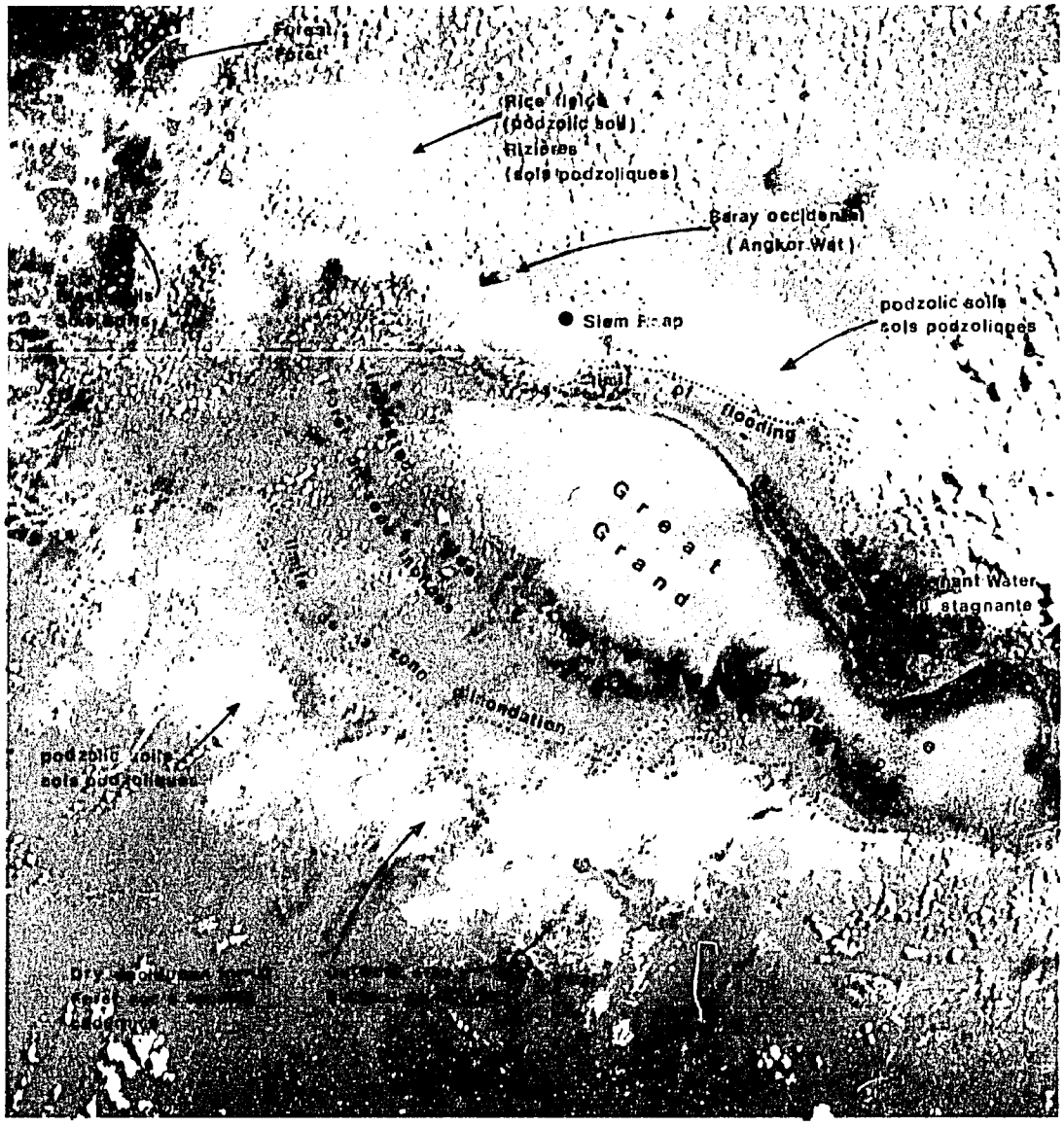

BASINWIDE PLANNING DATA AND TOOLS
INDEX MAP
GULF OF TONKIN
LUANG PRABANG
VIENTIANE
PHNOM PENH
SAIGON
SOUTH CHINA SEA
GULF OF THAILAND
MAP UNIT DESCRIPTION
1 PADDY FIELD
2 FIELD CROPS
3 PALM TREES
4 RUBBER PLANTATION
5 RUBBER PLANTATION DAMAGED/DESTROYED
6 PERENNIAL CROPS
7 GRASSLAND - PSEUDO STEPPE
8 MOUNTAINS
9 DENSE FOREST
10 MIXED FOREST - CLEAR FOREST
11 PREDOMINANT FOREST + BRUSHWOOD
12 SWAMP FOREST AND INUNDATED WOODY VEGETATION
13 PINE FOREST
14 BAMBOO
15 MANGROVE
16 MANGROVE FOREST
17 WATER
18 NON FORESTED WETLAND
19 BARE LAND
20 BURNED LAND
21 PREDOMINANT AGRICULTURAL LAND + FOREST
22 PREDOMINANT FOREST + LITTLE CULTIVATION
NOTE MAP OBTAINED BY INTERPRETATION OF ERTS - 1 IMAGERY (1972 - 1973) NAMELY IN COLOUR DIAZOCHROME FILMS
Scale 1 20 40 60 80 100 200 km
MEKONG COMMITTEE
APPLICATION OF ERTS - 1 IMAGERY
LOWER MEKONG BASIN
LAND USE
(PRELIMINARY MAP)
FIG 2
DATE

FIGURE 3




THEMATIC MAP OF GREAT LAKE IN DEMOCRATIC KAMPUCHEA PREPARED FROM SATELLITE IMAGERY

From imagery taken early in the rainy season, this composite clearly show the silty center of the Great Lake (bright blue), surrounded by patches of stagnant water (black). The latter represents water containing humic acids formed during the bog season in the inundated forest, which has a low pH sometimes detrimental to fish and also to crops. The yellow - colored belt represents paddy fields that have been farmed for ages.

Colour composite of a satellite picture ( scale 1:1 million) showing the Great Lake and adjacent area, Democratic Kampuchea, 8 August 1973.

Représentation en couleurs composites (échelle 1:1 million) d'une image du Grand Lac et de la zone avoisinante (Kampuchea démocratique) prise par satellite.

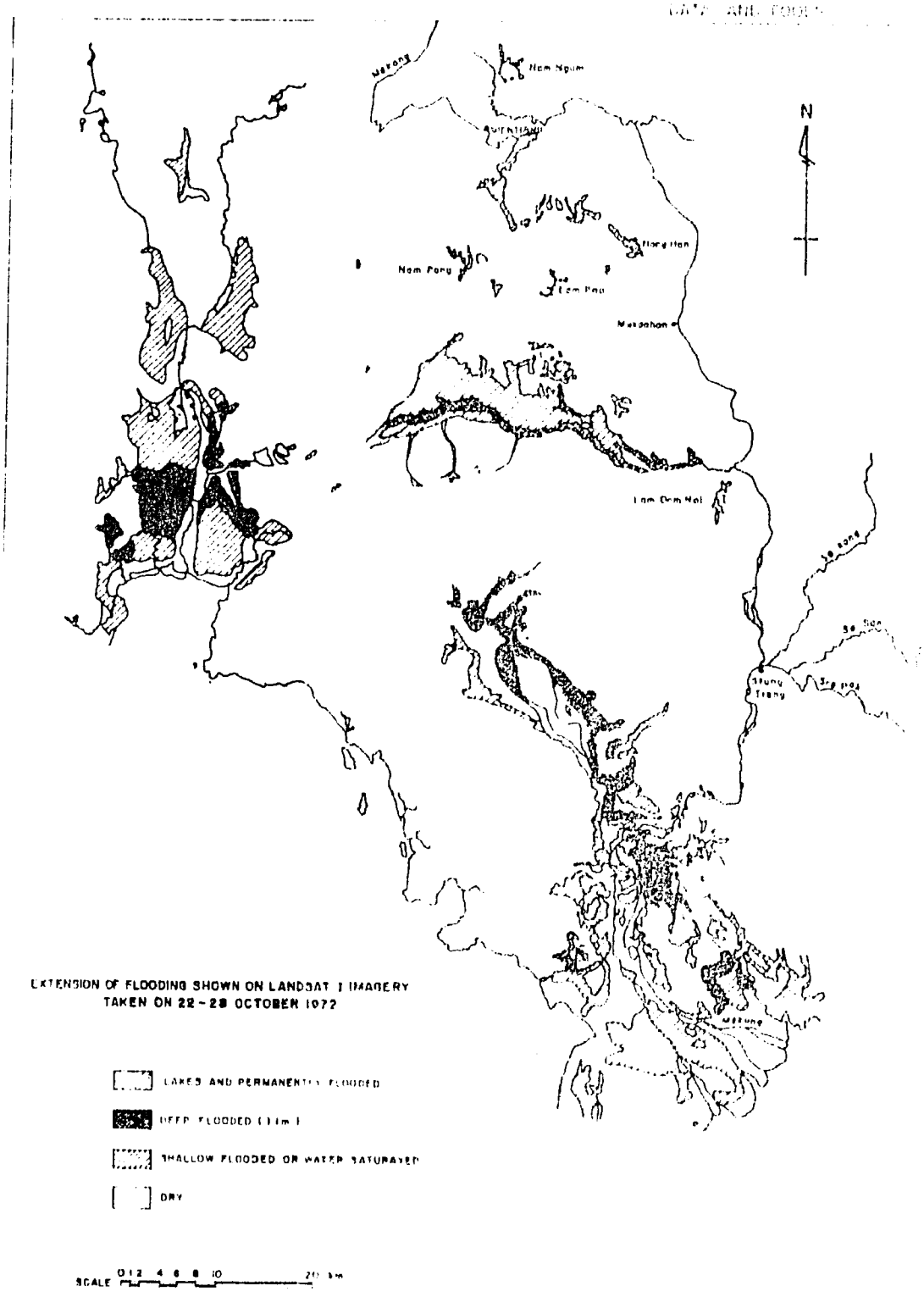



FIGURE 4

FLOOD INUNDATION IN LOWER MEKONG BASIN BY SATTELLITE IMAGERY

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## CLIMATE

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Table 6: Highest sustained wind velocity duration and direction

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# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## CLIMATE

### 1. Climate of lower basin

The climate of the lower Mekong basin, including the Pa Mong project area, is tropical, with minimum temperatures almost always considerably above freezing. The climate is influenced primarily by the two seasonal monsoons and the intertropical convergence zone, and to a lesser extent, by tropical cyclones and other tropical disturbances. The monsoons have been designated as the southwest monsoon and the northeast monsoon according to the movement of airmasses through the basin.

The southwest monsoon season, which is the rainy season, normally occurs in the lower basin approximately from May through October. It is a period of frequent and heavy rainfall, high humidities, maximum cloudiness, and tropical temperatures. The heaviest rainfall generally occurs in the months of August and September. In contrast, the northeast monsoon or the winter season is characterized by relatively little rainfall, lower humidities, least cloudiness and lowest temperatures over most of the basin. It normally starts from October and prevails until February.

The transition period follows the northeast monsoon during which the polar Pacific airmass, modified by tropical heat, moves into the basin from the east and southeast. This results in relatively high temperatures, low humidity, comparatively higher rainfall and cloudiness from February to May. This period is called the summer season or the hot season.

A short period of drought of one to two weeks is normally experienced during June and July, due to the influence of anticyclonic circulation of the airmasses. After the period of drought, rainfall becomes more frequent including heavy downpours resulting from the tropical storms which enter the basin. The frequency of tropical storms passing over the lower basin is shown in Table 1 for the months of May through December.

Geographical variation of average annual rainfall in the lower basin, where the Pa Mong projected is located, is from a minimum of about 1,000 mm near Khon Kaen in the northeastern part of Thailand, increasing to a maximum of about 4,000 mm in the mountainous fringes of the basin lying in the Lao PDR, Democratic Kampuchea, and Viet-Nam. Rainfall

distribution in the lower Mekong basin in normal years is given below (Ref. 1):

| Month | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount (mm) | 8 | 15 | 40 | 77 | 199 | 241 | 269 | 292 | 299 | 165 | 54 | 14 | 1,672 |
| (%) | 0.5 | 0.9 | 2.4 | 4.6 | 11.8 | 14.6 | 16.1 | 17.5 | 17.9 | 9.9 | 3.2 | 0.8 | 100.0 |

Details of the climatic conditions of the lower basin are given in References 1 to 4.

## 1.1 Meteorologic and climatic data

Information on rainfall, evaporation, temperature, humidity, wind, and other meteorologic data are obtained from a network of meteorological stations throughout the lower Mekong basin (See discussion on surface water). Generally the climatic data available for the lower Mekong basin adequately characterize the area for agricultural purposes. However field measurements of evapotranspiration are very limited, and estimates of water requirements of crops are, in most cases, based on observed evaporation and other climatic factors. Hydrometeorological data required to characterize storm patterns and behaviour are more limited than desirable for flood control, drainage, and other studies (Ref. 1).

Climatic data available on rainfall, temperature, relative humidity, evaporation, sunshine duration, solar radiation and wind at various meteorological stations located in the project area were presented in the Pa Mong stage one report, Appendix III (Ref. 2). Most of the records presented were for the period of years 1951-1960. Although there were many meteorological stations located in or near the Pa Mong project area, only those with reliable and long-term data directly related to project investigations were checked and published in the stage one report.

## 1.2 Summary of climatic conditions

Climatic conditions in the Pa Mong project area, as shown in Tables 2 and 3, are favourable for year-round crop production, if a full irrigation water supply is provided from November through April and a supplemental irrigation supply is available for the period from May to October (Refs. 2, 3).

(a) Rainfall: Rainfall in the project area is of three types: orographic, cyclonic and convective. The orographic and cyclonic rains produce nearly all the rainfall during the rainy season. Local convective rains of high intensity but short duration occasionally occur during the summer or hot season. Rainfall is on the

whole plentiful, but it is unevenly distributed seasonally. Generally about 88 per cent of the annual rainfall occurs from May through October. The estimated average annual rainfall at Pa Mong during 1951-1969 varied approximately from a minimum of 1,170 mm to a maximum of 1,750 mm, with an average value of 1,450 mm.

(b) Temperature: The mean monthly temperature is taken as the average of the mean daily temperatures. In the project area, it is rather high with relatively small variation throughout the year. The mean monthly temperature is from 26-30° C during the hot and rainy seasons, and drops to 25-20° C during the cool season. The mean monthly maximum and minimum temperatures are the average of the daily maximum and minimum temperatures during the month. Mean monthly maximum and minimum temperatures are high during the hot and rainy seasons and lower during the cool season.

The highest (maximum) temperature of record is 43.9° C on 26 April 1960 at Udon Thani, and the lowest (minimum) of record is 0.1° C on 13 January 1955 at Loei (Ref. 2, 3).

(c) Relative humidity: The mean monthly relative humidity is the average of the mean daily relative humidities for the month. The mean monthly relative humidity in the study area is directly influenced by the prevailing wind and rainfall. During the southwest monsoon season, the relative humidity is between 75-85 per cent. During the northeast monsoon the relative humidity is around 50-70 per cent (Ref. 2, 3).

(d) Evaporation and evapotranspiration: Measurements of evaporation were made at selected synoptic stations by screened or unscreened Class A pans, with the average annual results given in Table 2. Throughout the project area evaporation is uniformly highest in March and April, when temperatures are the highest and humidity is the lowest. The evaporation is lowest during the peak of the rainy season (Ref. 2, 3).

Potential evapotranspiration is defined as the maximum amount of water transfered from a wet surface to vapour in the atmosphere. This was estimated by the Haise-Jensen method (Ref. 2) for the Pa Mong project area and the average annual results for 10 selected synoptic stations

are shown in Table 2. More detailed information on potential evapotranspiration can be found in the Pa Mong Stage One report, Appendix III (Ref. 2).

As noted in Reference 3, the average annual net evaporation at each synoptic station was assumed to be the positive summations (positive values) of the average monthly potential evapotranspiration minus rainfall. This amount includes rainfall interception and evaporation from water, ground, and plant surfaces. The average annual station runoff potential was assumed to be the negative summations (negative values). This portion of the rainfall is available for runoff. Tables 4 and 5 give the average monthly and annual net evaporation and runoff potential at selected locations within the project area. More details of these studies are presented in References 2 and 3.

(e) Sunshine duration and solar radiation: During the rainy season, the heavy cloud cover over much of the lower Mekong basin reduces the sunshine duration and solar radiation. The daily records sometimes indicate virtually no sunshine duration during the rainy season, while in the dry season the daily observing chart may show as much as 11 hours per day. The average monthly sunshine durations observed during 1953-1968 at five synoptic stations varied between 4.8 to 9.5 hours per day for the project area (Ref. 2). The variation of average monthly solar radiation in the project area was comparatively smaller, with values from 396 to 503 gram-calories per square centimetre per day. Tables 4 and 5 give the summary of the average monthly and annual values of solar radiation for the Pa Mong project area.

(f) Wind: Generally the wind direction in the project area changes according to the monsoon seasons. During mid-October to mid-February the wind direction is northeast and east under the influence of the northeast monsoon. From mid-February to mid-May the direction is east and southeast; and from mid-May to mid-October the direction is south, southwest, and west under the southwest monsoon influence. The winds with highest velocities, but of short duration, usually occur in March and April.

Table 6 shows the maximum sustained wind velocity, duration, and direction data from four synoptic stations in the project area.

(g) Air quality: The lower Mekong basin is generally not densely populated, so that the resources of agricultural land and forest are still relatively plentiful. Hence the areas in the Pa Mong project are generally rural and forest, and consequently the project area is comparatively free of the air pollutants.

2. Probable effects of Pa Mong

Construction of Pa Mong may be expected to have some effects on climatic elements, as follows:

(a) Rainfall: Precipitation in the form of rain and snow is normally unaffected by water resources management actions. Exceptions are actions that modify regional climate (e.g. extensive irrigation development in a formerly arid area) and that are directed towards modification of water runoff patterns (e.g. watershed management to increase snowpack or to delay runoff). In such cases, the relationship between rainfall and streamflow should be established so that the extent of induced changes can be estimated (Ref. 5).

As noted in the previous discussions, the climate and rainfall regime of the lower Mekong basin and the project area are influenced primarily by the monsoons, the intertropical convergence zone, and the tropical cyclones. It is expected that the creation of Pa Mong reservoir will have no significant effects on these basic climatic influences, and consequently there will be no significant change in the overall rainfall regime of the lower Mekong basin including the Pa Mong project area.

(b) Evaporation and evapotranspiration: Water supply can be modified by induced changes in evaporation and evapotranspiration resulting from project development. This is largely the result of vegetation management, planned or accidental, such as irrigation development and changes in agricultural technology, changes in watershed vegetation through logging and clearing for various purposes, other land use changes such as extensive urban and industrial developments, and the creation of large reservoirs that increase evaporation losses (Ref. 5).

While the creation of Pa Mong reservoir will increase the water surface area and consequently the evaporation loss, the area where loss formerly occurred as evapotranspiration will be inundated. The amount of water representing this evapotranspiration loss will therefore be conserved in the reservoir area. The difference between these losses (under reservoir and natural conditions) represents the increased evaporation loss due to creation of the reservoir. By using the Thornthwaite method and the modified Penman method (Kohler et al method), the actual evapotranspiration and lake evaporation for the Pa Mong reservoir were estimated to be 1,039 and 1,256 mm/year, respectively (Refs. 6, 7). Hence there will be an approximate increase in evaporation loss of 25 per cent, due to the creation of Pa Mong reservoir.

Increase in evapotranspiration losses due to land use changes and irrigation development in the project area are more difficult to evaluate, primarily due to the lack of some of the pertinent data. As noted in the Pa Mong phase II report (Ref. 3), the Pa Mong project would modify the Mekong flow below Pa Mong. The estimated monthly modification of runoff at the Wat Sop gauging station (at Vientiane, Lao PDR) was computed for the year-50 Pa Mong reservoir operation study as shown in Table 7. The average 1951-1969 reduction of Mekong runoff at Wat Sop is approximately 15,600 million $m^3$ per year, including the net evaporation from the reservoir. However most of the reduction will be the 13,900 million $m^3$ used for Pa Mong project water requirements (Ref. 2, 3). These water losses will include evapotranspiration and evaporation losses, seepage and percolation losses, and water consumption. The total water depletion is approximately 11 per cent of the total annual inflow to Pa Mong reservoir, which is a comparatively small amount.

(c) Air quality: The major air quality impacts associated with impoundment development generally occur as a result of construction operations (See discussion of construction aspects). Construction activities which may result in dust and smoke pollution include clearing and grubbing, excavation, blasting, cement production, and movement of heavy equipment (Ref. 8).

(d) Humidity, temperature and other climatic elements: Climatic elements such as humidity, extremes in air temperature, wind, storms, and sunshine have a bearing on the feasibility and intensity of use of areas for such purposes as recreation and agriculture. Climatic factors also affect pests and diseases patterns. For the Pa Hong project, the creation of the large water reservoir, and more intensive and year-round irrigation will have a direct stabilization effect on humidity and temperature extremes in the project area, particularly during the dry monsoon season. Microclimatic changes will occur primarily due to the type of crop production chosen after irrigation is introduced (Ref. 9). Also, there will be some local effects upon wind speeds, particularly at places located in or close to the reservoir and the irrigation service areas (Ref. 10).

(e) Summary: For the Pa Hong project, the creation of the reservoir and other development activities will probably have no significant effects on most climatic elements including rainfall, sunshine, and storms. There will likely be some minor local effects upon evaporation and evapotranspiration, humidity, temperature and wind speed at certain places in or close to the project areas, especially during the dry season due to the import of irrigation water. However, these effects are expected to be diluted or neutralized by the wind currents common to the area. The probable effects with respect to different pool levels at Pa Hong reservoir should be of a similar nature, and approximately of the same magnitude of effect, regardless of pool level selected.

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TABLE 1

FREQUENCY OF STORMS PASSING OVER THE LOWER MEKONG BASIN (1947-1970)

(From Reference 4)

| Month | Number of storms | Per cent |
|---|---|---|
| May | 1 | 1.5 |
| June | 1 | 1.5 |
| July | 4 | 6.2 |
| August | 8 | 12.3 |
| September | 19 | 29.2 |
| October | 22 | 33.9 |
| November | 7 | 10.8 |
| December | 3 | 4.6 |
| Total | 65 | 100.0 |

TABLE 2

AVERAGE ANNUAL METEOROLOGICAL DATA OF SELECTED SYNOPTIC STATIONS

(From Pa Mong Phase II Report, Ref. 3)

| Station | Rainfall (mm) | Relative Humidity (%) | Pan Evapo-ration (mm) | Mean Temperature (°C) | Solar Radiation (Langley) | Potential Evapo-transpiration (mm) |
|---|---|---|---|---|---|---|
| Vientiane | 1,602 | 77 | 1,853 | 26.0 | 448 | 1,784 |
| Loei | 1,271 | 72 | 1,550 | 25.8 | 465 | 1,855 |
| Udon Thani | 1,489 | 28 | *2,140 | 26.0 | 460 | 2,015 |
| Khon Kaen | 1,192 | 71 | 2,202 | 27.2 | 437 | 2,007 |
| Roi Et | 1,409 | 70 | 1,848 | 27.2 | 432 | 1,974 |
| Chaiyaphum | 1,178 | 64 | 1,853 | 27.0 | 447 | 2,023 |
| Nakhon Ratchasima | 1,206 | 75 | 1,944 | 26.2 | 441 | 1,959 |
| Nakhon Phanom | 2,314 | 76 | *1,790 | 25.9 | 398 | 1,590 |
| Kalasin | 1,382 | 72 | *1,860 | 27.0 | 430 | 1,952 |
| Udon Ratchathani | 1,535 | 72 | 2,253 | 27.0 | 430 | 1,952 |
| Average | 1,460 | 73 | 1,910 | 26.5 | 439 | 1,912 |

Notes: * Estimated

Period: 1951 to 1969 (18 years)

1 Langley = 1 g-cal/cm$^2$/day (gram-calories per square centimeter per day).

TABLE 3

AVERAGE MONTHLY CLIMATIC DATA FOR PA MONG PROJECT STUDY AREA

(From Pa Mong stage one feasibility report, Ref. 2)

| Month | Temperature (°C) | Precipitation (mm) | Humidity (%) | Season |
|---|---|---|---|---|
| January | 21.7 | 6.7 | 67 | Winter |
| February | 24.3 | 18.4 | 66 | |
| March | 27.3 | 37.9 | 64 | Summer |
| April | 29.0 | 83.3 | 67 | |
| May | 28.7 | 220.2 | 76 | |
| June | 28.2 | 219.6 | 80 | |
| July | 27.9 | 201.1 | 80 | Rainy |
| August | 27.5 | 265.4 | 82 | |
| September | 27.1 | 312.1 | 84 | |
| October | 26.4 | 80.0 | 78 | |
| November | 24.7 | 10.3 | 73 | Winter |
| December | 22.3 | 1.1 | 70 | |
| Annual | | 1,456.1 | | |

Period: 1951 to 1968

TABLE 4

PA MONG SERVICE AREA AVERAGE NET EVAPORATION AND RUNOFF POTENTIAL

(From Reference 3)

Stage One, Period - Average of 1951-1960

| Month | Temperature (°C) | Radiation (g-cal/cm²/day) | ET (mm) | Rain (mm) | Net Evaporation (mm) | Runoff (mm) |
|---|---|---|---|---|---|---|
| | 1/ | 2/ | 3/ | | | |
| January | 21.3 | 428 | 130 | 6 | 124 | - |
| February | 23.9 | 442 | 136 | 15 | 121 | - |
| March | 26.9 | 472 | 180 | 29 | 151 | - |
| April | 28.8 | 503 | 200 | 81 | 119 | - |
| May | 28.4 | 475 | 192 | 223 | - | 31 |
| June | 28.0 | 439 | 170 | 232 | - | 62 |
| July | 27.7 | 421 | 166 | 225 | - | 59 |
| August | 27.3 | 408 | 159 | 294 | - | 135 |
| September | 27.0 | 401 | 149 | 318 | - | 169 |
| October | 28.4 | 427 | 161 | 71 | 90 | - |
| November | 24.4 | 436 | 149 | 8 | 141 | - |
| December | 21.7 | 424 | 132 | 0 | 132 | - |
| Annual | 26.0 | 440 | 1,924 | 1,502 | 878 | 456 |

Phase II - Thailand, Period - Average of 1951-1969

| | | | | | | |
|---|---|---|---|---|---|---|
| | 4/ | 5/ | 6/ | 7/ | | |
| January | 22.8 | 396 | 130 | 6 | 124 | - |
| February | 25.6 | 427 | 141 | 17 | 124 | - |
| March | 28.2 | 461 | 185 | 42 | 143 | - |
| April | 29.7 | 492 | 201 | 76 | 125 | - |
| May | 29.0 | 485 | 200 | 184 | 16 | - |
| June | 28.4 | 447 | 175 | 188 | - | 13 |
| July | 28.0 | 440 | 176 | 187 | - | 11 |
| August | 27.6 | 424 | 167 | 205 | - | 38 |
| September | 27.0 | 407 | 152 | 302 | - | 150 |
| October | 26.4 | 432 | 163 | 98 | 65 | - |
| November | 24.8 | 416 | 143 | 12 | 131 | - |
| December | 22.6 | 400 | 130 | 0 | 130 | - |
| Annual | 26.7 | 436 | 1,963 | 1,317 | 858 | 212 |

1/ Pa Mong Stage One - Appendix III - Table 7

2/ Pa Mong Stage One - Appendix III - Table 82

3/ Pa Mong Stage One - Appendix III - Table 83

4/ Average of Udorn Thani, Khon Kaen, and Roi Et - 1951 to 1969

5/ Average of Udorn Thani, Khon Kaen, and Roi Et - 1961 to 1969

6/ Average of Udorn Thani, Khon Kaen, Roi Et, and Chaiyaphum - 1951 to 1969

TABLE 5

PA MONG STUDY AREA AVERAGE ANNUAL NET EVAPORATION AND RUNOFF POTENTIAL

(From Reference 3)

| Station or Area | Temperature (°C) | Solar Radiation (g-cal/cm²/day) | ET (mm)[p] | Rain (mm) | Net Evaporation (mm) | Runoff (mm) |
|---|---|---|---|---|---|---|
| Vientiane | 26.0 | 448 | 1,784 | 1,692 | 782 | 690 |
| Nakhon Ratchasima | 26.2 | 441 | 1,959 | 1,206 | 892 | 139 |
| Khon Kaen | 27.2 | 437 | 2,007 | 1,192 | 953 | 138 |
| Roi Et | 27.2 | 438 | 2,011 | 1,409 | 896 | 294 |
| Nakhon Phanom | 25.9 | 398 | 1,590 | 2,314 | 683 | 1,407 |
| Pa Mong – Stage One | 26.0 | 440 | 1,924 | 1,502 | 878 | 456 |
| Phase II | 26.7 | 436 | 1,963 | 1,317 | 858 | 212 |
| Average | 26.4 | 434 | 1,890 | 1,518 | 849 | 476 |

TABLE 6

climate

## HIGHEST SUSTAINED WIND VELOCITY DURATION AND DIRECTION

(From Reference 2)

(a) October – January

Unit Knots

| Station | Time / Date | 1.00 | | 4.00 | | 7.00 | | 10.00 | | 13.00 | | 16.00 | | 19.00 | | 22.00 | | Period Highest | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Date |
| Nong Khai | 2 Dec.66 | – | – | – | – | NE | 22 | NE | 28 | NE | 22 | NE | 13 | NE | 15 | – | – | E | 61 | 14 Nov.66 |
| Udon Thani | 9 Dec.50 | E | 3 | E | 3 | E | 5 | E | 27 | E | 27 | E | 27 | E | 27 | E | 3 | SW | 43 | 3 Oct. 65 |
| Loei | 5 Oct.60 | – | – | – | – | S | 2 | E | 3 | NE | 27 | NE | 10 | NE | 6 | – | – | NE | 30 | 5 Oct. 60 |
| Khon Kaen | 17 Dec.65 | C | 0 | C | 0 | NE | 4 | ENE | 32 | NE | 24 | NE | 24 | NE | 24 | NE | 24 | NE | 61 | 22 Dec.65 |

(b) February – May

| Station | Time / Date | 1.00 | | 4.00 | | 7.00 | | 10.00 | | 13.00 | | 16.00 | | 19.00 | | 22.00 | | Period Highest | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dir. | Vel. | Dir. | Vel | Dir | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel | Dir | Vel. | Date |
| Nong Khai | 21 May 65 | – | – | – | – | NE | 4 | NE | 19 | E | 22 | E | 19 | E | 8 | – | – | SW | 61 | 23 May 65 |
| Udon Thani | 18 Feb 52 | C | 0 | C | 0 | NE | 3 | E | 10 | E | 16 | E | 21 | E | 27 | E | 27 | SW | 67 | 27 Apr. 66 |
| Loei | 29 Feb.56 | – | – | – | – | NW | 1 | SE | 21 | SE | 21 | SE | 6 | E | 3 | – | – | W | 47 | 22 Apr. 63 |
| Khon Kaen | 6 Mar. 67 | E | 19 | NE | 19 | NE | 11 | NE | 10 | NE | 10 | NE | 10 | NE | 5 | NE | 6 | N | 62 | 8 May. 62 |

(c) June – September

| Station | Time / Date | 1.00 | | 4.00 | | 7.00 | | 10.00 | | 13.00 | | 16.00 | | 19.00 | | 22.00 | | Period Highest | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dir. | Vel. | Dir. | Vel. | Dir | Vel | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir. | Vel. | Dir | Vel. | Dir | Vel. | Date |
| Nong Khai | 13 Aug. 68 | – | – | – | – | SW | 11 | W | 22 | SW | 22 | SW | 22 | C | 0 | – | – | SW | 61 | 19 Aug.65 |
| Udon Thani | 7 Sept.51 | W | 6 | W | 16 | W | 16 | W | 16 | W | 21 | NW | 21 | NE | 27 | E | 21 | W | 40 | 1 Sept.56 |
| Loei | 18 Sept.62 | ENE | 12 | – | – | ESE | 16 | ESE | 20 | ESE | 27 | ESE | 21 | SE | 3 | – | – | NW | 33 | 25 Jul. 55 |
| Khon Kaen | 14 Jul. 51 | W | 6 | – | – | W | 11 | W | 27 | W | 27 | W | 35 | W | 40 | – | – | NNW | 60 | 7 Jul. 67 |

1 Knot = 1.85325 km/hour

145

TABLE 7

ESTIMATED MONTHLY MODIFICATION IN RUNOFF FOR PA MONG PROJECT OPERATION

(From Reference 3)

Units: million $m^3$

| 1951 - 69 Average Month | Inflow | Pa Mong Reservoir | | | | Diversions | |
|---|---|---|---|---|---|---|---|
| | | Change in Storage | Power Release | Spill and River Release | Net Evap. | Total | Net Return |
| January | 4,545 | -6,650 | 8,673 | 3 | 310 | 2,209 | -42 |
| February | 3,323 | -6,560 | 7,551 | 3 | 283 | 2,046 | 71 |
| March | 3,010 | -7,543 | 8,219 | 3 | 254 | 2,077 | 49 |
| April | 2,846 | -7,138 | 8,452 | 3 | 121 | 1,408 | 402 |
| May | 3,947 | -6,241 | 9,487 | 3 | -38 | 736 | 389 |
| June | 8,902 | -2,894 | 11,035 | 3 | -77 | 835 | 31 |
| July | 18,578 | 5,637 | 12,210 | 3 | -74 | 802 | 3 |
| August | 33,048 | 19,267 | 12,866 | 327 | -86 | 674 | 6 |
| September | 30,366 | 17,820 | 11,394 | 969 | -102 | 285 | -15 |
| October | 17,409 | 1,889 | 13,390 | 1,000 | 97 | 1,034 | 346 |
| November | 10,379 | -2,441 | 11,370 | 378 | 312 | 760 | 325 |
| December | 6,338 | -5,145 | 9,741 | 3 | 316 | 1,423 | -18 |
| Annual | 142,691 | 0 | 124,388 | 2,698 | 1,316 | 14,289 | 1,547 |
| Per Cent of Inflow | 100.0 | 0 | 87.2 | 1.9 | 0.9 | 10.0 | 1.1 |

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## CONSTRUCTION ASPECTS

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# PA MONG ENVIRONMENTAL ASSESSMENT

## CONSTRUCTION ASPECTS

### 1. Introduction

Construction of the Pa Mong project will involve a variety of construction activities, and will cover a relatively large construction area. While the project is still in the feasibility stage of planning, and construction plans not yet developed, a preliminary evaluation can be made of the anticipated environmental problems.

A summary of project features, taken from Appendix V of the Pa Mong Stage One Feasibility Report (Ref. 1), is as follows:

(a) For a maximum pool level of 250 m MSL, there will be three dams, namely Pa Mong, Nam Mong, and Nam Lik. Pa Mong dam will be a solid concrete gravity dam with a crest length of 1,360 m and a spillway with a capacity of 36,000 $m^3$/sec. Nam Mong dam will be of a rolled earthfill type, with a crest length of 2,030 m. Nam Lik dam, to be of the double-curvature, thin-arch concrete type, is the smallest of the three, with a crest length of 435 m.

(b) There will also be numerous earthfill dikes in the Pa Mong project. The total length of all dikes will be about 23,330 m, with the longest dikes in the Nam Mong - Nam Pong area.

(c) Upon the closures of the three dams, a large reservoir will be created. At elevation 250 m MSL, the total storage capacity of this reservoir will be 107.4 billion $m^3$ and the water surface area will be 3,846 $km^2$.

(d) The initial Pa Mong powerplant will consist of two powerhouses, one on each side of the river at the toe of the dam. There will be eight generating units, with a total installed capacity of 4,800 megawatts.

(e) Transmission lines will be used to convey power from Pa Mong dam to different destinations. Four 500-kilovolt lines will be the most important ones, linking Pa Mong and Bangkok, which will be 560 km long. Other transmission lines, ranging in capacity from 115 kilovolts to 230 kilovolts, will have a total length of 313 km.

Irrigation systems will also be constructed to serve a total area of about 43,000 hectares. These systems will consist of 644 km of main canals and laterals, 1,200 km of tunnels, and

338 km of surface drains.

Construction of the above-mentioned structures will have effects on environment in many ways. This presentation describes the anticipated effects and, where possible, mitigating measures to reduce and control these effects.

2. Effects on water quality

Because the construction activities will disturb soil conditions in the vicinity, it can be expected that considerable silt will be washed into the waterways, thereby creating increased turbidity and siltation over a considerable stretch of the river. The construction activities which will induce increased siltation will involve large land areas. Clearing and grubbing will cause removal of vegetation and major root systems. Earthwork operations involve moving natural soils from one location to another by excavating, filling, and compacting. When soils for fills are taken from borrow areas, these areas may be left as man-made ponds. Rock excavation will be followed by loading the broken rock, hauling to the fill site, dumping and placing. Construction of large dams usually requires either borrow areas, from which needed materials can be obtained, or landfill or spoil areas, where excess excavated materials can be placed. It is expected that borrow areas will be located close to the construction sites, and will involve stripping of top-soil followed by excavation and hauling of the underlying materials.

In summary, increased turbidity and siltation in the river section downstream from the construction areas can be caused by construction involving earthwork, dredging of dam foundations, erosion of river banks, movement of heavy equipment in and around water, scarification of the area, and excavation and stripping of materials. Almost all activities involving removal of surface materials will bring about surface erosion and hence will increase turbidity levels in the water.

The major adverse effects of increased turbidity in rivers include reduced suitability of water downstream as a source of water supply, reduced stream capacity due to sediment deposition (Ref. 2,3,4), reduced photosynthetic processes in the stream (Ref. 2, 5), and reduced benthic populations in the river sections where siltation is extensive (Ref. 6). Such effects can significantly alter the stream ecology where the added silt changes the stream from an essentially clear to a turbid condition. Because the lower Mekong, like most Southeast Asian rivers, is normally quite turbid, it is anticipated that none of these effects will be serious.

To mitigate problems caused by increased turbidity and siltation due to construction operations, the following measures are recommended: (a) scheduling excavation and dirt-moving

phases of constructions for periods of low or no surface runoff (Ref. 4), (b) erosion control measures, and (c) provision of settling basins to remove silt before the runoff reaches the river (Ref. 4). Several methods can be used to cope with surface erosion. Upon completion of construction, borrow areas and exposed cut and fill slopes should be graded, sloped to drain, and seeded with grass (Ref . 7, 8, 9). Application of chemical adhesives to disturbed surfaces is also recommended (Ref . 7, 9). Where possible, the topsoil should be removed, stored, and replaced to provide good soil base for restoration of vegetative cover (Ref. 9).

3. Effects on air and noise pollution

During the construction stages of the Pa Mong project, air-borne particulate matter can be produced by emissions from heavy equipment. Another source of particulate matter and other air pollutants is open burning of wood waste from clearing and grubbing operations. Clouds of dust are expected to be formed by movement of construction equipment, rock excavation, and excavation of borrow materials. The impacts of air pollution will be short-term and are not considered serious, as these impacts will be confined to the construction areas.

Noise pollution is usually generated during construction periods by on-site and on-road hauling operations and construction of project facilities. Increased noise levels will be caused by rock blasting. It is believed that noise disturbance due to construction will be most severe during the nighttime. Noise impacts can be considered short-term. One adverse effect of increased noise level caused by rock blasting and heavy equipment is the disturbance to wildlife in the vicinity of construction sites. This effect is also considered short-term, and some of wildlife driven away by noise are expected to return to their places of habitat after the construction phases. Because most of the Pa Mong construction sites are expected to be in remote areas, impacts of noise pollution on human populations are not expected to be significant.

4. Effects on aquatic life and wildlife

(a) Aquatic life: During construction periods, siltation resulting from extensive construction operations will have moderate impacts on benthic animals of the rivers below the construction sites. Fine sand and silt normally provide the least favorably habitat for these animals. Thus siltation can cause a significant but temporary reduction of benthic populations in those sections of the river. Phytoplankton communities will also be affected, as increased turbidity in the water will decrease the depth through which light penetrates. Because phytoplankton and benthic animals are basic foods for higher animals and fishes, productivity of the river will be

temporarily reduced. However, the recovery of productivity after completion of construction phases is expected to be rather rapid.

(b) Effects on wildlife: As previously discussed, noise disturbance and the presence of humans and equipment will have considerable effects on wildlife inhabiting areas close to construction sites. Though these effects are considered to be short-term and some wildlife will return after construction is completed, some permanent reduction in wildlife population density in the vicinity of the project area can be expected because of the urban communities which will become established in the vicinity.

Clearing of forested areas for construction of project features and for rights-of-way for transmission lines will also have effects on wildlife. There is a tendency for wildlife density to decrease along rights-of-way. Although the width of most rights-of-way is only about 50 m to 100 m, the total land area covered by the right-of-way will be considerable, the total length of all transmission lines being about 870 km. There will also be certain changes in the types of inhabitants along the rights-of-way due to alteration of wildlife habitats. In addition to direct effects on wildlife, maintenance of the transmission line rights-of-way can induce surface erosion, since the rights-of-way are usually kept barren of any extensive vegetative cover.

Construction operations at the Pa Mong project will also include stream channellization. Channel widening or straightening generally involves the removal of streamside vegetation, and, in some cases, this is the only cover available for wildlife habitats. These operations may cause a substantial loss of larger animals and waterfowl.

Construction of the Pa Mong irrigation systems, particularly main canals and laterals, can also adversely affect wildlife inhabitating areas close to these systems. Canals can obstruct the passage of several important animals species, hence special provision needs to be made to include crossways and also to permit animals to climb out of the canals (See discussion on wildlife).

In summary, construction of Pa Mong facilities will have some adverse effects on wildlife, but the effects should be temporary and generally not significant.

5. Effects on archaeological and aesthetic values

(a) Archaeological values: Loss of archaeological values will be due primarily to the impoundment. However, construction may also contribute to a part of the loss. This will be due to damages of archaeological elements by heavy equipment during the construction phases. Excavation of some areas without pre-construction investigations can also result in loss or damages to archaeological materials.

In order to minimize loss of archaeological information both during and after construction of the Pa Mong project, complete reconnaissance surveys of archaeological elements in construction areas should be conducted by qualified archaeologists. Valuable artifacts should be salvaged for identification, and sites of archaeological importance located so that damages will be avoided or minimized during construction (See discussion on archaeology).

(b) Aesthetic values: Construction of the Pa Mong project will result in scarring of the existing landscape. Borrow areas, spoil areas, cleared land, quarries, riprap sources, powerplants, access roads, and transmission lines will alter the existing landscape. During construction and several years thereafter, it is anticipated that effects on scenic and aesthetic quality will be noticeable.

To mitigate adverse aesthetic effects, the construction programme should include plans for environmental protection aspects including landscape preservation and dust abatement. Quarry slopes should be rounded and shaped to provide natural appearance. Waste materials should be properly disposed of, and borrow areas graded, restored with topsoil, and replanted with suitable vegetation (See discussion on recreation and aesthetics).

6. Socio-economic effects

The socio-economic effects of Pa Mong are reviewed in detail in the discussions of socio-economics, public health, and resettlement. The main effect of the construction activities will be to create sizeable new communities in the dam-site vicinity comprising both local population and many in-migrants. Hence a new socio-economic environment will be created from the blending of cultures, and sizeable areas of land will become urbanized with all the advantages, including

higher incomes and greater availability of goods and services, and disadvantages of urban living. Particular problems to be faced will be provision of adequate infrastructure for the new communities, and special measures for control of communicable diseases including malaria, which could result from importing of these diseases or of workers with little immunity to existing local diseases.

7. Summary of effects

Most of the effects noted above, excepting the socio-economic impacts, will be temporary in nature and also, with proper construction planning, should not pose any serious problems.

Creation of new communities, not only in the vicinity of the damsite but at other construction centers needed for building the irrigation systems, will require careful planning if the new communities are to afford the quality of life that should be attainable. The economic basis for attaining this quality of community environment will be available, as part of the cost of project construction. However, careful planning and controls, for managing land use and for provision of community facilities, will be needed to achieve the desired results. The Mekong Committee will be in an advantageous position to furnish the necessary guidelines to the riparian country governments.

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# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## FISHERIES

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# PA MONG ENVIRONMENTAL ASSESSMENT

## FISHERIES

### 1. Introduction

One of the most controversial issues for virtually all major dam projects being considered in the 1970's has been effects on fisheries, largely because protection of fisheries has not been adequately considered in the planning of such projects in the past. This has resulted not only in serious unnecessary adverse effects but in insufficient data by which the effects both bad and good might be quantified and judged. Because of this unfortunate past record elsewhere in the world, the Mekong Committee's programme for Pa Mong has included careful attention to this subject, perhaps moreso in the pre-construction phase than for any major dam project in the developing countries. The data produced and the guidelines indicated by the data are, of course, not by any means complete at this time; however, the continuing programme of study underway is believed to represent competent attention to the problem at this stage of planning of the Pa Mong project. Implementation of any large scale dam construction in a river system is bound to bring about significant changes in the aquatic environment. Fish are closely dependent on the physical, chemical, and biological features of the environment for their growth and survival including execution of important behavioral patterns necessary for the completion of their normal life cycles. Effects of dam construction on fish stocks could be either beneficial, harmful, or innoccuous, depending on the nature and magnitude of environmental changes, and tolerance ranges of the fishes to adjust to them.

In the lower Mekong basin fish and fish products provide an estimated 50 to 80 per cent of the total protein requirements in the diet of the people. At least 25 per cent of the rural population are engaged, wholly or partially, in occupations directly or indirectly related to fisheries. From two to eight per cent of the gross national product in different countries of the basin is reported to be derived from fisheries sources. Also, fish demand and supply forecasts indicate in no Southeast Asian country will the fish supplies meet the demands if dependence is placed on continuing traditional methods of fisheries.

In view of the importance of fish in the economy and nutrition of the Mekong riparian countries it is imperative that any development measures implemented in the region should not only avoid effects detrimental to fisheries to the extent feasible but incorporate positive enhancement measures. The Mekong Committee, therefore, at an early stage in its project planning, instituted a fisheries programme with the object of assessing the probable effects of dam construction on fisheries and of taking measures that would offset or minimize adverse effects and maximize benefits. The purpose of this presentation

is to review this programme, particularly with regard to its effectiveness for conserving the natural fisheries environment and for utilizing these fisheries for the well being of the region.

## 1.1 Tropics versus temperate zones

Probably the greatest attention to evaluating effects of dam construction on fisheries has been given in the Pacific Northwest of the American continent. Numerous in-depth studies in that region have generated a basic philosphy applicable to that region which may be summarized as follows (Ref. 1) : (a) Impoundment drastically alters the riverine environment beyond the capabilities of many fish species to adjust, hence these species are adversely affected, and (b) dams interfere with the migratory fish species (representing some of the most important commercial and sports fisheries) by preventing access to spawning areas.

This basic philosophy evolved for temperate climatic zones is, unfortunately, often used for evaluating effects of dams on fisheries in the tropics, where conditions of the environment, the levels of tolerance to environmental changes, and the biology and ethiology of individual species of fishes are vastly different. For example, migratory runs of fishes depending on a specific home for spawning are almost non-existent in tropical rivers. Further, because of the widely fluctuating environmental features in tropical rivers, species of fishes that inhabit these rivers have a wide range of tolerance to changes in various critical environmental factors. Any realistic assessment of problems of dam construction relating to fisheries in the lower Mekong basin must be based on the local environmental conditions of the habitat and the biology and habits of the inhabitants. It is such a realistic assessment, based on the existing knowledge of tropical riverine environments and species of fishes, that forms the basis of the Mekong Committee's fishery programme.

## 1.2 Problem of basic data

If can be safely said that a detailed understanding of the complex ecology of fisheries, including scientific understanding of fish-food webs or chains, is yet to be developed for any major river basin because programmes to accomplish such comprehensive understandings are a recent development. The relationships are scientifically so complex that even well-funded programmes will require many years to permit really quantified understanding of the relationships between the numerous parameters affecting even a single fish species. In the case of the lower Mekong basin only a scattering of scientific data on the basin fisheries existed when the fisheries programme got underway. However, a majority of the fish species (at least 85 per cent) that occur in the Mekong are also distributed in rivers in adjacent regions (for example the Indian sub-continent)where considerable work has been done on

relevent fish bionomics. Surveys have shown that the environmental conditions in several rivers in the Ganges-Brahmaputra basin, for example, are very similar to those in the Mekong.

1.3 Magnitude of effort

The fisheries programme was established in 1967 and has since involved over 1,000 professional man-months of effort. The cost of execution of all the ten projects already approved by the Committee is estimated at US$ 12 million.

1.4 Components of programme

The fisheries work programme of the Mekong Committee relating to Pa Mong has comprised the following components, each to be discussed in detail:

(a) Surveys and studies: Collection, collation, analysis, and interpretation of basic information on fisheries, including both scientific and socio-economic aspects, both for the Mekong river mainstream and tributaries throughout the lower basin, including the estuarine and affected marine waters, and selected tributary reservoirs. In addition, information has been collected from experience in other Asian tropical areas where fisheries have been affected by water development projects. Table 1 presents a summary of these surveys and studies. Of these, the basinwide survey-study, now underway, represents the first approach to a comprehensive evaluation of fishery resources in the lower basin.

(b) Development activities: Pilot projects for demonstrating how to enhance fish productivity through opportunities presented by Pa Mong, including use of imported species, by (a) managed fish production in selected tributary reservoirs and planning for such management at Pa Mong and (b) fish culturing in ponds utilizing irrigation waters made available by Pa Mong.

(c) Rehabilitation measures: Pilot projects for demonstrating how the existing productivity of prawns/shrimps and of a selected species of catfish and of other endangered valuable fish species which might be depreciated by the effects of Pa Mong, can be maintained and even enhanced through controlled culturing methods.

(d) Related projects: These include the Mekong Committee's water quality monitoring programme and several studies in aquatic biology (see discussions on water quality and on aquatic biology).

2. Existing fisheries environment

The data presented in the basinwide survey-study plan

and the other studies noted above have been summarized to present a brief picture of the existing fisheries environment in the lower basin without the influence of mainstream dams.

## 2.1 Fish production

The fisheries of the lower Mekong basin are of great economic and dietary importance to the some 40 million inhabitants of the area and have an even greater future potential. Fish is second only to rice as important and desired food by people living in the basin, and is the major source of animal protein. The annual per capita fish consumption for Thailand and Democratic Kampuchea approximates 22 kg, for Viet-Nam, 12 kg and for the Lao PDR, 13 kg; this comprises 50 to 80 per cent of the animal protein intake. In addition the fishing industry in these countries makes up between two and eight per cent of the gross national product.

Although only crude figures are available, the fish harvest from the lower basin including affected contiguous inshore waters of the South China sea may approach 550,000 metric tons with a market worth of about $300 million. Of this total, the commercial harvest from the mainstream and its tributaries is about 200,000 tons and the subsistence harvest adds at least 100,000 tons. The aquacultural activities and the estuarine and coastal fishery directly influenced by the Mekong river discharge contribute the remaining 250,000 tons.

The extensive harvest that results from these diverse fisheries of the lower basin and adjacent waters of the South China sea includes hundreds of species of finfishes, and many kinds of shellfishes (crustaceans such as shrimps, prawns, and crabs, and molluscs such as clams, mussels, and oysters) as well as frogs, crocodiles, and a variety of plants ranging from marine algae through water chestnut, water lettuce, water celery, water cress, and other edible species.

## 2.2 Physical system

The lower Mekong and its tributaries are typical tropical rivers, subject to a monsoon conditioned regime and having a violently fluctuating environment. As in any other tropical river, individual environmental features exhibit a wide range of variation both in space and time. In the main Mekong, the annual amplitude of variation in flow is from less than 2,000 $m^3$/sec during the dry period and 52,000 $m^3$/sec during floods. Flash floods and large scale inundation are a common feature in several areas. Due to continued scouring action of floods over a long period of time, large and extensive depressions or pools have been formed in the beds of rivers at several places. These pools retain water throughout the year hence maintain a transient lacustrine environment during the dry months. February to May usually constitute the low water period, when fluviatile sections of many of the tributaries are reduced to low flows and the only relatively stable aquatic environment is provided by the pools in stream beds, where the bulk of fish population takes refuge.

Water temperatures in the river are high and fluctuate within the wide range of 20°C to 35°C at different points during different months of the year. Values of pH range between 7.0 and 8.2 and dissolved oxygen values vary widely between 2.8 and 7.5 mm in different sections of the river. The water level in the river starts rising by about the end of May, reaches its peak in August or September, and finally subsides in November. With the onset of floods, water temperatures rise and dissolved oxygen and pH levels fall mainly as a result of decomposition of the vast amount of organic debris brought in by the floods. Turbidity increases sharply due to the mass of alluvial silt in flood waters. Increase in turbidity brings down plankton levels, at least temporarily. Later, as a result of the allochthonous nutrients brought in by the floods, plankton blooms appear in the flood inundated zones. It is estimated that in Vietnamese delta alone, an area of about one million hectares is inundated and that the water level rises by 4 to 5 metres during floods. Average current velocities increase from 0.2 m/sec in February to about 1.4 m/sec in August. Flood induced changes in the environment return to normality and dry period conditions begin to set in by December or January.

The fluviatile sections of the river itself are not very productive due to the relatively high turbidity, fast current, sandy nature of the bottom, and low plankton production. It is the pools in the river beds and in the oxbows and other inundated regions near the rivers that are the main zones of productivity.

Some details on each of the three distinct fishery zones in the lower basin are as follows:

(a) Riverine zone upstream from Kratie: This zone is distinguished by relatively high stream gradients, especially for the tributaries, by an erosional substrate, occasional rocky rapids, and relatively narrow and steep-sided gorges. It includes 2,200 km of the mainstream with 25 major tributaries. In the dry season the inhabitants are mostly riverine. During monsoons the mainstream and tributaries spill onto floodplains along the mainstream and the lower reaches of the tributaries. The extent of these flooded areas is significant but small compared to the grandiose scale of flooding in the delta.

(b) Inundation zone: This deltaic zone is characterized by extreme variations in extent of flooded areas, ranging from some 4,040 $km^2$ of permanent wet area to as much as 53,600 $km^2$. The main river gradients are low, the substrate is depositional, and there are no rocky rapids nor narrow gorges. A unique feature of this zone is the Great Lake - Tonle Sap complex which serves to receive flood

flows, then to augment the dry season flow in the mainstream, with the surface area of the lake ranging from 3,000 $km^2$ to 13,000 $km^2$. The lake is one of the most if not the most fish productive lake in the world.

(c) Estaurine coastal zone: This includes the final downstream 100 km of the mainstream and its distributaries, the associated mangrove and cajeput swamps, and the adjacent coastal waters of the South China Sea to the extent affected by the Mekong discharges, usually up to 30-40 km offshore (including some 6,000 $km^2$ of coastal area). The mangrove swamps are believed to have an important role in fish reproduction which needs to be evaluated (see discussion on aquatic biology). This estuarine-marine complex, like estauries elsewhere, is believed to support very productive fisheries harvested not only in the estuary but also finfish harvested in the offshore coastal waters.

## 2.3 Fisheries ecology

Over 200 different species of fish have been recorded from the Mekong basin. In the Mekong, during the dry months of the year, carps (family: Cyprinidae; 54 per cent), catfishes (families: Clariidae, Schibeidae, Bagridae, Sisoridae and Akysidae; 19 per cent) and murrels (family: Ophicephalidae; 8 per cent), together constitute about 81 per cent of the fish fauna. The remaining 19 per cent consists of feather-backs (Notopteridae) and other miscellaneous groups. This composition varies only slightly during different seasons. Tributaries of the Mekong appear to have more or less identical distribution of the different groups of fishes.

The life cycles of a vast majority of fish in the Mekong, as in other tropical rivers, depend prominently on the annual inundation cycle. With the onset of floods and concomitant submergence of rice fields, ditches, swamps, oxbows and other low lying areas over a considerable distance on either side of the river bank, a predominant section of the fish population migrates laterally from the rivers to the inundated areas, mostly for spawning. The distances traversed in the lateral migrations and the duration of sojourn in the inundated zone differ with different species, depending on their environmental requirements and tolerances. Fishes with low oxygen requirements, or those with accessory respiratory mechanisms, like murrels, some catfishes, and Anabantids occupy and persist for longer periods in the peripheral zones of inundation, where disolved oxygen and pH are generally low, due to decomposing organic matter and terrestrial vegetation. Most Cyprinids, which have higher oxygen requirements and lower tolerance to pH fluctuations, occupy the proximal zone of inundation, spawn there and move riverwards with receeding floods, much earlier than the preceeding groups of fishes.

If the flood recedes quickly, as happens during years of relatively sparse rainfall, large numbers of eggs and hatchings die due to desiccation; if, on the other hand, the flood waters persist for a relatively long period, as in years of heavy rainfall, large scale mortality of fry and fingerlings occurs due to deoxygenation and drastic changes in pH resulting from decay of organic matter in flood waters. This may indicate that flood regulation which eliminates very high or very low flood might actually be beneficial to fisheries. The observed high fecundities in most of the tropical river fishes permits them to survive these periodic large scale mortalities. Some of the young that result from the spawning activity in the inundated zone enter the main river and repopulate it. Others are left behind in the water bodies inland, grow there and provide a rich crop of fish. Thus, a sort of natural restocking of the water bodies on either side of the river in the flood-covered plain takes place annually. The fact that fish fauna represented in these stagnant waters is essentially the same as the riverine fauna is an indication that most of the riverine species in the Mekong and its tributaries can thrive in lentic environments.

Fish fauna in tropical rivers are well adapted to a widely fluctuating environment. Unlike temperate zone fishes, the tolerance ranges for tropical zone fishes for various critical environmental factors such as temperature, pH, dissolved oxygen, etc. are very wide. Exceedingly interesting adaptations to survive inhospitable millieus and frequent and abrupt environmental changes have evolved in some of these fishes. Accessory respiratory organs or modifications in the opithelium of the suprabranchial cavity to enable the fish to utilize atmospheric oxygen are found in catfishes of the families Clariidae and Heterropneustidae, climbing perch, Anabas spp., and murrels, Ophicephalus spp. These organs enable the fishes to survive periods of deoxygenation of water that usually occur in the peripheral zones of inundated areas during flood seasons. Another interesting adaptation is the faculty of locomotion over wet land, for appreciable distances, in fishes like Anabas spp., Clarius spp. and Ophicephalus spp. This adaptation ensures survival when habitats dry up, either because of a suddenly receding flood or failure of precipitation. These few instances are cited to emphasize and underline the point that tropical fishes have adapted themselves in many ways to changes and amplitudes of various, often harsh, environmental features.

In addition to the lateral migration described above, migrations up and down the river are suspected to take place for some species mainly on the basis of their seasonal appearance in fish catches in different sections of the river at different times of the year. No positive evidence is available as to whether these species do in fact perform the suspected migrations over long distances and, if they do, as to the times, ranges and goals of such migrations. It is

entirely possible that members of identical species occurring in different sections of the river are merly discrete local stocks and not individuals of a migratory population.

There are about 27 species of marine and estuarine fishes belonging to families, Carcharinidae, Pristidae, Clupeidae, Syngnathidas, Scombrosocidae, Polynemidae, Centropomidae, Sciaenidae, Scombridae, Solidae and Tetradontidae, which occur in the freshwater areas of the Mekong. Very little is known about their life histories, but available evidence indicates that some of them are permanent residents in freshwater stretches of the river or connected lakes. Of the 27 species of saltwater fishes, only a few are of commercial value. Perhaps the only truly anadromous species in the Mekong are Hilsa spp., which are suspected to migrate several hundred kilometers up to the river. Anguilla spp. are the only known catadromes. However, all the species are of little commercial value in the lower Mekong basin. A commercially important freshwater migrant which moves into estuaries for spawning is the giant freshwater prawn, Macrobrachium rosenbergi.

The fisheries ecology in the natural lower Mekong river system has been modified to some extent by construction of dams on tributaries. Prior to their development, all these tributaries were seasonal streams, at least in the vicinity of the dam sites. A stable lacustrine environment has been created by impoundment, in place of a widely fluctuating tropical stream environment. Studies of these new environments indicate the post-impoundment changes in environmental factors are within the normal range of fluctuations to be expected even in natural rivers and tributaries in the pre-impoundment phase. The tropic environment also appears more favourable than in the pre-impoundment phase, judging from the greater abundance of plankton and benthic organisms in the reservoir.

Fish fauna in the Nam Pong reservoir one year after impoundment comprised only 54 species as against 85 in the pre-impoundment phase, indicating a significant reduction in the number of species. However, total production of fish increased remarkably, from negligible harvests in the streams prior to impoundment to about 1,600 tons annually (average for 1969-71) from the reservoir. There is also a significant increase in yield per unit area in the impoundment, which is about 40 kg/ha/year as compared to average yilds of about 12 kg/ha/year in tropical rivers. Important among the species of fish that were suspected to have disappeared or migrated to the river section above the reservoir after impoundment are the carp, Labeo bicolor and the catfishes, Wallagonia attu, Bagarius bagarius, Kryptopterus cryptopterus, K. apogon and K. bleekeri. The relative abundance of different species also changed after impoundment. While carps continued to be the most common in respect of number of species, their relative contribution by weight to catches reduced from 55.9 per cent, prior to impoundment, to 24.1 per cent. On the other hand, populations of

predacious murrels increased to 34.8 per cent of catches by weight, as against 16.5 per cent before dam construction.

The above general account of the Mekong environment and its fish indicates that construction of dams does not bring about any environmental changes which are outside the range of fluctuation occurring in natural rivers; such construction would however remove or reduce the amplitude of fluctuations in environmental features. Even prior to impoundment, these fishes are well adapted to and spend parts or all of their life cycles in the lentic environment of pools in the river beds or inundations near the rivers. Thus, it appears that for a vast majority of the riverine species, creation of man-made lakes probably makes the environment more favourable for their development. The main problems arising from Pa Mong will probably be the effect of flow regulation on the normal fisheries in the inundated areas and in the estuarine and marine zones.

Further details on each important category of fishery in the lower basin are described as follows:

(a) Inundated zone fisheries: As previously noted, the most productive of all Mekong basin fisheries are those dependent on seasonal flooding; hence these fisheries, especially in the deltaic lowlands, may be especially vulnerable to proposed schemes for eliminating or minimizing floods. In the deltaic lowlands, downstream from Khone Falls, floodwaters may cover almost the entire low gradient drainage basin of the Mekong and its tributaries, all the way to the estuarine zone in Viet-Nam. In Democratic Kampuchea, possibly one fifth of the area of the entire country may be inundated. A part of this area is flooded by the elevated water level of the Great Lake which usually triples its size. The water level is elevated by precipitation on the lake surface, by runoff from the surrounding land, and in most years by the reversal of its outlet, the Tonle Sap river, to bring Mekong mainstream floodwaters back upstream into the lake basin. In Viet-Nam, the flood usually inundates the entire upstream third of the Vietnamese delta.

Upstream from Khone Falls, where the mainstream usually has high banks, flooding covers only relatively small areas. These areas typically are around the submerged mouths of tributaries, some of the riverside flatland such as in the vicinity of Vientiane, and the more or less headwater plateaus on some upstream tributaries. Certain of these tributaries, as in northeast Thailand, have perennial swampy lakes which are substantially enlarged during flooding.

Engineering works and water flow management will

alter the timing and extent of the annual inundation. A major mainstream impoundment, such as Pa Mong, would have effects in reducing inundation throughout the lower basin, for example, in the Great Lake of Democratic Kampuchea. The lake has a depth of less than 1 m at low and between 8 and 10 m at high water levels, depending on the seasonal rainfall. As previously noted, the floods inundate a plain of about 13,000 $km^2$, including the lake, and at low water, the lake covers about 3,000 $km^2$. Preliminary estimates indicate upstream storage of 60 million $m^3$ at Pa Mong or Stung Treng would lower the highest water level of the lake by about 60 cm once every 30 years, by about 40 cm once every 4 years. As the inundated area of the Great Lake is like a flat pan, even small but regular reductions in water level would tend to dry up a part of the unique fisheries environment.

Despite the importance of inundated zone fisheries in the lower basin, there are no quantitative data on standing crops of fish stocks for estimating yield potentials, and only sparse information on the basic hydrodynamics of fish production. In the inundation zone of the delta, four principal habitat types have been recognized based on oxygen and acidity factors, progressing from farthest away from the rivers toward the rivers as follows, (1) the perioheral habitat which is mainly in the rice fields and is suited to fish life, (2) the putrid habitat characterized by decomposing organic material, which supports little fish life, (3) the recovery habitat, where dissolved oxygen reappears and which supports "blackfishes" adapted to low oxygen and high acidity, and (4) the riverine habitat which is well oxygenated and has abundant and diverse fish fauna.

Reliable fishery statistics for the inundation zone, as for the other zones, do not exist, and the data that are available are conflicting. In the entire inundation zone, the Great Lake - Tonle Sap complex has been the single most important source of fish production and harvest. During the mid-1930's the annual catch was reported as high as 100,000 tons, corresponding to 100 kg/ha of high water surface area and 300 kg/ha for low water conditions. The principal types of commercial fishing gears in the delta, in addition to seines, are days, samras, and barrages (large weirs), all stationary devices which strain out the fish as the floodwaters recede.

(b) Riverine fisheries: Within the entire lower basin, more than 10,000 km of freshwater riverine channels of the mainstream and tributaries provide fishing grounds for commercial, artisinal, and subsistence fishermen.

The fisheries of this riverine zone are distinguished from those of the inundation zones described previously in that riverine fishing is mostly in flowing water (except when these waters are impounded) and are pursued during lowest water stages when inundation zone fisheries have disappeared.

The total catch from the riverine fisheries of the Mekong basin, although locally very significant, has never been quantified (except for preliminary assessments in a few new impoundments). Principal methods of fishing include seining, drift-netting, life-netting, trapping, and hook-and-line fishing. When riverine fisheries depend on migratory species, they may be vulnerable to damming which interferes with spawning migrations, but the potential extent of this interference is not known for the Mekong system. With the possible exception of the fishery at Khone Falls, it has not yet been scientifically determined that any of the riverine fisheries depend on, or are significantly influenced by, longituding migrations of fishes in the Mekong and associated major rivers (see Section 2.3 (d)).

The existing information on riverine fisheries above Khone Falls is very sparse and that available relates mostly to reservoirs. Eleven reservoirs have been completed on Mekong tributaries (8 in Thailand, 3 in the Lao PDR) and one (Prek Thnot) is under construction in Democratic Kampuchea. The total surface area of the 11 completed reservoirs is 1,600 $km^2$, compared to approximately 3,800 $km^2$ expected for Pa Mong. Pre-impoundment fishery surveys show a rich and varied fish fauna.

Fish catch surveys have been made to a limited degree at three Thai reservoirs, principally at Nam Pong. Both commercial and subsistence fishing are practiced at Nam Pong as elsewhere along the Mekong. The commercial fishermen use mostly beach seines or fish with lift nets mounted on rafts. The presence of drowned forests in Nam Pong reservoir interferes with fishing efficiency, and another problem is the extent of the drawdown (up to 3 km) which separates the fishing village from the water's edge.

(c) Estuarine/marine fisheries: The fisheries of the brackish waters in the Mekong estuary proper in Viet-Nam and of the recipient adjacent waters of the South China Sea are second in magnitude and importance only to the inundation zone fisheries. In these estuarine and coastal waters, shellfish are more prominent than in the inland parts of the basin. Marine organisms predomenate, as there is a progressive downstream change from freshwater tom marine habitat. Also,

huge masses of marine fish seasonally concentrate in the offshore ocean waters, presumably due to the discharge of nutrients in floodwaters.

Like all estuaries, that of the Mekong is potentially among the most efficient of all aquatic systems for fishery production. This efficiency is reinforced by the shallowness of the waters and the relative nutrient richness of the ecosystem, the estuary being situated at the downstream end of a vast drainage basin. This ecosystem is highly vulernable to alternations in the quantity and timing of mainstream discharge implicit in the installation of dams and operation of water management systems upstream and in poldering of the lower reaches of the delta.

With respect to salinity gradients in the estuarine zone, it is believed that the brackish zone of the estuary (the "critical zone" with salinity ranging from 1 to 15 parts per thousand) plays a key role in the life history of many valuable estuarine and marine species of fish and shellfish, similar to estuaries elsewhere. Apparently juveniles of many fishery species benefit from low-salinity habitats because of the elevated biological productivity along with reduced predators, disease, and parasites. The extent of such a critical zone in the Mekong estuary and its significance, and the effects of alternations in flow regions, needs careful evaluation (see discussion on salinity).

Finfish biological and life history information is minimal for the Mekong estuary and adjacent coastal waters but limited studies have been made of a few types including the mackerels and milkfish. These data support the belief that the estuarine zone is heavily used for breeding and nursery purposes by many fish and shellfish. Also some valuable marine fishes (such as Rastrelliger, Stromateurs, and Mugil) are reported to move through the estuary as far as the border between Viet-Nam and Democratic Kampuchea during the dry season.

A number of studies have been made of the biology of shellfish in the Mekong estuarine zone, which exist in great quantities and diversity with wide distribution. They are of considerable economic value including lucrative maricultural operations. As with finfishes, however, little is known of the temporal and spatial distribution movements of shellfish life history stages or of the environmental factors associated with river flow pattern alternations which may be important to their continuing productivity. Among the prevalent and economically important shellfishes are the giant freshwater prawn, Macrobrachium rosenbergi, which requires brackish water for its

larval stages, the shrimps of the penaeid genera, Penaeus and Metapenaeus including the jumbo tiger prawn, Penaeus monodon, and the mud crab, Scylia serrata.

The fishery yield and value from this ecosystem, the Mekong estuary and waters of the South China Sea under direct Mekong influence, have never been quantified in spite of their substantial size and great local economic and nutritional significance. Extrapolations of existing records and statements by experienced government officials in Viet-Nam indicate that the annual production of these waters from all types of fisheries (commercial, artisinal, and subsistence fishing, and from aquaculture) may approximate 250,000 metric tons. Wartime constraints have limited the exploitation of these estuarine and related coastal fisheries, and no doubt the total catch would be significantly greater with improved fishing methods and modern technology. Since 1969 systematic surveys using trawling and purse seines have been conducted in the coastal waters as part of the UNDP/FAO/Vietnamese fishery development project, but mostly outside the nearshore zone affected by the Mekong river system.

(d) Migratory fisheries: Of the many species of fishes that move longitudinally or laterally for unknown distances within the lower Mekong basin, analysis of the available information yields a preliminary selection of eight species whose migrations might be interrupted by damming activities, as shown in Table 2. All of these eight species are important in the region: Pangasianodon gigas because of its giant size, rarity, and cultural esteem; and the other seven because of their role in commercial fisheries and in aquaculture. However, the existing information is not sufficient to enable assessment of impacts from dams or to determine the feasibility of ameliorative interventions. For each of the eight selected species, a synopsis of existing information and a map of its known distribution in the lower Mekong basin is included as an appendix in the survey-study plan report.

In addition to the eight species of suspected migratory fishes denoted in this preliminary selection, several others have been cited as making longitudinal movements in parts of the system. For example, the Tonle Sap commercial day traps which depend on downstream migration for their catches (November - February), take some 45 species. At Khone Falls on the Mekong mainstream, where the trap fishery depends on upstream movement, some 40 species have been taken

during two intervals, November - February and April - July, with most species different in the two periods. Three of the eight species previously mentioned pass both down the Tonle Sap and up the Mekong at Khone Falls, and at least eight additional species are known to have similar movement characteristics.

One of the overriding concerns for longitudinally migratory fishes in the Mekong system is whether or not they can survive in the rivers and tributaries, or in reservoirs, after damming. It appears that at least Cirrhinus jullieni can survive, as it has in Nam Pong reservoir impounded in 1966. This is now one of the most important commercial species at Nam Pong, comprising nearly 20 per cent of the total landings. Furthermore, the available evidence suggests that at least three other species might become productive in reservoir situations, namely Pangasius pangasius, Pangasius sutchi, and Cirrhinus microlepis.

If losses of valuable migratory fish, mainly due to blocked spawning runs, were to occur and prevail over gains, a not unlikely event in the light of experiences with other heavily fished tropical rivers, they might amount to several per cent of the current fish harvest from the residual river. The total Pangasius fishery downstream from Pa Mong, a fraction of which is bound to be affected, is worth at least $ 10 million annually. This fishery is not only pursued in the main river and its tributaries but several species of this genus, especially P. larnaudii and P. sutchi, are reared in floats and cages in Democratic Kampuchea and Viet-Nam. The important point here is that the fry are reported to be carried downstream from as yet unknown spawning sites up-river, some perhaps above the proposed damsite at Pa Mong. This indicates the magnitude of possible losses and the need for gathering further information to solve this potential problem.

## 3. Development activities

### 3.1 Reservoir fisheries management

(a) Tributary reservoirs: The Mekong Committee's fisheries programme has included, whenever possible, implementation of fisheries development measures in completed tributary reservoirs. These measures include attention to the production of fish and to the socio-economic aspects of fish catching, transporting, marketing, and otherwise disposing of the fish catch. A summary of these activities is included in Table 1.

( ) Pa Mong reservoir: Preliminary planning for exploiting the fisheries of Pa Mong reservoir has been based on experience elsewhere especially in India (Ref. 3).

Careful planning and preparation will be needed to realize the expected minimum annual harvest of 20 kg/ha or 8,000 tons. This will require partial clearing of vegetation before impoundment to permit efficient fishing and massive stocking of the proper species as the reservoir is filled, to prevent proliferation of undesired trash species. Further requirements are for training of fishermen after resettling them into planned new villages along the reservoir, and the establishment of fish landing and processing sites. An important aspect in the early years is recognition that an initial period of high fertility and fish production for several years will tend to be followed by a decline for several years, then a gradual rise to a stable situation. Management should aim to harvest as much of peak production as possible and to counteract the decline through measures such as fish culturing and spawning reserves.

The fish species tentatively selected for use at Pa Mong are the following:

Grass carp (Ctenopharyngodon idellus)
Silver carp (Hypothalmichthys molitrix)
Bighead carp (Aristichthys nobilis)
Common carp (Cyprinus carpio)
Two local carps (Puntius gonionotus, Probarbus jullieni)
Several species of catfish of the genus Pangasius

The first four species are not native to the river but they have proved most effective in comparable situations; the remaining ones are native, but likely would not reproduce naturally fast enough to prevent the establishment of less desirable kinds. Such plantings in a reservoir of the size of the proposed Pa Mong will require abundant fish rearing facilities and the programme for propagating and raising the proper species must be underway before impoundment. At least three large fish hatcheries and fish propagation research stations in the reservoir vicinity will be required.

It is presently difficult to envisage settlement patterns around the proposed reservoir but population concentrations with road access are likely to develop at each of the dam sites included in the Pa Mong system. Fish landing sites and storage and processing facilities should first be developed at those sites. The experience at the smaller tributary reservoirs will be used to guide the new fishery including selection of types of fishing gear to be used, design of fish landing, storage, processing, and hauling facilities, and choice of the methods for exploitation (including possible use of cooperatives).

The Pa Mong Phase II report incorporates plans for reservoir fisheries at Pa Mong as outlined above with estimates of costs including allowances for capital investment, forest clearance, and operation and maintenance. For the total estimated annual fish production of 8,000 tons, the net benefit of sales value over costs average from $ 3.64 to $ 3.69 million/year (for 50 and 100 year periods of analysis respectively).

(c) Pilot project for fishery development: All of the preliminary studies noted above have indicated the need for a comprehensive project to develop a much firmer basis for the planning and management of reservoir fisheries. Such a project was drafted by the Mekong Committee in July 1975 (Ref. 47), to cost about $ 4 million for work extending over 6 years. This includes four component studies at four tributary reservoirs to represent a range of conditions, namely (1) a perennial stream reservoir in a plains area (such as Lam Dom Noi in Thailand), (2) a steep gradient stream reservoir (such as Nam Ngum in the Lao PDR), (3) a floodwater reservoir (e.g. Prek Thnot, Democratic Kampuchea), and (4) a delta impoundment on alluvium (e.g. Dan Heim lake in Viet-Nam).

## 3.2 Fish farming

A very important aspect of the Mekong Committee's fisheries programme (Ref. 3), to make up for possible or anticipated lossess in existing natural fish productivity, is the plan to establish commercial fisheries throughout the lower basin where a continuing supply of good quality water will be assured, including the Pa Mong irrigation areas and the delta area where pumped freshwater will be available throughout the dry season. Such fish farms would be located in low lying areas not suitable for farming.

Based on experiences in tropical Asia, especially in India, and also the existing commercial fisheries in the lower basin, two types of fish farming operations appear feasible, namely (1) homestead fish culture, using small isolated ponds (1 ha or smaller) situated among large tracts of agricultural lands, and (2) commercial farms in larger areas of about 50 ha in size, which would be subdivided into individual ponds of about 2.5 ha, considered large enough to provide a good family income compared to a typical family agricultural activity. A portion of the pond area would be used for hatchery and nursery purposes, to provide the necessary fingerlings each year, over a four-month period from July through November. This can also be used to produce commercial fish the rest of the year thus reducing overall hatchery operation costs.

Production from the commercial farms is estimated to be at least 2 tons/ha/year, with the fish species used limited to high quality carps (both imported and local species) which

command good prices. An average price of $ 0.45/kg was assumed as a weighted average, which, after considering all capital and operating costs, would realize a net income of more than $ 500/ha of productive water surface. It is estimated that about 97.5 per cent of the total area of the farm fishery units will be productive, allowing for dikes, ditches, and appurtenances.

(a) Pa Mong phase II: The Pa Mong Phase II report includes provision for commercial fish farming as discussed above on a comprehensive scale throughout the irrigated areas. The total land areas allocated for fish farm units and hatcheries, located on relatively level nornarable lands, are approximately 5,200 ha for the Stage One service area and 101,400 ha for the Phase II service area (all in northeast Thailand or the Lao PDR). This land will receive good quality water from the project canal system, free of toxic agricultural chemicals and other harmful pollutants. The total fish produced by fish farming in the combined service areas, at 2 tons/ha/year for net farming area, would be approximately 204,000 tons (Table 3). The Phase II report includes detailed information on costs, which indicate a net annual benefit from the farm fisheries of about $52 million (at $ 500 per hectare).

(b) Pilot fish farms: To demonstrate the feasibility of the fish farming concepts included in the Pa Mong project service area and proposed elsewhere in the lower basin, including developing firm cost data and guidelines for construction and operation, the Mekong Committee is currently pursuing a programme for building and operating five pilot fish farms, each of about 50 ha, one in the Lao PDR (relating directly to the Pa Mong service area), two in Viet-Nam (one for freshwater and one for brackish water species) (Ref. 16, 40), and one each in Democratic Kampuchea and Thailand (Ref. 16, 40). These pilot ponds will explore various levels of production, i.e. intensities of fish production, relating to amounts of water and type of aeration used, to demonstrate how production levels can be increased from traditional levels (about 0.3 tons/ha/year) to as much as 40 tons/ha through progressively increasing use of modern technology. Also, each of the pilot ponds will allocate part of its area for fish hatchery and nursery purposes, to supply high-quality fry both for the pond and for sale to private fish farmers who now have to depend on erratic supplies.

As the first step a feasibility study was completed in August 1974 (Ref. 17) which included preliminary engineering data for four of the systems, including constructing and operating costs, which are

summarized in Table 4. The August 1974 report confirms that the concept of the fish farms for fresh waters is entirely feasible throughout the basin, in fact should result in high internal rates of return ranging from 20 to 35 per cent. Further study is needed to prove out the feasibility of using brackish water but it is expected, based on experience elsewhere, that continuing study and research will provide the solutions. The Mekong Committee is now pursuing funds for proceeding with construction of the pilot ponds.

As an example of the results of the feasibility study, for the project in the Lao PDR, located at Tha-Ngone, near the Nam Ngum river about 25 km north of Vientiane, the water will be supplied from the Nam Ngum river through the existing south main canal. A discharge of 720 $m^3$/hour is allocated to this fish farm on the condition this quantity of flow (less seepage and evaporation) will be returned to the irrigation network. The total farm area is 47 ha, with 45 ha for fish production and 2 ha for fish hatchery, nursery, and storage operations. Three levels of production will be investigated, namely (1) "semi-intensive/water aerated ponds" (5.7 per cent of area) expected to produce yield of 15 tons/ha with water discharge at 150 to 600 $m^3$/ha/hour, (2) "semi-intensive, with water and mechnical aeration" (55.6 per cent of area) to yield 15 tons/ha for a water discharge of 15-60 $m^3$/ha/hour, and (3) "extensive level with water aeration" (38.7 per cent of area), to yield 6 tons/ha with a water discharge range from 15 to 53 $m^3$/ha/hour, representing situations where intensive production techniques are not feasible. The fish to be cultured will be mostly catfishes (80-85 per cent) and carps (15-20 per cent). The recommended best use of the total available water surface (47 ha) allocates 45 ha divided among the three levels of culturing noted above plus 2 ha for hatcheries and appurtenances. The expected yield is 11.5 tons/ha average or 519 tons total per year.

(c) Fish feed mills: A key factor in the success of the programme of fish farming proposed by the Mekong Committee will be the avialability of fish feeds in adequate quantity and quality. At present there are no commercial fish feed plants in the lower basin, hence even where intensive fish cultivation is practiced the full production potentials are not being realized because of dependenceon irregular and usually sub-standard feeds. A new Mekong Committee project, approved in 1975 (Ref. 31), is a feasibility study for establishing a pilot plant to produce pelletized fish feed in each of the four riparian countries. The study would estimate the demands for

fish feed, survey local materials available for making feed including nutritive value and costs, develop recommended feed compositions for different fish species, and develop the economic and commercial feasibility for establishing pelletizing plants.

## 3.3 Marketing studies

The Pa Mong Phase II report includes an analysis of the fish supply and demand situation for the lower basin and particularly for the Pa Mong project service area. The available data indicate future fish production, without the project, will fall far short of expected demand. Assuming the existing fisheries can be increased (without the project) to maintain the present per capita level of consumption (estimated at 8.9 kg) in northeast Thailand and Vientiane province, the annual production in these two areas will have to total 166,000 tons 1985 and 221,000 tons by 2000. However, the potential per capita annual demand for fish in the service area is expected to increase to 23.3 kg by 1985 and to 31.5 kg by 2000, assuming that fish in these amounts are available at reasonable prices. The projected population and production of fish both without and with the project are compared to the potential demand in Table 3.

The fisheries associated with the development of Pa Mong reservoir and the Stage One irrigation area would be fully developed by the year 1990. The difference between fish production without project development and potential demand in northeast Thailand and the Vientiane plain is estimated at 360,000 metric tons in 1990 and 561,000 tons by the year 2000. The Pa Mong reservoir's fish production of 200,000 tons plus that from the farm fisheries from Stage One (10,000 tons) and Phase II (194,000 tons) total 404,000 tons. Hence, even with this production, a portion of the total potential demand would still have to be imported if the projected demand is to be met.

To obtain information of the effect of fish price on demand, a study was made of this relationship in the Bangkok area in 1970 where detailed information could be obtained. Analysis of these data by polynomial regressions indicated sales increased with price reduction, levelling out at $ 0.40/kg. Although Bangkok represents a different set of conditions from the servolce area, a major similarity is in the manner of marketing, i.e. the fish are brought to market in the early morning hours and sold that same day. Also, some price data collected in the northeast indicated good quality common fresh water fish sold for prices seldom below $ 0.40 /kg and often higher.

## 3.4 Fish processing

Dams constructed in the lower basin tributaries have led to rapid increases in fresh water fish production.

Technology and facilities for fish processing and preservation have not, however, improved commensurately, and the fish products reaching the area's markets are often poor in quality. The "fresh fish" arriving at the market may be not so fresh and the existing fish products may be vehicles for transmitting bacterial diseases and helminth parasites. Also, consumers of dried and salted fish, it has frequently been reported, have been poisoned by the preservative chemicals used.

Production of the large quantities of fish envisioned for the Pa Mong project will require better methods of processing. A project is planned by the Mekong Committee (Ref. 18) for investigating traditional methods of fish processing; analysing the end products for pathogenic, parasitic, and chemical contamination; and suggesting improved methods, where possible and feasible, that would result in an end product that is both palatable and safe for human consumption.

## 4. Rehabilitation activities

### 4.1 Prawn and shrimp farming

Prawn and shrimp fisheries in the deltaic regions are usually among the earliest casualties of upstream dam construction that alters the flow and salinity regimen in the estuarine regions. Studies elsewhere show that valuable brackish water shrimp fisheries of the Nile delta have disappeared as a result of construction of the Aswan dam in Egypt (Ref. 19) and a lucreative giant freshwater prawn fishery declined perceptibly in the Codavari and Krish in estuarines in India following the construction of barrages (Ref. 20, 21). A considerable decline in the giant prawn fishery has also been reported in the Chao Phraya river in Thailand, possibly due in part to construction of upstream impoundment.

The giant freshwater prawn, Macrobrachium rosenbergi, which is distributed in most of the river systems in southeast Asia, spends its adult life in freshwater areas in the vicinity of estuaries and migrates down to brackish waters for spawning. It is perhaps the most important species of prawn in the world by virtue of its size, consumer preference, and growing demand in world markets. In the Mekong delta this species is harvested both in fresh and brackish water regions.

Because upstream impoundments on the Mekong river may adversely affect important prawn and shrimp fisheries in the delta, the Mekong Committee initiated a project in 1970 to employ recently developed techniques in breeding prawns in captivity to permit culturing them in the vast areas in the delta available for the purposes (Ref. 22). The project encompasses several activities, to be completed by 1980, namely (a) training of riparian technicians in pertinent techniques, (b) bilogical surveys of prawn resources and

cultivable water areas in the delta, (c) feasibility studies for establishing a pilot prawn culture farm, and (d) adaptive research and pilot operations in spawning prawns and shrimp under captive/culture conditions.

The first phase of the project, training, has been completed, including (a) a course conducted in 1972-73 at the University of Hawaii, (b) a review workshop and international conference held at Vung Tau, Viet-Nam in March - April 1975, and (c) a techniques workshop of ten weeks held June - September at Honoluu (Ref. 48). Also, a prawn hatchery was constructed at Vung Tau and successful prawn breeding operations were conducted as part of the training programme.

An additional project for establishing a marine shrimp hatchery in Viet-Nam is also under consideration (Ref. 29), aimed at culture farming of two of the largest marine shrimp species in the region, Peneaus monodon (the "tiger shrimp") and P. indicus, both being in great demand in the world markets. Recent research has developed techniques by which young shrimp can be successfully produced in hatcheries, and it is proposed to establish such a hatchery at the brackish water fish farm planned at Go Cong. The project cost is estimated at US$ 400,000, covering a period of four years.

## 4.2 Catfish propagation

Pangasius pangasius and P. sutchi are two of the more important of several species of Pangasius that contribute considerably both to capture and culture fisheries in the Mekong, particularly in the deltaic region (Ref. 23). In addition to the capture fishery pursued in the main river and its tributaries, several species of the genus are cultured in ponds, floats, and cages. The culture of Pangasius in the region represents perhaps one of the most efficient fish culture operations known anywhere, utilizing as they do, different types of inexpensive feeds including human and animal feces. Fry for culture purposes is derived from seasonal collections from natural stocks in rivers.

While little is know about the habits of pangasids in the Mekong itself, investigations on the Gandetic Pangasius (P. pangasius) have shown that the species migrates from rivers to estuaries for spawning and rearing of young. Seasonal distribution of several species in different stretches of the Mekong also strongly suggests that the species is migratory. This has led to the apprehension that construction of mainstream dams might disrupt the spawning runs and consequently reduce stocks of several species of the genus and the availability of their fry.

To offset these anticipated possible negative effects of dam construction, the Mekong Committee has initiated a

project on artificial propagation of P. pangasius by the application of techniques previously developed by the Committee and currently being applied with success in Thailand (Ref. 23). This would immediately make available large numbers of P. pangasius fry to fish farmers more easily and less expensively than the current method of collection from natural sources and thus provide the additional impetus for further expending P. pangasius culture. In the future, after the construction of mainstream dams, the anticipated loss to the commercial capture fishery could be offset by stocking rivers by artificial propagation, and thus making this fishery independent of the expected reduced supply of fry.

This project involves training of Vietnamese fishery personnel in the techniques of hypophysation and rearing (completed in 1975), design and construction of a breeding and rearing centre in Viet-Nam (completed in 1975), and artificial propagation on a commercial scale.

The methodology developed for propagation of the selected catfish species can be extended, if necessary, to conserve any of the species listed in Table 2 which may prove to be endangered by construction of Pa Mong.

4.3 Brackish water fish seed prospecting

The Mekong delta has a great potential for the development of brackish water aquaculture. In the context of Mekong development, attention to aquaculture in the delta can serve several vital functions, among which are (a) developing new sources of fish production to compensate for possible fishery losses elsewhere; (b) optimizing the benefits of delta development as between aquaculture and agriculture, taking into account the productive potential of specific areas and the relative economics of alternative ways of using them; and (c) rehabilitating commercially or biologically important species of fish which may be endangered by water control measures.

The available area with potential for brackish water aquaculture has been estimated at 150,000 hectares in Viet-Nam and 50,000 in Democratic Kampuchea. Unlike freshwater aquaculture, where seed of culturable species can be obtained through artificial inducement of spawning, brackish water aquaculture has been dependent on natural sources for its seed. This is because several biological and technical problems have so far hindered the application of analogous freshwater techniques for artificially induced spawning of brackish water species. Supply of seed in adequate quantity and of a desired quality has thus become one of the major contraints to the development of brackish water aquaculture. Recognizing the importance of this subject the Mekong Committee in 1975 (Ref. 30) approved a project with the objective of ensuring an adequate supply of seed of

commercially valuable species of fish and shrimp. The project includes field explorations for locating seed sources, determining seasonal distribution and best exploitation times, fabrication of gear for collecting and segregating seed, preparation of a key for identifying post-larvae and juveniles of desirable species, and training.

## 5. Studies of effects of Pa Mong on fisheries

### 5.1 Pa Mong flow regulation

Water releases from dams are an important operational factor from the point of view of fisheries (Ref. 3, 15). Releases should be managed to avoid inordinate reduction in the wetted perimeter of the residual river, which may result in desiccation of downstream spawning grounds of mainstream spawners; to maintain an adequate supply of cool water to offset sudden changes in the temperature regimen of the river below the dam; to maintain adequate water levels in the swamps and oxbow lakes connected to the residual river, which serve as spawning and nursery grounds for several riverine species; and to prevent formation of stretches of difficult passage for fish in the section of the river below the dam.

In the case of Pa Mong, the water depths and wetted perimeters in the river below the dam are expected to be never less than the existing levels. However, as previously noted, it will probably be necessary to include consideration of reduction in inundation fisheries in the management of water releases, and perhaps also consideration of effects on estuarine fisheries as related to salinity and nutrients.

Withdrawal of water from the reservoir at depths below the thermocline (more than 30 m) is recommended, to remove anaerobic waters in the hypolimnion thus reducing the extent of the anaerobic zone and also releasing nutrients in this zone for stimulating fish production downstream. Release of such oxygen-depleted waters might cause a problem immediately below the dam, but the ample turbulence should achieve reaeration within short distances (see discussion on reservoir ecology).

Another possible problem relates to drawdowns, which can seriously impair spawning through exposure of eggs and fry in spawning areas. Studies will be needed to evaluate the effects of drawdowns on the fish species to be used at Pa Mong, for developing guidelines for drawdown management. However, a generally applicable recommendation is that drawdowns be as gradual as possible and that for a period of about two months in the flood season (the peak spawning season for carps) there should be no appreciable drawdown. Also, experience will indicate how drawdowns can be used for reducing undesirable species of fish and unwanted weeds.

## 5.2 Fish production in Pa Mong reservoir and immediate vicinity

The Pa Mong Stage One Feasibility Report (Ref. 45) included the following estimates of gains and losses in fisheries in the new reservoir and the immediate upstream and downstream vicinities:

(a) Immediate downstream fishery: The immediate fishery, from Pa Mong to the mouth of the Nam Ngum (a distance of 20 km), is expected to be greatly depreciated due to the greatly altered environment from turbine water releases, especially bottom scouring effects. Some species will certainly adjust to the altered flow pattern, and some species will likely be attracted at each day's peak flow to regions immediately below the dam especially during the spawning season. It will be necessary to exercise positive control over fishing in this vicinity, to prevent overfishing which might have serious adverse effects on spawning, hence on downstream fisheries. Assuming that fishing will be prohibited in this stretch of the river, the losses will be about 500 tons annually.

(b) River stretch inundated by reservoir: In addition to the immediate downstream section, a sizeable river stretch will be flooded above the dam, depending on the selected pool level. However, significant fishery exploitation now takes place only in the 30 km stretch immediately upstream of the dam. The estimated loss is about 400 tons/year (Ref. 46).

(c) Reservoir fishery: As previously noted, the preliminary estimate of the potential annual yield of the future Pa Mong reservoir fishery is 8,000 tons/year (based on 20 kg/ha). To achieve this will require careful planning and implementation of the coordinated programme including provisions for hatcheries, training, and fish catching/hauling/processing/marketing. Under conditions expected to prevail at completion of the project, initial yields of about 60 per cent are expected, to increase gradually to the sustained maximum. Use would be made of imported exotic species only if testing programmes show these would be definitely preferable to local species.

## 5.3 Effects of flood control on inundation fisheries

As a step toward quantifying the effect of flood control at Pa Mong on downstream fisheries, a study made by the Mekong Committee in 1975 on downstream effects of Pa Mong on hydrology and agriculture in Democratic Kampuchea part of the Mekong delta was extended to include a preliminary estimate of reductions in inundation in this area (Ref. 44). For purposes of this analysis it is assumed that the extent

of seasonal inundation, as measured by hectare-months, would be a meaningful parameter more-or-less proportional to the amount of fish produced in the inundated areas. While admittedly a crude parameter, which does not take into account the effects of depth and many other factors, yet it likely represents roughly the amount of nutrients available for conversion to fish and thus the amount of fish produced.

The analysis was made for the floods for two selected years, 1961 and 1963, the former representing a once/20 years flood (5 per cent of years) and the latter a one/2 years flood (50 per cent of years). For each land unit a set of typical hydrographs were developed, with and without Pa Mong, plus a curve showing the relation between elevation and accumulated acreage based on a 1:50,000 contour map with a one metre contour interval. From these the water levels sustained for various time periods were obtained (from one to five months), together with the corresponding areas, from which the extent of inundation in ha-months was computed by considering the total inundation to comprise a series of "layers". Also, an index, I, called the inundated area-duration index, was calculated by dividing the extent of inundation by the land area involved, resulting in a number indicating the level of fish productivity. The results are shown in Table 5.

The following tentative conclusions were made, based on the assumtion the extent of flood regulation would be sufficient to maintain a maximum release from Pa Mong of 2,000 $m^3$/sec over the flood period from 1 July - 31 October:

(1) The Great Lake alone accounts for three-quarters of the inundation area in part of the Mekong delta in Democratic Kampuchea, as measured by ha-months of inundation, and also has the highest index.

(2) The ha-month index reflects the general land form, the higher the terrain elevation, the lower the index, and vice versa.

(3) The ha-month values fluctuate significantly from normal to high flood years, the approximate ratio being 1.0 to 1.2.

(4) With Pa Mong, excluding the Great Lake, the extent of inundation is reduced by 19 per cent in high flood years and by 17 per cent in normal flood years, and including the Great Lake, the reductions are 13 per cent and 16 per cent respectively. The reduction is less pronounced in the Great Lake area (10 per cent) and highest (30 per cent) in the highlands (e.g. in Tonle Toch terrace).

(5) The differences in extent of inundation between with and without Pa Mong are approximately equal

to the differences between high flood and normal flood years.

While the analysis was limited to Democratic Kampuchea, some general conclusion can be drawn for the areas throughout the lower basin in that the reduction in inundation is less in the flat terrain areas and higher in the higher terrains. The effects should be considerably less in the Vietnamese part of the delta, which represents a major part of the total inundation zone fisheries. As is pointed out in the analysis (Ref. 44), the effects of reduction in inundation are very beneficial to agriculture in making it feasible to grow rice and other crops on lands otherwise not useable because of the frequency of flood damage. As noted in the discussion on agriculture, the value of the added crop benefits will be very substantial and together with fish farming benefits, should considerably outweigh the loss in fisheries.

The above estimates, based on an assumed 2,000 $m^3$/sec release, would be achievable for a Pa Mong high pool level of 260 m MSL. For a 250 m pool level the extent of reduction in inundation would be considerably less. While it is not yet possible to make firm estimates, some rough estimating is possible. Assuming the extent of inundation fisheries may be as much as 200,000 tons/year, the total estimated losses in the lower basin may be approximately 20,000 tons/year including some 4,000 tons in northeast Thailand/the Lao PDR, 3,000 tons in Democratic Kampuchea, and 13,000 tons in Viet-Nam. For the northeast Thailand/the Lao PDR zone, the loss of 4,000 tons/year would be offset by 8,000 tons/year from Pa Mong reservoir plus 204,000 tons/year from farm fishing (including about 10,000 tons/year from the Stage I service area). For Democratic Kampuchea the loss of 3,000 tons/year would be offset by fish farming (not yet estimated) plus increased agricultural productivity of about 500,000 tons/year of rice (or equivalent dry-foot crops). In Viet-Nam the losses would be offset by fish farming plus agricultural benefits to as much as 3 million hectares of farmlands or potential farmlands.

## 5.4 Delta agricultural development

While the Mekong Committee's programme of fisheries studies has not yet considered in detail the effects of proposed irrigated agriculture in the Mekong delta, some preliminary evaluations have been made (Ref. 41). The delta development project aims at providing a system of water control management that would ultimately permit year-around cultivation of high yielding varieties of rice and other crops which have precise requirements of water levels during their growing season. The envisioned water control system would include facilities for flood protection, salinity control, irrigation, and drainage and water transportation, hinging on upstream water management. Despite the

knowledge that all such activities bring about environmental changes that are bound to affect fisheries, no detailed studies have yet been executed as a part of the project pertaining to its fisheries aspects. In the absence of any such studies it is not possible to forecast the probable effects on fisheries of specific activities that might be contemplated in a delta development plan. However, a general account of what could happen, or what has happened, in similar situations elsewhere, can be made. Each deltaic ecosystem in unique in many ways, hence, the possibility of recurrence of similar events in the Mekong delta is not necessarily implied. Only specific studies in the Mekong delta itself could ascertain the likely effects of agricultural and other developments on its valuable fishery resources.

Changes in the configuration of the basin by bulkheading and filling, dredging and ditching of marshes, diversions, barriers, seawalls, tide control structures and so on, could result in alteration of drainage patterns and circulation which in turn could effect distribution of critical environmental factors such as salinity, temperature, magnitude of flows and velocity of currents, siltation, intrusion of seawater, and water table levels. All these environmental changes could lead to alterations in vegetative cover, in the supply of nutrient material, changes in spawning, nursery, and feeding areas, and consequently to changes in fishery productive potentials. The consequences of these changes become compounded through synergistic interactions when several such factors act simultaneously.

In addition to changes resulting from agricultural engineering structures and systems, intensive irrigated agricultural operations themselves, involving the use of pesticides, herbicides and fertilizers, could be equally hazardous to fisheries. Rapid increase in the use of artificial fertilizers, particularly phosphorous and nitrogen compounds, as a result of application of intensive agricultural techniques, could lead to serious pollution of the water bodies receiving the agricultural return flows. Increased fertilizer loads could lead to development of excessive algal blooms and massive oxygen depletion. Some fish and other forms of aquatic life needing high levels of oxygen for their survival could be seriously affected and several spawning and feeding areas for fish could be rendered useless. Pesticidal and herbicidal pollution is another serious hazard to aquatic life resulting from intensive agriculture, leading to accumulations of toxic materials in the food chain which may even pose hazards to man. Relative toxicities of herbicides are nearly at unity for plankton, shrimp, crab, oyster and fish. Compared to this scale of effects by herbicides, organophosphorous compounds have relative toxicities of 0.5 for plankton, 1,000 for shrimp, 800 for crab, 1 for oyster, and 2 for fish. Polychlorinated hydro-carbon compounds in comparison have toxicities of 3 for plankton, 300 for shrimp,

100 for crab, 100 for oyster, and 500 for fish. It is obvious that fish are most sensitive to polychlorinated hydrocarbons and that crustaceans are most affected by organophosphorous pesticides.

It must also be recognized that estuaries are remarkably resilient systems that have the capability of quickly adjusting to changes imposed by man. Well planned manipulations based on an adequate understanding of the estuarine environment could well result in overall benefits, i.e. the gross ecology of an estuary can be managed advantageously.

The Mekong Committee plans to include in its fishery programme studies to evaluate the effects of agricultural development in the delta on its fisheries as well as continuing studies on the development of aquaculture in the region. It is anticipated these studies will produce sufficient basic information so that proper attention to fisheries conservation and enhancement can be incorporated into the evolving delta agriculture plan.

### 5.5 Salinity changes in delta

Studies of anticipated salinity changes in the delta made by the Dutch Delta Team (Ref. 46) show that the proposed agricultural programme will affect salinity gradients but do not indicate any necessary adverse effects on fisheries (see discussion on salinity). The effects of Pa Mong regulation on the salinity zone during the wet season (when salinity intrusion is minimal) would be small. During the dry season the higher freshwater flow, to the extent this is permitted to flow to the sea, would shift the brackish water zone downstream; however, much of the extra freshwater will be extracted for irrigation. There will be significant changes in the dry season salinity gradient patterns in the smaller channels or branches to be enclosed by gates (for minimizing intrusion). The ecosystem of the mangrove swamps bordering the sea could be significantly altered by such gates. Although the design of these gates is not part of the Pa Mong project per se, they would be related assuming the gates are built to realize maximum irrigation advantages from Pa Mong. The design of such gates and enclosure systems, when the delta development programme reaches this stage, should carefully consider effects on salinity and on the delta ecosystem.

## 6. Summarized assessment of environmental effects of Pa Mong

### 6.1 Changes in fisheries productivity in lower basin

With the exception of changes in environment due to use of toxic agricultural chemicals, the types of environmental changes due to storage and flow regulation at Pa Mong and magnitude of these changes are expected to be within the

natural range of variations without the project. Hence such changes should not drastically alter the fisheries ecology but might cause significant changes in the levels of fish productivity.

(a) Inundation fisheries: Flood control at Pa Mong will likely result in significant reductions in the present levels of inundation zone fisheries, with the percentage of reduction being higher for uplands than for lowlands. The losses in fisheries will be most significant in Democratic Kampuchea, where vast areas are regularly inundated and where the flood control measures will significantly alter inundation patterns. This will cause reduction in the extent of inundation (as measured by hectare-months) ranging from about 30 per cent in the highlands to about 10 per cent in the lowlands for a Pa Mong high pool level of 260 m MSL. The reductions will be considerably less for lower pool levels. Also, the benefits from increased production of rice and dry-foot crops made possible by the reductions in inundation should more than offset the value of the lost fisheries.

(b) Riverine fisheries: The new fishery in Pa Mong reservoir should yield not less than 20 kg/ha/year, which should far exceed the losses due to elimination of the zone of river to be inundated and due to disturbances in a limited stretch of the river downstream from the dam (estimated to extend 20 km downstream). There may be some migratory species which may be endangered by blockage of the river by the dam, but it is by no means certain that any such species are of significant value either commercially or culturally. Further studies are underway or scheduled to identify those important migratory species which are endangered and develop artificial methods for propagating and maintaining them (see Section 6.2).

(c) Estuarine and marine fisheries: Development of in intensified agriculture in the Mekong delta made possible by upstream storage at Pa Mong will involve numerous alterations in the environment due to engineering construction activities and due to the farming operations themselves, especially use of agricultural chemicals. While engineered alterations in patterns of flow, water depths, salinity, etc. have in the past usually led to adverse effects on estuarine fisheries, with careful attention to this factor (incorporation of attention to ecology as a constraint in design of the system) it should be possible to minimize most adverse effects and to obtain definite benefits from some of the

alterations (for example, in establishing more uniform hydrologic and salinity patterns throughout the year). While this concept of engineering design is relatively new, a whole, new technology is being steadily evolved which should be most helpful in design of the delta agricultural system. Similarly, much experience is being obtained elsewhere in how to utilize agricultural chemicals without serious adverse effects on environment, and with a sound water pollution regulatory programme this problem is subject to proper control (see discussion on water quality).

With respect to nutrient influx into the delta and thence to the ocean, the indications are that there will be no significant reduction in influx of nutrients due to Pa Mong. While silt and associated nutrients will be trapped at Pa Mong, the normal silt load should be restored to the river through resuspension of silt downstream. Also, decomposition of inundated vegetation in the reservoir will lead to discharge of additional nutrients to the river system especially if withdrawals are made from the lower anaerobic zones. Also, studies of deltaic systems elsewhere indicate that the bulk of the nutrients in the delta waters may be derived from land runoff in the delta zone itself rather than from upstream sources.

## 6.2 Artificial propagation and culturing (aquaculture)

To make up for possible losses in fisheries due to Pa Mong, and in any case to help increase fish productivity in the lower basin to meet growing needs, a programme of fish farming is planned, made possible by the year-around supply of good quality irrigation water to be made available by Pa Mong, both in the irrigation division zones and in downstream areas especially in the delta. Such farms would be located on lands not suitable for agricultural cropping, and by utilizing more intensive methods of culturing can be expected to yield up to 40 kg/ha/year. The Pa Mong Phase II irrigation system, for example, includes provision for approximately 100,000 ha of these fish farms, and the delta has potentials for large scale applications of these methods especially in brackish water areas.

In addition to culturing ordinary fishfood species (primarily carps), the projects underway include pilot studies for artificial propagation and culturing of prawns and shrimps in the delta, and also to explore the feasibility of artificial culturing of Mekong catfish (Pangasius) as a commercial foodfish. Also, to support and complement the fish farming projects, the overall Mekong Committee programme includes ongoing projects for development of pelletized fish food manufacture and for improved methods for processing the fish

products to preserve their quality between harvesting and marketing.

In summary, through the aquaculture measures planned by the Mekong Committee, it is expected to offset the negative effects of dam construction even before they occur. While these programmes in aquaculture are in their early stages of development, it can be anticipated, on the basis of similar ongoing programmes elsewhere, that full-fledged commercial aquaculture on a large scale can be underway by the time of dam completion. Moreover, due to the vast areas and environment in the lower basin favourable to such ventures, it should be feasible to develop these industries not only to offset losses from impoundment but to increase productivity systematically over the years to levels considerably beyond those possible depending only on natural stocks.

## 6.3 Total fish production

It is anticipated the overall programme of the Mekong Committee, with respect to Pa Mong and related developments including delta agricultural improvements, should result in some significant losses of inundation zone fisheries, significant gains in riverine fisheries (by replacement of riverine with reservoir fisheries), little effect on estuarine and marine fisheries, and together with use of artificial farming of fish and shellfish, in a very significant overall increase in fish production as compared to without project conditions. In Democratic Kampuchea and Viet-Nam where there may be significant losses in inundation fisheries, these will be more than offset by increased agricultural gains as well as by fish farming.

## 6.4 Endangered species

As noted above, artificial methods for propagating and culturing Mekong catfish will permit preservation of *P. gigas* and of other catfish species which might be endangered by Pa Mong. This approach can be extended as needed to conserve other species which may be endangered by Pa Mong (Table 2).

## 6.5 Pa Mong pool levels

The choice of pool level at Pa Mong will affect the fisheries situation in the lower basin in many ways, in that the extent of downstream environment alterations will depend on the extent of flow regulation, hence on the capacity of the reservoir. The magnitude of the reservoir fishery will depend primarily on the extent of area inundated. The planned fish farming activities will depend upon the availability of year-around fresh water which will depend upon the extent of the irrigation system and on the minimum dry season flow level to be discharged to the delta. The reduction in inundation zone fisheries will depend on the amount of storage available at Pa Mong for flood regulation purposes, which will be greater for higher pool levels.

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TABLE 2

MIGRATORY FISH SPECIES IN MEKONG RIVER

**(Important Fish Species Suspected of Being Longitudinal Migrants in Mekong River)**

| Family and species | Authority of Record | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Smith, 1945 | Bardach, 1959 | Pantulu, 1965 | CTC, 1969: [illegible] | Sao-Leang, 1969 | Pantulu, 1970 & 1972 | Chaithepha, 1972 | Tua-Kiet, 1972 pers. comm. |
| Cyprinidae | | | | | | | | |
| Cirrhinus microlepis | - | x | x | x | x | x | x | x |
| Cirrhinus jullieni | - | - | x | x | - | x | x | - |
| Probarbus jullieni | - | - | x | - | - | x | - | - |
| Thynnichthys thynnoides | - | - | x | x | - | x | - | - |
| Schilbeidae | | | | | | | | |
| Pangasianodon gigas | x | - | x | x | - | x | x | x |
| Pangasius pangasius | - | - | - | - | - | x | - | x |
| Pangasius sutchi | - | - | x | - | - | x | - | x |
| Pangasius sanitwongsei | - | - | x | x | - | x | - | x |

NOTE: Data taken from report, "Fisheries Aspects of Ba Mong Project", V.R. Pantulu and John E. Bardach, Mekong Committee, 1969.

TABLE 3

FISH PRODUCTION IN NORTHEAST THAILAND AND VIENTIANE PROVINCE

(Estimated Production of Fish without and with Pa Mong Project
Compared to Potential Demand in Northeast Thailand
and Vientiane Province, Lao PDR, 1985–2000)

| Year | Population estimate (1,000) | Potential Demand for fish | | Production of fish (M. tons) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Per Capita (Kg) | Total (M. tons) | Streams and reservoirs without project (M. tons) | Pa Mong reservoir | Stage One Farms | Additional State II Farms | Total |
| 1985 | 18,685 | 23.3 | 435,000 | 136,000 | - | - | - | - |
| 1990 | 20,784 | 26.2 | 545,000 | 135,000 | 200,000 | 10,000 | 194,000 | 404,000 |
| 1995 | 22,709 | 28.8 | 654,000 | 202,000 | 200,000 | 10,000 | 194,000 | 404,000 |
| 2000 | 24,818 | 31.5 | 782,000 | 221,000 | 200,000 | 10,000 | 194,000 | 404,000 |

NOTE: Data taken from Pa Mong Phase II report

TABLE 4

CHARACTERISTICS OF PILOT FISH FARMS

(From "Feasibility Study on Pilot Fish Farm Projects in the Mekong Basin", S. K. H. International Consultants Ltd. for Mekong Committee, August 1974)

| | Vinh-Long Viet-Nam | Go-Cong Viet-Nam | Tha-Ngone Lao PDR | Phnom Penh Democratic Kampuchea |
|---|---|---|---|---|
| 1. Farm size, water surface, ha | 51 | 52 | 47 | 51 |
| 1.1 Production ponds area, ha | 45 | 45 | 45 | 45 |
| 1.2 Service ponds area, ha | 6 | 7 | 2 | 6 |
| 2. Average annual yield per ha of production area, ton | 12.9 | 4.4 | 11.5 | 12.9 |
| 3. Average annual income, cost & profit per kg fish US$ | | | | |
| 3.1 Income | 1.06 | 0.64 | 0.90 | 1.06 |
| 3.2 Variable costs | 0.51 | 0.66 | 0.50 | 0.51 |
| 3.3 Taxes | 0.06 | 0.07 | 0.05 | 0.06 |
| 3.4 Capital costs | 0.12 | 0.23 | 0.14 | 0.12 |
| Total costs | 0.69 | 0.96 | 0.69 | 0.69 |
| 3.5 Net profit or loss | 0.37 | (-)0.32 | 0.21 | 0.37 |
| 4. Investment cost, US$ | 588,000 | 416,000 | 609,000 | 618,000 |
| 4.1 Construction works | 313,000 | 162,500 | 334,000 | 343,000 |
| 4.2 Design and management services | 275,000 | 253,500 | 275,000 | 275,000 |
| 4.3 Foreign exchange component | 510,000 | 373,000 | 543,000 | 539,000 |
| 5. Internal Rate of Return | 35.05 | - | 20.9 % | 35.0 % |
| 6. Benefit Cost Ratio: | | | | |
| 6.1 At 8% discound rate | 4.8 | - | 2.7 | 4.8 |
| 6.2 At 12% | 3.5 | - | 1.9 | 3.5 |

TABLE 5

EFFECTS OF PA MONG FLOOD CONTROL ON FLOODING INUNDATION IN THE DELTA IN DEMOCRATIC KAMPUCHEA

| Land Unit | Total Area ($km^2$) | Year | Extent of Inundation (Ha-Months) | | Inundation Index 1/ | | Per Cent Reduction in Inundation |
|---|---|---|---|---|---|---|---|
| | | | Natural | W/Pa Mong | Natural | W/Pa Mong | |
| Muk Kompul Floodplain | 1,050 | 1961 | 3,490 | 2,890 | 3.52 | 2.75 | 17 |
| | | 1963 | 2,945 | 2,425 | 2.80 | 2.31 | 17 |
| Tonle Toch Terrace | 1,400 | 1961 | 2,580 | 1,745 | 1.84 | 1.25 | 32 |
| | | 1963 | 1,805 | 1,230 | 1.29 | 0.88 | 32 |
| Prey Venh Floodplain | 1,845 | 1961 | 5,655 | 4,450 | 3.07 | 2.41 | 21 |
| | | 1963 | 4,790 | 3,340 | 2.60 | 1.81 | 30 |
| Kandal Island | 1,325 | 1961 | 3,560 | 3,070 | 2.69 | 2.32 | 14 |
| | | 1963 | 3,150 | 2,315 | 2.38 | 1.75 | 26 |
| Takeo Depression | 2,700 | 1961 | 6,820 | 5,710 | 2.53 | 2.11 | 17 |
| | | 1963 | 5,530 | 4,010 | 2.07 | 1.49 | 28 |
| Great Lake Area | 18,050 | 1961 | 63,200 | 56,400 | 3.50 | 3.12 | 11 |
| | | 1963 | 55,200 | 48,750 | 3.06 | 2.70 | 12 |
| Total (excluding Great Lake Area) | 8,320 | 1961 | 22,105 | 17,865 | 2.66 | 2.15 | 19 |
| | | 1963 | 13,280 | 13,320 | 2.20 | 1.60 | 27 |
| Grand Total | 26,370 | 1961 | 85,305 | 74,265 | 3.23 | 2.82 | 13 |
| | | 1963 | 73,480 | 62,070 | 2.79 | 2.35 | 16 |

1/ Inundation Index = Extent of Inundation/Total Area.

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## FLOOD CONTROL

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# PA MONG ENVIRONMENTAL ASSESSMENT

## FLOOD CONTROL

## 1. Introduction

### 1.1 Problem of flooding in the lower basin

Each year the Mekong inundates several million hectares of arable land, for most of which there are no significant flood protection measures. Up to certain levels the effects of flooding are mainly beneficial, i.e., facilitating the cultivation of land, generating valuable fisheries in the inundated areas, deposition of alluvial silts, and doing little damage. Severe floods, however, cause heavy damage to crops and other properties, including considerable loss of life. Flooding is not confined to the lowland floodplains in Democratic Kampuchea and Viet-Nam, but strips of land on both sides of the Mekong in the Lao PDR and Thailand, are also flooded during the high floods that occur once every few years. Also, the tributaries spill over their banks, as in the case of Nam Mun and Nam Chi in the Khorat plateau. Flooding in tributaries also results from the backwater effects of tributaries unable to drain into the Mekong (Ref. 1, 3, 1).

A natural problem presented by the Mekong is thus the control of floods. The provision of flood control and protection by Pa Mong will not only alleviate flood damage, but will also facilitate the introduction of an irrigation system in the delta and thereby enhance agricultural production. The increased production will result in part from land not presently cultivated but which could be reclaimed after flood control measures have been established.

### 1.2 Hydrologic and economic data on flood damage

The hydrological data describing the magnitudes and characteristics of flood flows in the lower Mekong are substantial. The hydrometeorological data required to characterize storm patterns and behaviour are more limited than desirable for flood control and related studies. Generally the systematic measurement of the rate of flow in the mainstream and major tributaries was started in 1959, but the record of river stages at some stations goes back over half a century. It is thus possible to simulate the historical flow data from available historical stage records, using the stage-discharge relations found to exist between stage and river flow (Ref. 1). The available hydrological data cover the lowest flow years of record in 1957-1958, and the highest peak flow of record in 1966 for the upper reaches of the Mekong, where the Pa Mong dam is proposed to be located.

Economic data on flood damage needed for project benefit evaluation is inadequate in the lower Mekong basin. Collection of economic data in the past was prompted mainly by the need for relief at the time of each flood, and the flood damage estimates have seldom been made systematically so as to provide a historical series. However in the agricultural sector which has been subject to relatively heavy flood damage, some data are available. An organized effort at collecting economic data was made after the 1966 Mekong flood, for the flooded areas in northeastern Thailand and in the Lao PDR below Pa Mong. Flood estimates made by various governmental departments supplemented by small-scale field survey results led to fairly detailed assessment of damage in each riparian country (Ref. 1).

## 1.3 Modelling tools

For Pa Mong flood control regulation and benefit evaluation studies, the SSARR (Streamflow Synthesis and Reservoir Regulation) computer model for the lower Mekong basin and the Mekong delta mathematical model are the principal modelling tools used for simulation of flows in the Mekong river and water levels in the delta areas, respectively. The SSARR model is used primarily for simulation of regulated hydrographs at the various selected stations in the upper and middle reaches, and the Mekong delta model is used to determine the average water levels of the model meshes located within the Mekong delta. The basic input data for the SSARR model include daily rainfall and stream flow data, hydraulic characteristics of the selected river-channel reaches, and regulated flows from Pa Mong reservoir. The Mekong delta model consists of 293 meshes, each representing an area ranging from a few hectares to over 1,000 $km^2$. All meshes are characterised by distribution of terrain elevations within each mesh and by the hydraulic characteristics of its links with adjacent meshes. With these inputs, and given initial and boundary conditions, the water levels in all meshes can be calculated by computer. The IBM 360/40 computer in Bangkok and the CDC 3600 computer at the Asian Institute of Technology are used to run the programme.

The SSARR computer model and the Mekong delta mathematical model still represent on experimental programme, but have produced worthwhile data for Pa Mong flood control evaluation studies. These models will be continually improved over the years through improvements both in basic data inputs and in use of new technology. Details concerning these programmes are presented in References 11-19 and 26 and also in Section 4 of this discussion.

## 1.4 Flood control study programme

The flood control and related studies conducted by or for the Mekong Committee relating to the Pa Mong project are presented in References 1-24 and 26-33. The studies included:

(a) Collection, compilation and evaluation of basic data and information on flood characteristics and damage, floodplain areas, and existing flood control programmes and protective measures in the lower Mekong basin (Ref. 1-8 and 20-32).

(b) Flood frequency analysis and design flood studies for the Pa Mong project and related projects (Ref. 1, 6-8, 10 and 31-32).

(c) Flood control benefits evaluation studies for the Pa Mong projects and related projects (Ref. 1, 6-7, 20-24 and 31-32).

(d) Pa Mong flood regulation and downstream effects studies (Ref. 1, 6-9, 24 and 26-30).

(e) Flood forecasting and modelling studies for the lower Mekong basin and the Mekong delta (Ref. 11-19 and 26).

(f) Vang Vieng and Loei valleys flood protection studies (Ref. 31, 32).

It is believed that the effort made by the Mekong Committee in its flood control study programme is substantial and represents the most intense programme of preparation yet attempted at the feasibility stage of planning for any major water resource development project in developing countries.

## 2. Existing situation

### 2.1 Flood regime and flows

The hydrologic regime of the Mekong in the lower Mekong basin is remarkably regular. The river generally starts to rise in May following the onset of the wet season, and reaches its highest elevation in August or September for the upper reaches and in September or October for the lower reaches (as defined in Section 2.3). In addition to the major flood peak, there are usually several smaller peaks superimposed on the broad swell of the annual rise as the result of flooding in the headwaters or tributaries. The river stage afterward falls rapidly until December and then recedes slowly to reach its lowest elevation from March to May.

At the height of the flood season there is usually extensive flooding in the lowland floodplain in Democratic Kampuchea and Viet-Nam, including a large portion of the Mekong delta. Flash flooding in the tributaries generally takes place towards the end of the wet season, when the absorption capacity of the basin is low and heavy rainfall more frequent. Exceptional floods occurring every few years also cause extensive inundation of the floodplains along the upper and middle reaches, particularly the Vientiane and Nong Khai plains, as well as in the Mekong delta as shown in Figure 1.

Flood behaviour in the lower basin varies from one part to another depending on climatic factors and physiographic conditions. Areas subjected to flooding depend on topography and vary from year to year depending on the volume of overbank flow (Ref. 1). A tabulation of the highest floods of record up to 1975 for the lower Mekong is presented in Table 1.

As noted in Reference 1, when the Mekong flows into the lower basin at Chiang Saen, it brings about 90,000 mcm of water annually from the upper Mekong basin. Estimates based on records covering 54 years at Vientiane, indicate that the annual peak may be as high as about 26,000 $m^3$/sec (Ref. 1, 10, 21) in a flood year as in 1966, against 11,300 $m^3$/sec in a dry year as in 1957. In a normal year, an annual peak flow of the order of 17,100 $m^3$/sec is to be expected and is confined within banks. Annual peak floods at Vientiane for various return periods can be predicted as shown in Table 2. The adopted inflow design flood for Pa Mong reservoir has the following characteristics (Ref. 6, 7):

| Peak Discharge ($m^3$/sec) | Maximum 30-day Volume (million $m^3$) |
|---|---|
| 52,000 | 84,500 |

The magnitude of difference between the Mekong flows of the dry and wet seasons is indicated by the flow at Kratie in Democratic Kampuchea. There the average flood flow reaches 52,000 $m^3$/sec, compared to an annual average flow of 14,120 $m^3$/sec and an average low flow of 1,760 $m^3$/sec. The magnitude of the annual peak flow of the Mekong river, disregarding individual peaks, and annual runoff volume observed during 1960 to 1965 increased progressively downstream as far as Kratie and then decreased, as shown in Table 3.

From Chiang Saen to Kratie the Mekong receives yearly more than 300,000 million $m^3$ of water from 457,000 $km^2$ of catchment. Below Kratie the river overtops its banks when rising above 7 m MSL. Extensive overbank flooding takes place on both banks but on the western bank the flows escape towards Tonle Sap and the Great Lake. The Mekong main channel also adds its flow to the Great Lake through Tonle Sap during the rising flood, and the action is reversed during the later flood recession.

When the Mekong at Phnom Penh rises above approximately 15,000 $m^3$/sec, its flow not only runs into the lake, but also spills onto overflow channels towards the lowlands along the Bassac and the Mekong rivers. Some 20,000 million $m^3$ of overflow empties back into the main rivers (Mekong and Bassac) as return flow yearly. The river level rises gently at a rate of a few centimetres a day and the flood volume is spread over several months.

Between Chau Doc and Vam Cong the Bassac and the Mekong are connected by a channel (Vam Nao) through which about 40 per cent of the Mekong flow turns into the Bassac during the annual crest stage. This results in the smaller flow in the Bassac being equalized with that of the Mekong below the connecting point. The active crossover flow into the Bassac begins when the flow at Vam Cong rises above 12,500 $m^3$/sec and reaches its highest point when the river at Vam Cong is flowing at 20,000 $m^3$/sec. The overland flow also escapes easterly across the Plain of Reeds and drains into that area (Ref. 1).

## 2.2 Flood inundated areas

The approximate areas subjected to flooding by the 100-year flood for the various reaches of the river were estimated as shown in Figure 1 (Ref. 1, 5 and 22):

(a) Upper reaches: Pa Mong to the confluence of the Mekong and Nam Ca Dinh in the Lao PDR, 3,500 $km^2$.

(b) Middle reaches: Nam Ca Dinh to Kratie in Democratic Kampuchea, 650 $km^2$.

(c) Lower reaches: Lowland floodplain in Democratic Kampuchea and Viet-Nam, 70,000 $km^2$.

Inundation in the upper and middle reaches occurs usually at the lower reachs of tributary outlets, due to congestion of mainstem and tributary flows. Along the stretch between Vientiane and Nong Khai the river occupies extensive floodways, 10 km wide in Thailand and 3 to 6 km in the Lao PDR. The 1966 flood filled these floodways and swept downstream with an inundation depth varying from 1 to 4 m, flowing at a relatively slow velocity of about 0.1 to 0.3 $m^3$/sec. The total maximum overflow in the floodway was estimated at 4,700 $m^3$/sec against 21,300 $m^3$/sec moving in the river channel. The flood inundation area was more than 500 $km^2$. For the maximum probable flood, the area flooded might be nearly 700 $km^2$ (Ref. 1).

The ground surface elevation in the lowland floodplain in Democratic Kampuchea and Viet-Nam varies from 12 m at the extreme near Kompong Cham to about 2 m above mean sea level at Can Tho. The flood begins to rise in July, running through many openings in the natural levees, filling the depressions beyond, and gradually overtopping the banks. As the river level continues to rise, water flows into the Great Lake both through the Tonle Sap and overland, filling it at approximately the peak of the flood. While the Great Lake is filling, the flood continues to spread downstream, filling the large depressed area of the Plain of Reeds to the east and crossing the Trans-Bassac area towards the Gulf of Thailand in the west, with the main channels

continuing to carry the major portion of the flow into the South China Sea, the remainder being held in temporary storage. At the peak of the flood, the delta is a continuous body of water with occasional protrusions of isolated rock knolls. Towards the end of the flood season, in November, the flood water recedes to the main channel, first from the banks, then through openings of the natural levees and through many canals. The recession begins in the upper delta and continues south, flood water draining back into the river until the cycle is completed some time in January. Because of this regular pattern of flooding there have been remarkable adaptations or rice cultures within the delta. Figure 2 shows the floodplain areas in the lower reaches of the Mekong river, corresponding to the information presented in Table 4.

Based on the SOGREA mathematical model, which simulates the hydraulic conditions in the Mekong delta during flood seasons (Ref. 26), the inundated areas during the 1961 flood were estimated (Ref. 9) as shown in Table 5 based on the assumed condition of a constant minimum release of 2,000 $m^3$/sec from Pa Mong. A preliminary evaluation of the possible effects of Pa Mong on the flood regime of the Mekong delta was also made for the 1961 flood. The results of this study, as shown in Table 5, indicate the possible flood-relief areas were very significant in the delta in Democratic Kampuchea, and less significant or almost none in the Vietnamese delta (Ref. 9).

## 2.3 Existing flood control measures

From Reference 1 to 8, the existing flood control measures in the lower basin may be summarized as follows:

(a) Reservoirs: The small reservoirs built on the tributaries for irrigation and power provide protection to areas in their immediate vicinity. However, taken overall, the volume of tributary storage available to moderate floods is small in relation to the total runoff and has no appreciable effect on the flood peak in the mainstream. Substantial improvement in the moderation of floods cannot be effected without the construction of dikes and dams on the mainstem, such as those proposed for Pa Mong and Stung Treng, which will have considerable storage capacity.

(b) Embankments: At Vientiane a low dike, 40 km in length, protects an area of 16,000 ha; on the opposite side of the river two dikes, each 60 km long, constructed near Nong Khai and Nonpisai, protect 14,700 ha. An embankment 61 km long constructed on the right bank of the Nam Chi affords protection for 32,000 ha in the vicinity of Roi Et. The dikes of the Choesung Prey project near Kompong Cham safeguard

(b) a lowlying area of 50,000 ha situated some 20 km from the Mekong. Those of the An Truong project, on the edge of the flooded area north of Can Tho, likewise serve to minimize the destructive effects of flooding. In addition to these, many dikes along the coast prevent the intrusion of sea water.

(c) Natural levees and silt deposition: Silt is deposited mostly along the river banks, building up natural levees in the course of time. Silt is also carried into depressions at some distance from the river. In Democratic Kampuchea the deposition of silt in lowlying areas is enhanced in places by the construction of canals (colmatage) linking depressions with the nearest river channel. Canals constructed for this purpose are equipped with sluices to regulate the inflow of floodwaters. Silt-laden water is not normally allowed into the depressions until after the rice harvest. To aid the deposition of silt the natural levees bordering the main channels have been cut through at suitable places and the natural water courses breaching them have been widened and deepened. Such projects are in operation at Beng Khnor and Kiki Thom near Phnom Penh.

(d) Influence of Great Lake: Under natural conditions the Great Lake exerts a powerful influence on flow in the delta, absorbing a considerable portion of the flood runoff from the Mekong and from the land surrounding the lake. In a normal year the lake begins to rise in June and absorbs 56,000 million $m^3$ over a period of 100-120 days, of which 34,000 million $m^3$ comes from the drainage area of the lake and the rest from the Mekong river. During this period the water level rises on the average by 9 m and the surface area expands from 3,000 $km^2$ to about 10,150 $km^2$. From October to May, with the recession of the flood in the Mekong, the flow is reversed and the lake drains away through the delta channels.

(e) Drainage: The drainage of floodwaters from the delta is affected by numerous natural waterways connecting the Mekong and the Bassac and their tributaries, and by an extensive network of canals constructed mainly for navigation. The primary canals of the network (ranging from 12 to 60 m in width) have a total length of 1,579 km; secondary canals (8 to 18 m in width) total 480 km. Smaller canals, spaced at intervals of about one kilometre, are linked with the primary and secondary canals and natural waterways. Numerous canals and waterways comprise the network and they have cross-sections adequate for navigation, but the general flatness of the delta makes it

difficult to dispose of surplus floodwater, hence further measures are needed to improve drainage. These must be taken into account along with measures to reduce the volume of flood spillage by diking and storage (Ref. 1).

## 2.4 Flood damage

The Mekong overflows its banks and inundates to varying degrees areas in the riverine and lowland floodplains, jeopardizing the health and lives of people, causing losses of livestock and considerable damage to property, and imposing restrictions on economic activity generally. Types of property destroyed or damaged include standing crops, especially paddy, housing, industrial and business premises, and public works, particularly highways and bridges.

As stated in the Indicative Basin Plan (Ref. 1) the Mekong in an extreme year is capable of flooding some 50,000 $km^2$ of land, mostly in the delta, and of causing property damage averaging more than $25 million/year. The 1966 flood in the Vientiane and Nong Khai plains caused property damage amounting to an estimated $22 million in that area, and property damage downstream in the delta lowlands was estimated at an additional $31 million. The effect of annual flooding on agricultural production is believed to be even more significant than property damage in the lowlands. Average annual property damages were estimated to be $3.8 million for the upper reaches (Ref. 6, 22) and $21 million for the lower reaches (Ref. 1). So far, there is no estimation on average annual property damage in the middle reaches, which is believed to be comparatively small.

## 3. Probable effects of Pa Mong flood control

Environmental considerations relative to provision of flood control at Pa Mong include the following (Ref. 25):

(a) Modification of streamflow characteristics particularly in altering the hydrographs at times of flood.

(b) Reduction in flood stages and resultant damage reduction.

(c) Inducement of erosion resulting from keeping streams near bankful stage during release of flood storage from reservoirs.

(d) Effect of modified streamflow characteristics on downstream environmental values, such as aquatic and fishery resources, land use, agriculture and water-based recreation, etc.

The discussions to be presented in this discussion, however, will be limited primarily to Item (b), because discussions of Items (a), (c), and (d) are included in the other portions of this report.

## 3.1 Summary of environmental impacts

Pa Mong reservoir at HWL 250 m MSL would have a total effective storage of about 80,600 million $m^3$, of which 21,000 million $m^3$ would be available for flood control, without reducing the firm power output (Ref. 1). This provision for flood control is equivalent to about 70 mm of runoff for the total drainage area above Pa Mong damsite (Ref. 3, 7). As shown in Figures 3-4 and Tables 8-9, the control exercised by Pa Mong would reduce the highest flood peak of record (1939-1970) at Vientiane from about 26,000 $m^3$/sec down to 13,000 $m^3$/sec, enough to keep the flow of Mekong within its banks from below Pa Mong damsite to Pakse and at the same time materially reduce the flood flow in the Mekong delta, particularly in Democratic Kampuchea. For the 100-year flood, Pa Mong reservoir regulation would reduce the flood peak at Vientiane from 26,000 to 15,600 $m^3$/sec, and reduce the flood depth to some extent in the Mekong delta (as indicated in Table 7). There would possibly be some damage in the upper and middle reaches from floods of magnitudes occurring at frequencies of about or larger than 100 years, due to the combined effects of regulated flow and flows from tributaries. With respect to the delta in Democratic Kampuchea, the overall effects of Pa Mong flood control would probably reduce the depth of flood and flooded area to a significant extent as shown in Tables 5 and 10 (Ref. 9).

Flood control storage provided in Pa Mong reservoir is expected to control potential flood water runoff from an area of 305,500 $km^2$ (Ref. 3, 7). It is estimated that flood protection would be provided in varying degrees to downstream floodplain areas, approximately 3,500 $km^2$ in the upper reaches, 650 $km^2$ in the middle reaches, and 70,000 $km^2$ in the lower reaches. Release resulting from normal operation of the reservoir would produce a more sustained and uniform flow of water downstream from Pa Mong. The effect of storage releases for power would have significant effects on river stages and flow volumes all the way to the delta during the dry season (Ref. 7). The augmentation of dry season flow from Pa Mong together with the tidal sluices and embankments will help to push back saline water intrusion in the delta, facilitating both agriculture and the use of water for domestic consumption (Ref. 1, 8).

Probable downstream impacts of Pa Mong flood control include reduction of damage and loss of life from floods, prevention of loss of fertile top-soil in floodplain areas, more effective use of lands along riverine floodplains and lowland floodplains, and provision of water for low flow

augmentation. These probable environmental effects are expected to be greater for the areas close to the damsite and gradually diminished towards the downstream areas. The anticipated effects therefore will probably be greatest in the upper reaches and minimal in the lower reaches and very little in the Mekong delta.

Based on limited study and field investigation of the 1966 flood and other available data, the preliminary estimated annual benefits expected to result from flood control of Pa Mong amount to $7.2 million in the upper reaches, $0.9 million in the middle reaches, and $3.5 million in the lower reaches (Ref. 1, 6), as shown in Table 6. These include benefits attributable to the reduction of actual flood damage and those attributable to more intensive use of land freed from flood hazards. Average annual benefits which will result from flood storage and regulation of water in Pa Mong reservoir are estimated to be $11.6 and $13.2 millions for 50- and 100-year period of analysis, respectively (Ref. 6). These are preliminary estimates and subject to modification as more data become available, particularly for the lower reaches where flood damage data are still extremely scare (Ref. 28).

The probable adverse environmental impacts of providing flood retention storage for Pa Mong include inundation of additional lands by Pa Mong reservoir and inducement of increasing potential of loss from occasional floods that exceed the design flood in downstream floodplains, mainly due to expanded investment in flood-prone areas. However the studies to date do not provide sufficient data and information to permit a more detailed assessment of these possible adverse environmental effects.

A preliminary qualitative assessment has been attempted of the extent of both detrimental and beneficial effects of Pa Mong flood control, based on the available information given in References 1 to 35. A summary of this assessment is presented in Table 11, which shows the net environmental effects are much more beneficial than detrimental.

## 3.2 Effect of different pool levels

With respect to different pool levels at Pa Mong reservoir, the probable environmental effects, particularly concerning flood damage reduction in downstream floodplains, will of course be greater for higher full pool levels, although the effects of a similar nature would be expected for the four alternative pool levels selected. The evaluation studies on Pa Mong flood control benefits, to date, have been performed largely for FWL 250 m MSL, and to a much lesser extent for the other three alternatives. Therefore it is not now possible to estimate the net differences in quantitative terms or in a more precise manner than those presented in Table 11.

## 4. Flood forecasting and warning

In 1968 it was recognized that the resources developed by the Mekong Committee in its hydrologic and meteorologic data programme, including expertise in meteorology, hydrology, and computer technology, furnished the basis for establishing a basinwide system of flood forecasting which could be of great value in providing the riparian governments with a reliable system of flood warning along the Mekong. The initial forecasting programme was carried out during the 1970 Mekong flood season on a trial basis, by applying the SSARR (Streamflow Synthesis and Reservoir Regulation) computer model developed for forecasting operations on the Columbia river in the USA. The 1970 results were sufficiently reliable to establish the programme as a regular contribution, with continuing refinement each year. Provision is made for expert consulting assistance from the U.S. National Weather Service and Corps of Engineers, including annual evaluations of the programme's reliability and effectiveness, and for training of Mekong Committee staff and of riparian country technicians.

In brief the programme creates a mathematical model of the river system wherein the drainage basin is separated into eleven homogenous hydrologic units, and the outflow from each of the subbasins computed from rainfall. The subbasin outflow is added to the mainstream flow, routed through the channel to the next key downstream point and combined with the outflow from the next subbasin. For key stations in the delta, the forecast is manually computed from the correlation of upstream hydrographs, local rainfall, and tidal cycles. Details of the programme are given in References 17, 18, 19, 20.

The present system makes daily predictions for the periods of one of five days in advance using information received from 17 hydrologic stations and 29 rainfall stations (including 5 on the left bank), for 13 key locations on the mainstream from Chiang Saen in northern Thailand to Tan Chau and Chan Doc in the delta. These 29 rainfall stations are generally located on the plain areas or in the valley, and mostly in the Nam Mun basin in Thailand, not in the critical subbasins. In addition, APT (automatic picture transmission) mosaics from weather satellites are used in basin rainfall estimates, to supplement the paucity of available rain gauge data from the left bank zone. The forecasts are made over the period of high water (from mid-June to late October) and are disseminated daily by telephone and radio to the four National Mekong Committees each working day and also on holidays during critical periods of high flows. The IBM 360/40 and CDC 3100 computer in Bangkok is used to run the programme.

Thus far the flood forecasting has been satisfactory in the upper portion of the river, from Chiang Saen to Pakse, where the availability of data permits both making and checking

the predictions. A further improvement in the forecasting programme is planned through installation of a telemetering system for the subbasin between Chiang Saen and Luang Prabang. Assuming the tele-automatic rain-gauge now being tested is successful, a number of these gauges will be installed in this subbasin area.

The entire forecasting programme is, of course, an experimental programme, but has produced meaningful worthwhile data and will be continually improved over the years through improvements both in basic data inputs (including obtaining rainfall data from China and Burma) and in use of new technology (including applications of the extended SSARR or LSSARR model to delta areas influenced by tides).

## 5. Flood protection schemes

### 5.1 Vang Vieng protection

The proposed Pa Mong reservoir at HWL 250 m MSL would inundate some 3,700 ha of agricultural area and 1,800 ha of other lands in the Vang Vieng valley of the Lao PDR, including Vang Vieng town. A study for evaluating possibilities for preventing flooding of the valley and diverting its drainage into Nam Ngum reservoir was sponsored by the Mekong Committee in 1974 (Ref. 32). The scope of work was limited essentially to a study of engineering measures, designs, and cost estimates for protection schemes with Pa Mong at HWL 230, 240, 250, and 260 m MSL. The completed report (Ref. 30) is of prefeasibility grade.

For each of the assumed dam heights of Pa Mong, the proposed protection scheme will consist of a protection dam and as many as seven reservoir rim dikes for excluding the valley from Pa Mong reservoir, a diversion channel for diverting the valley drainage to Nam Ngum reservoir, and an enlargement of the existing Nam Ngum spillway capacity. The recommended protection dam is a homogeneous earth dam across the Nam Song stream, with a riprap face on the Pa Mong reservoir side and a rockfill toe on the other side. Excavation of the diversion canal is expected to provide enough materials to favour construction of an earth dam. The diversion canal will be a riprap channel about 7 km long and the bottom width would be either 46 or 52 m. Along both sides of the channel, 26 side drain structures are included in the design. Diversion of Nam Song flow to Nam Ngum reservoir would require an enlargement of the Nam Ngum spillway by 16 m to keep the maximum water level in the reservoir down to its design flood surcharge level of 214.5 m MSL. Also, an additional separate spillway would be added to Nam Ngum dam at the right bank, which would cost about $5.2 million.

The recommended protection scheme would cost between $34 to $48.7 million, depending on the height of Pa Mong dam and whether a design for the 100- or 200-year flood is selected. The spillway construction cost of $5.2 million is not included in these estimates.

## 5.2 Loei valley protection

Pa Mong at HWL 250 m MSL would inundate about 4,500 ha of residential and business land, 55,000 ha of agricultural area, and 135,000 ha of other lands in the Loei valley of Thailand. A pre-feasibility grade study for evaluating possibilities for preventing flooding of the valley and diverting its drainage into Pa Mong reservoir was completed in 1975 (Ref. 32).

Two plans are proposed for protecting flooding of the valley when Pa Mong reservoir is filled at the high pool levels of 240, 250 and 260 m MSL, for both the 100- and 200-year floods. Plan I, recommended for Pa Mong HWL 250 and 260 m MSL, will consist of a dam (and reservoir) near the mouth of Loei river, equipped with a pumping plant to lift the flood waters into Pa Mong reservoir, and seven other dams (and reservoirs) situated on the upper portion of Loei river and on the tributaries. Plan II, recommended for Pa Mong HWL 240 m MSL, will comprise a dam on the Loei river downstream from the town of Loei river upstream from Loei, a bypass canal for diverting the floods from the upper basin into Pa Mong reservoir, a side drainage canal parallel to the bypass canal to collect side flows, and a pumping plant to control the floods of Loei and two reservoirs on the tributary basins to retard the floods for the pumping plant and side drainage canal.

Plan I could prevent flooding of areas covering some 490 and 900 $km^2$ and protect some 9,500 and 12,000 families (estimated for 1974) from inundation by Pa Mong reservoir at HWL 250 and 260 m MSL, respectively. Plan II for Pa Mong HWL 240 m MSL would prevent flooding of an area of about 20 $km^2$ and protect about 2,800 families inside Loei from flooding by Pa Mong. These two flood protection plans would affect some land areas and communities in other parts of the basin by construction of the flood protection components.

The total estimated costs of the flood protection plans for the 100- and 200-year floods are respectively $103 and $108 million for Plan II for Pa Mong 240 m MSL; $251 and $285 million for Plan I for Pa Mong 250 m MSL; and $310 and $347 million for Plan I Pa Mong HWL 260 m MSL. The estimated costs would include construction, relocation and resettlement, and operation, maintenance, replacement, and administration. Also, four potential irrigation development projects were found to be economically attractive for inclusion into the flood protection plans with benefit-cost ratios greater than unity.

The plans formulated for preventing flooding of Loei valley were found to be technically feasible for all high pool levels under consideration for Pa Mong reservoir. It was noted during the field investigations that the social-economic development of the Loei valley is relatively high compared with other rural areas in the northeast Thailand (Ref. 32).

6. Summary and conclusion

As previously noted, the effort made by the Mekong Committee in its Pa Mong flood control study programme is substantial. In the Pa Mong optimization and downstream effects study, the Mekong Committee is conducting a number of additional investigations on various aspects of Pa Mong flood control (Ref. 27-32). These include flood regulation, flood control benefit evaluation, and low flow regulation. The overall complex of studies (Ref. 1 through 35) conducted by or for the Mekong Committee, to date, are sufficient to permit a general assessment of the environmental impact of flood regulation by the Pa Mong project.

A preliminary qualitative assessment has been attempted of the extent of both detrimental and beneficial effects of Pa Mong flood control, with results as shown in Table 11, which indicates the net environmental effect is much more beneficial than detrimental. These environmental effects are greater for the areas close to the damsite and gradually diminish towards the downstream areas. The anticipated effects therefore will be greatest in the upper reaches and minimal in the lower reaches and very little in the Mekong delta. The probable environmental effects will be greater for higher full pool levels, although the effects of a similar nature would be anticipated for all alternative pool levels.

Additional studies will be required to complete the picture of flood control effects of Pa Mong. Some specific suggestions for additional studies are as follows:

(a) An additional flood regulation study should be performed for the design flood in order to examine the degree of flood reduction. It is recognized that certain assumptions and criteria must be set up before this study can be started.

(b) The Pa Mong flood control benefit evaluation study is required for updating the previous findings in order to obtain more precise estimates. This study should include selection of appropriate concepts and procedures for evaluation of flood control benefits in the various river reaches, survey and collection of pertinent economic and geomorphologic data of

(b) floodplains, derivation of flood damage-frequency relations, and evaluation of flood control benefits.

(c) Proper determination of the design flood is of the utmost importance for flood control projects, as this affects both the safety and cost of the structures, as well as the extent of their effects. Estimation of the inflow design flood for the Pa Mong project has been based on limited data (Ref. 6, 7). Additional study is needed to derive or to improve the accuracy of design floods for the Pa Mong project and other related projects (Ref. 31, 32). This study should include detailed investigation of floods and related hydrometeorological factors and development of procedures for estimating design floods of ungaged watersheds located within the lower basin.

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TABLE 1

HIGHEST FLOODS OF THE MEKONG

(From Reference 15)

| Station | Period of Record | Day of Peak | Water Stage Elevation (m MSL) | Peak Discharge ($m^3$/sec) |
|---|---|---|---|---|
| Chiang Saen | 1961-72 | 3 Sept. 66 | 371.13 | 23,500 |
| Luang Prabang | 1950-72 | 2 Sept. 66 | 289.58 | 25,200 |
| Vientiane | 1913-72 | 4 Sept. 66 | 170.75 | 26,000 |
| Mukdahan | 1924-72 | 15 Sept. 66 | 137.75 | 36,200 |
| Pakse | 1924-72 | 31 Aug. 39 | 99.86 | 46,200 |
| Stung Treng | 1924-72 | 2 Sept. 39 | 48.79 | 65,700 |
| Kratie | 1924-72 | 3 Sept. 39 | 21.92 | 66,700 |

TABLE 2

ANNUAL PEAK FLOODS AT VIENTIANE

(From Reference 1)

| Return Period (years) | Magnitude ($m^3$/sec) | Water Stage (m MSL) |
|---|---|---|
| 1,000 | 32,000 | 171.90 |
| 100 | 26,600 | 171.15 |
| 50 | 25,000 | 170.75 |
| 25 | 23,200 | 170.62 |
| 10 | 21,000 | 170.16 |
| 5 | 19.300 | 169.72 |
| Mean Maximum | 17,100 | 169.08 |

TABLE 3

MEKONG ANNUAL PEAK FLOWS (1961 to 1973)

| Station | Distance from Outlet (km) | Drainage Area above Station | Annual Peak Flow ($m^3$/sec) | Annual Runoff ($10^6$ $m^3$) |
|---|---|---|---|---|
| Chiang Saen | 2,370 | 189,000 | 12,100 | 92,020 |
| Luang Prabang | 2,010 | 268,000 | 17,030 | 133,610 |
| Vientiane | 1,584 | 299,000 | 17,330 | 149,350 |
| Thakhek | 1,261 | 373,000 | 26,630 | 241,560 |
| Mukdahan | 1,125 | 391,000 | 29,020 | 257,650 |
| Pakse | 869 | 545,000 | 36,460 | 302,190 |
| Stung Treng | 668 | 635,000 | 51,320 | 422,470 |
| Kratie | 545 | 646,000 | 52,100 | 433,160 |
| Phnom Penh | 322 | 663,000 | 44,430 1/ | 410,790 1/ |
| Phnom Penh | 332 | 663,000 | 50,000 2/ | 512,000 2/ |
| Outlet Mekong + Bassac | 0 | 744,000 | 44,000 2/ | 550,000 2/ |

1/ Channel flow only.

2/ Channel flow plus estimated spill (derived from Reference 1).

TABLE 4

LOWLAND FLOODPLAIN AREAS SUBJECT TO INUNDATION

(From Reference 1)

| | | (1,000 ha) | |
|---|---|---|---|
| 1. | Total area of lowland floodplain (for the 100-year flood) | 7,388 | |
| 2. | Area not subject to annual flooding in Vietnamese delta | 2,028 | |
| 3. | Area subject to annual floods | 5,360 | |
| | (A) Lake and river perennially under water | 404 | |
| | (B) Land area flooded during high water | 4,956 | |
| | (1) Lands not presently cultivated for various reasons (including deeply flooded condition, high-velocity water moving over land, and toxic soil) | 1,912 | |
| | | Gross Area | Estimated Net Area[a/] |
| | (2) Cultivated land | 3,044 | 2,132 |
| | (a) Floating rice area | 920 | 728 |
| | (b) Double-transplant area | 452 | 300 |
| | (c) Single-transplant area | 1,176 | 800 |
| | (d) Other cultivated area | 496 | 304 |

a/ Net area after deduction of roads, house areas, etc.

TABLE 5

ESTIMATED INUNDATION IN 1961 FLOOD BASED ON SOGREAH MODEL

(From Reference 9)

| Region | Total Area (1,000 ha) | Inundated Area (1,000 ha) | | Difference (1,000 ha) |
|---|---|---|---|---|
| | | Without Pa Mong | With Pa Mong | |
| Quadrilatere de I'Ouest | 453 | 422 | 416 | 6 |
| Cis Bassac Viet-Namien | 422.5 | 418 | 414 | 4 |
| Plaine des Jonc | 852 | 770 | 725 | 45 |
| Trans Bassac Khmer | 462 | 375 | 322 | 53 |
| Left bank of Mekong | 601 | 493 | 346 | 147 |
| Grand Lac | 1,728 | 1,603 | 1,419 | 184 |
| Mekong upstream | 26.5 | 25.6 | 25.1 | 0.5 |
| Vaico upstream | 118.4 | 7.6 | 7.3 | 0.3 |
| Mekong V.N. | 42.6 | 42.6 | 42.6 | 0 |
| Bassac V.N. | 8.4 | 8.4 | 8.4 | 0 |
| Vaico downstream | 4.2 | 4.2 | 4.2 | 0 |
| Total | 4,718.2 | 4,168.4 | 3,726.6 | 439.9 |

Remarks: 1. The 1961 flood is designated a 10-year event (for the delta in Democratic Kampuchea).

2. Pa Mong is operated only for flood control with constant release of 2,000 $m^3$/sec throughout the flood season.

TABLE 6

AVERAGE ANNUAL EQUIVALENT FLOOD CONTROL BENEFITS, PA MONG, FOR 50- AND 100-YEAR PERIODS OF ANALYSIS

(From Reference 6)

| Period of Analysis | Area (Reaches) | Prevention of Flood Damage (US$) | Type of Benefit: Increased Utilization of Property Freed from Flood Hazards: Development of New Crop Lands (US$) | More Intensive Farming (US$) | Urban Enhancement (US$) | Subtotal (US$) | Total (US$) |
|---|---|---|---|---|---|---|---|
| 50-year period | Upper reaches | 3,539,000 | 1,113,000 | 1,725,000 | 859,000 | 3,697,000 | 7,236,000 |
| | No.1* | (2,315,000) | (628,000) | (1,341,000) | (807,000) | (2,776,000) | (5,091,000) |
| | No.2* | (1,224,000) | (485,000) | ( 384,000) | ( 52,000) | ( 920,000) | (2,145,000) |
| | Middle reaches | - | - | - | - | - | 875,000 |
| | Lower reaches (delta) | - | - | - | - | - | 3,500,000 |
| Total | | | | | | | 11,611,000 |
| 100-year period | Upper reaches | 4,419,000 | 1,231,000 | 2,113,000 | 920,000 | 4,264,000 | 8,683,000 |
| | No.1* | (2,854,000) | (696,000) | (1,642,000) | (864,000) | (3,202,000) | (6,056,000) |
| | No.2* | (1,565,000) | (535,000) | ( 471,000) | ( 56,000) | (1,062,000) | (2,627,000) |
| | Middle reaches | - | - | - | - | - | 1,050,000 |
| | Lower reaches (delta) | - | - | - | - | - | 13,233,000 |

* The area of upper reaches was further divided for study purposes into subreaches 1 and 2 (Ref. 6).

The damage value estimates were based on 1969 prices and rates.

TABLE 7

SUMMARY OF THE 100-YEAR FLOOD REGULATION STUDY

(From Reference 22)

| Locations | Unregulated Flood Stage (m) | Regulated Flood Stage (m) | |
|---|---|---|---|
| | | Pa Mong (21,000 million $m^3$) | Pa Mong & Stung Treng (70,000 million $m^3$) |
| Kompong Cham | 16.1 | 15.0 (1.1) | 13.3 (2.8) |
| Phnom Penh | 11.2 | 10.5 (0.7) | 9.8 (1.4) |
| Tan Chau | 5.5 | 5.0 (0.5) | 4.5 (1.0) |
| Sadec | 2.4 | 2.0 (0.4) | 1.8 (0.6) |

Remark: Values in parenthesis are the river stage reduction in m.

TABLE 8

MAXIMUM REGULATED PEAK DISCHARGES AT KEY DOWNSTREAM STATIONS

(From Reference 29)

| No. | Project | HWL/LWL (m) | Maximum Controlled Discharge ($m^3$/sec) | | | |
|---|---|---|---|---|---|---|
| | | | Vientiane | Bungkan | Stung Treng | Kratie |
| 1 | Pa Mong | 260/235 | 13,000 1/ | 18,000 2/ | 58,398 3/ | 62,[illegible] |
| 2 | " | 250/220 | 13,000 | 18,000 | | 63,[illegible] |
| 3 | " | 240/210 | 13,000 | 21,095 5/ | 60,331 3/ | 64,[illegible] |
| 4 | " | 230/205 | 17,000 | 23,849 5/ | 62,811 3/ | 66,[illegible] |
| 5 | Stung Treng | 68/81 | | | 44,000 | 50,[illegible] |
| 6 | Sanbor | 42/38 | | | | 60,000 |
| 7 | " | 42/40 | | | | 61,[illegible] |

1/ Bankfull flow at Vientiane is 17,000 $m^3$/sec. Highest peak daily recorded flow of the 1936–1970 period was 25,900 $m^3$/sec.

2/ Bankful flow at Bungkan is 18,000 $m^3$/sec. Highest peak daily recorded flow of the 1936–1970 period was 27,837 $m^3$/sec.

3/ The figures represent the highest routed flow from Pa Mong combined with the local inflows. The bankful flow at Stung Treng was assumed as 40,000 $m^3$/sec. Highest peak daily recorded flow of the 1963–1969 period was 63,237 $m^3$/sec.

4/ Same remarks as in 3/. The bankful flow at Kratie was assumed as 44,000 $m^3$/sec. The highest peak daily recorded flow was 66,700 $m^3$/sec.

5/ Highest peak daily discharge obtained by routed flow from Pa Mong combined with local inflow.

TABLE 9

MAXIMUM REGULATED PEAK DAILY DISCHARGES AT KEY DOWNSTREAM STATIONS

(From Reference 29)

| No. | Alternative Systems | HWL/LWL (m) | Maximum Controlled Discharge ($m^3$/sec) | | | | Remarks |
|---|---|---|---|---|---|---|---|
| | | | Vientiane | Bunakan | Stung Treng | Kratie | |
| 1 | Pa Mong + Stung Treng | 250/220 98/81 | 13,000 1/ | 18,000 2/ | 36,000 | 41,515 4/ | Tests with 35 flood years completed 6/ |
| 2 | Pa Mong + Sambor | 250/220 42/40 | 13,000 | 18,000 | 56,105 3/ | 54,000 | " |
| 3 | Pa Mong + Stung Treng + Sambor | 250/220 88/81 42/38 | 13,000 | 18,000 | 36,000 | 38,000 | " |
| 4 | Pa Mong + Stung Treng | 240/210 98/81 | 13,000 | 18,000 | 38,000 | 42,330 4/ | " |
| 5 | Pa Mong + Sambor | 240/210 42/40 | 13,000 | 18,000 | 59,231 3/ | 57,000 | " |
| 6 | Pa Mong + Stung Treng + Sambor | 240/210 88/81 42/38 | 13,000 | 18,000 | 38,000 | 40,000 | |
| 7 | Pa Mong + Stung Treng | 230/205 88/81 | 17,000 1/ | 23,180 5/ | 41,000 | 46,615 4/ | Tests with 35 flood years completed |
| 8 | Pa Mong + Sambor | 230/205 42/40 | 17,000 | 23,180 5/ | 64,152 3/ | 61,000 | " |
| 9 | Pa Mong + Stung Treng + Sambor | 230/205 88/81 42/38 | 17,000 | 23,180 5/ | 42,000 | 44,000 | " |
| 10 | Pa Mong + Stung Treng + Sambor | 260/235 88/81 42/38 | 13,000 | 18,000 | 38,000 | 40,000 | |
| 11 | Stung Treng + Sambor | 98/81 42/38 | | | 44,000 | 46,000 | Tests with 35 flood years completed |

6/ Flood year spans from 1 July to the end of October of a calendar year, as defined in Progress Report of Pa Mong Downstream Effects (MKG/R.19 Rev.1, Appendix A) (Ref. 27).

(Other footnotes are the same as in Table 8)

TABLE 10

AVERAGE AREA FREED FROM INUNDATION IN THE DELTA IN DEMOCRATIC KAMPUCHEA BY FA HONG

(From Reference 9)

| Land Unit | Total Area ($km^2$) | Year Analyzed | Flood-Frequency (year) | Area Freed From Inundation ($km^2$) |
|---|---|---|---|---|
| I. Tonle Sap Flood Plain | 18,050 (4,350)* | 1957 | less than 1 | 950 |
| | | 1963 | 2 | 1,970 |
| | | 1961 | 10 | 1,950 |
| | | 1940 | 15 | 1,680 |
| II. Muk Kompul Flood Plain | 1,060 | 1957 | less than 1 | 80 |
| | | 1963 | 2 | 160 |
| | | 1961 | 10 | 60 |
| | | 1940 | 15 | 40 |
| III. Tonle Toch Terrace | 1,440 | 1957 | less than 1 | 90 |
| | | 1963 | 2 | 260 |
| | | 1961 | 10 | 270 |
| | | 1940 | 15 | 260 |
| IV. Prey Venh Flood Plain | 1,850 | 1957 | less than 1 | 120 |
| | | 1963 | 2 | 300 |
| | | 1961 | 10 | 310 |
| | | 1940 | 15 | 130 |
| V. Plain of Reeds (Democratic Kampuchea) | 570 | 1957 | less than 1 | 110 |
| | | 1963 | 2 | 140 |
| | | 1961 | 10 | 30 |
| | | 1940 | 15 | 10 |
| VI. Kandal Island | 1,330 | 1957 | less than 1 | 150 |
| | | 1963 | 2 | 240 |
| | | 1961 | 10 | 120 |
| | | 1940 | 15 | 80 |
| VII. Takeo | 2,700 | 1957 | less than 1 | 150 |
| | | 1963 | 2 | 350 |
| | | 1961 | 10 | 510 |
| | | 1940 | 15 | 400 |
| Total Area | 27,000 | | | |

* Excluding Great Lake area (Mesh # 283 of Mekong Delta Mathematical Model).

TABLE 11

SUMMARY OF ASSESSMENT OF EFFECTS OF PA MONG FLOOD CONTROL

(Pa Mong Project as Isolated Unit)

| Considered Elements | Pa Mong Full Pool Elevation (m M.L) | Areas of Interest | | | | |
|---|---|---|---|---|---|---|
| | | Reservoir Vicinity | Pa Mong Service Area | Downstream Floodplains | | |
| | | | | Upper Reach | Middle Reach | Lower Reach |
| Flood damage reduction | 230 | -1 | 0 | +2 | +1 | 0 |
| | 240 | -1 | 0 | +3 | +1 | 0 |
| | 250 | -2 | 0 | +4 | +3 | +1 |
| | 260 | -2 | 0 | +4 | +3 | +1 |
| Modification of streamflow characteristics in term of decreasing flood flows | 230 | • | 0 | +3 | +2 | 0 |
| | 240 | • | 0 | +3 | +2 | 0 |
| | 250 | • | 0 | +4 | +3 | +1 |
| | 260 | • | 0 | +4 | +3 | +1 |
| Modification of streamflow characteristics in term of increasing dry season flow | 230 | • | 0 | +3 | +2 | +1 |
| | 240 | • | 0 | +3 | +2 | +1 |
| | 250 | • | 0 | +4 | +3 | +2 |
| | 260 | • | 0 | +4 | +3 | +2 |

Notes: 0 : insignificant or no effect
1 : limited extent of effect
2 : significant effect
3 : Moderated significant effect
4 : very significant effect
• : no estimation
+ : beneficial
- : detrimental

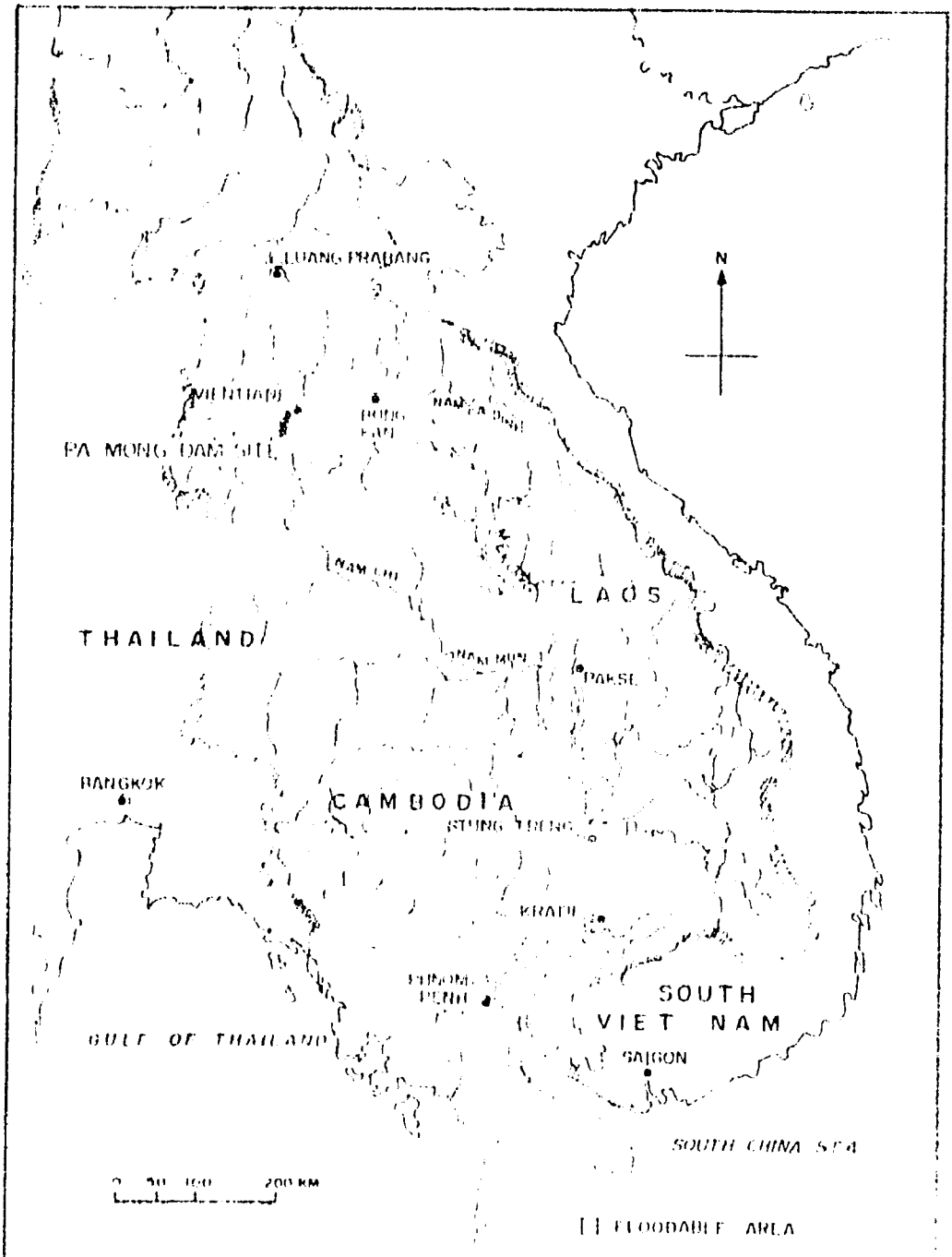


FIGURE 1

MEKONG FLOOD ZONES DOWNSTREAM OF PAN MONG CORRESPONDING APPROXIMATELY TO 100 YR. FLOOD

(From Reference 22)

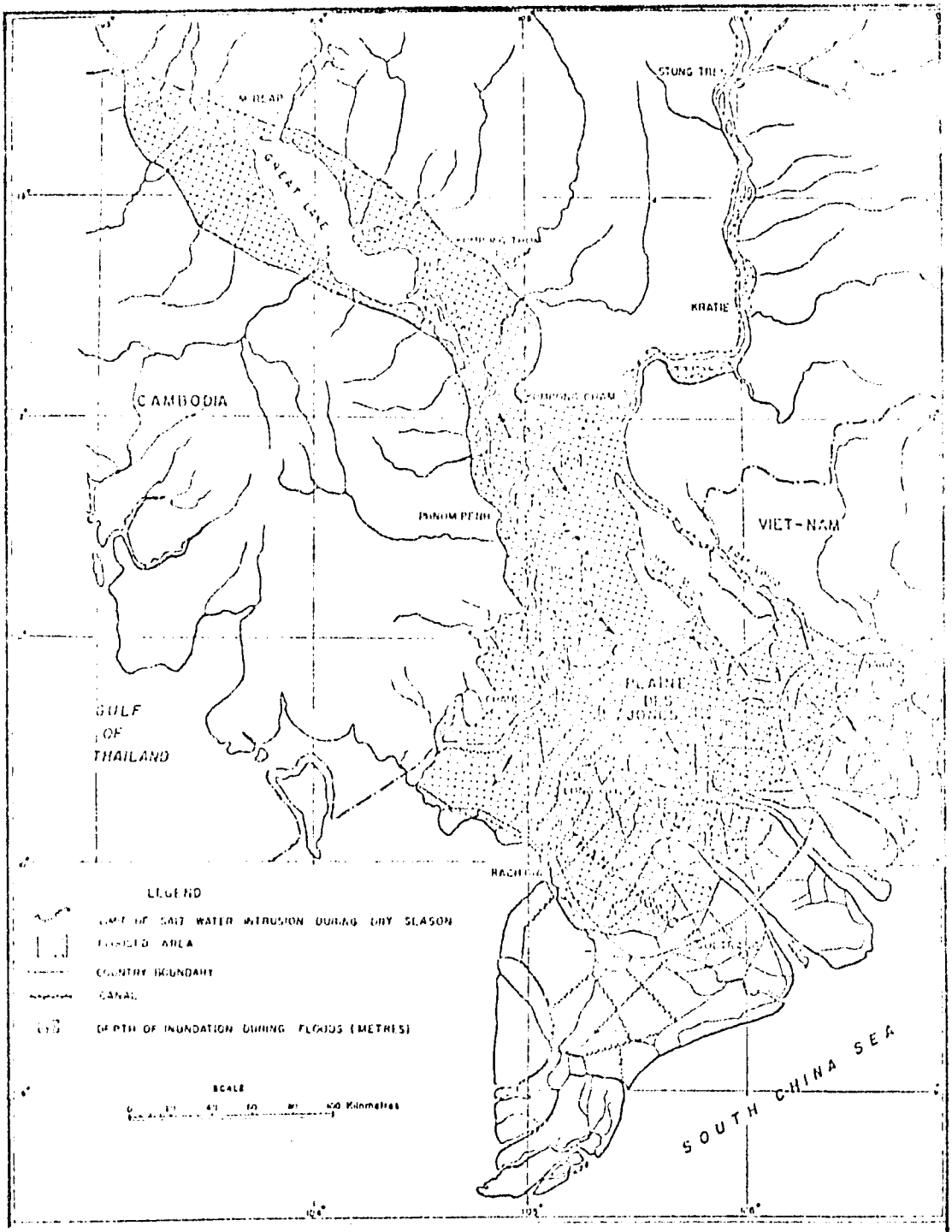


FIGURE 2

FLOODPLAIN AREAS IN LOWER REACHES OF MEKONG RIVER

( From Reference 4 )

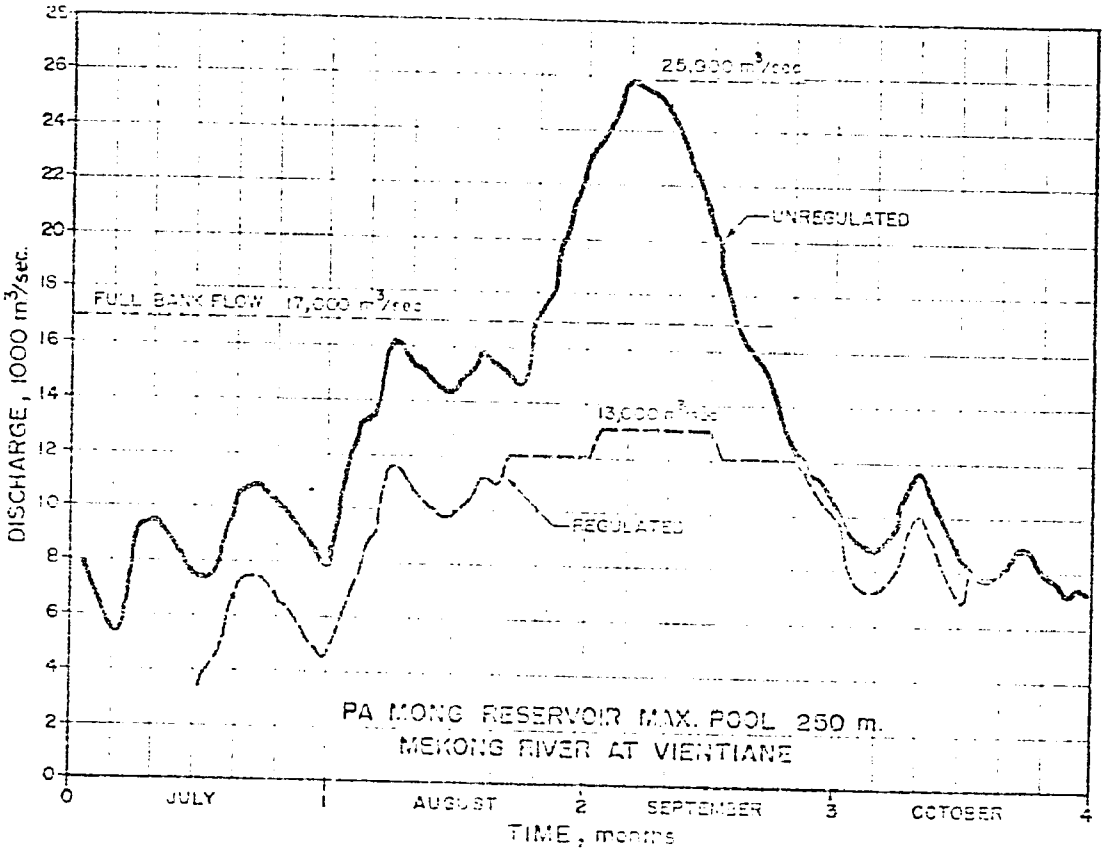


FIGURE 3 A

COMPARISION OF REGULATED AND UNREGULATED HYDROGRAPHS OF 1966 FLOOD FOR MEKONG RIVER AT SELECTED STATIONS

( From Reference 27 )

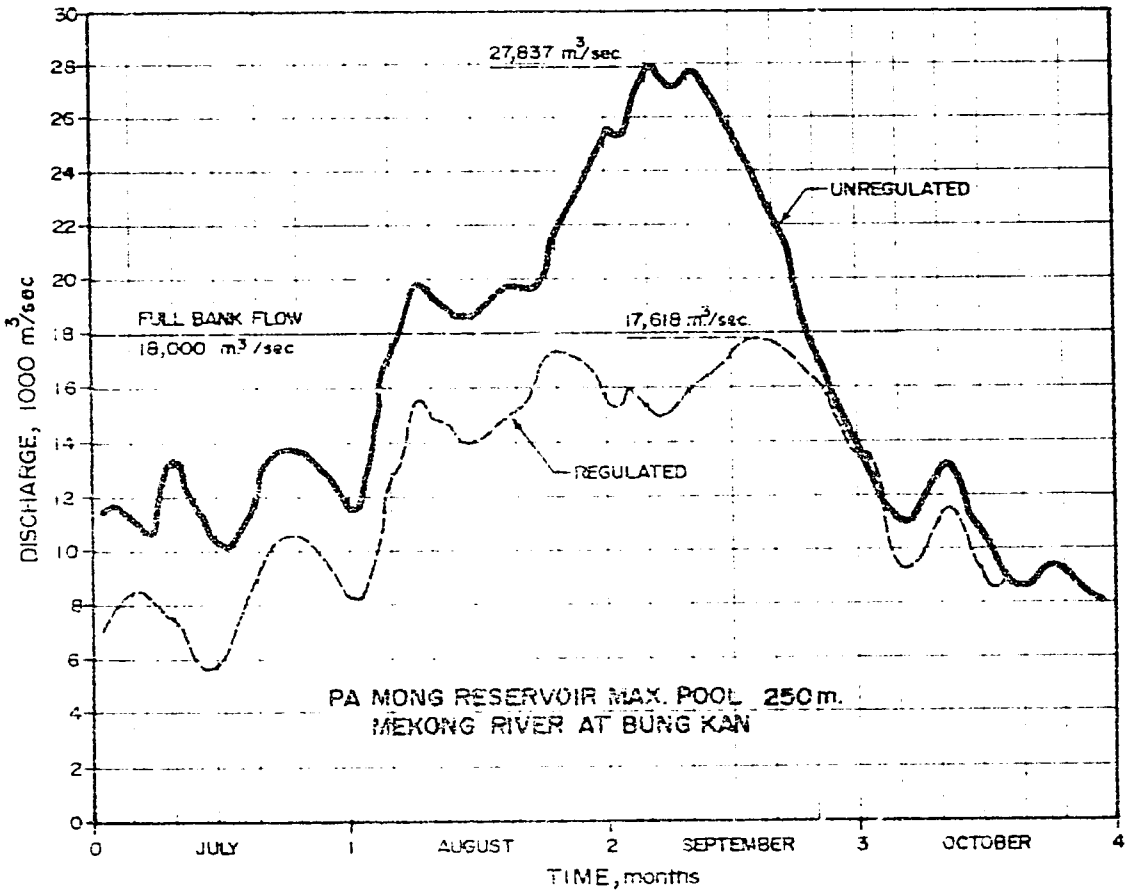


FIGURE 3B

COMPARISION OF REGULATED AND UNREGULATED HYDROGRAPHS OF 1966 FLOOD FOR MEKONG RIVER AT SELECTED STATIONS

Flood control

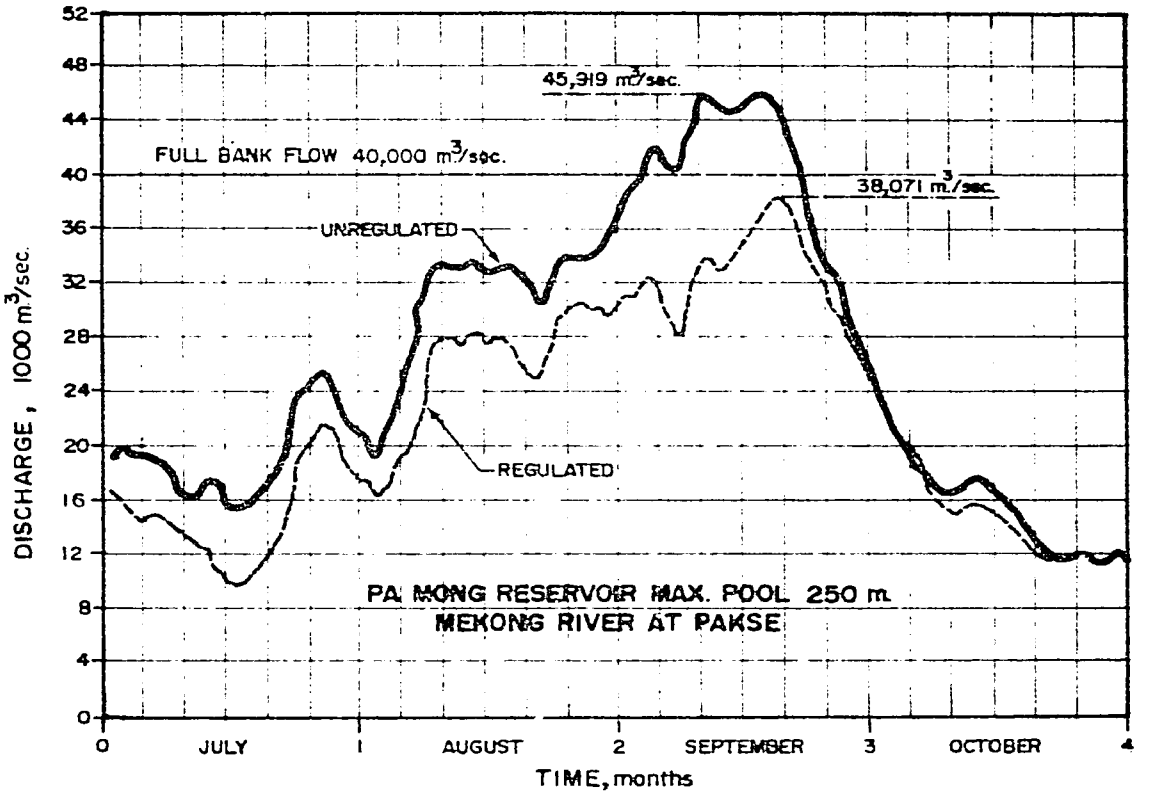


FIGURE 3C

COMPARISION OF REGULATED AND UNREGULATED HYDROGRAPHS OF 1966 FLOOD FOR MEKONG RIVER AT SELECTED STATIONS

( From Reference 27 )

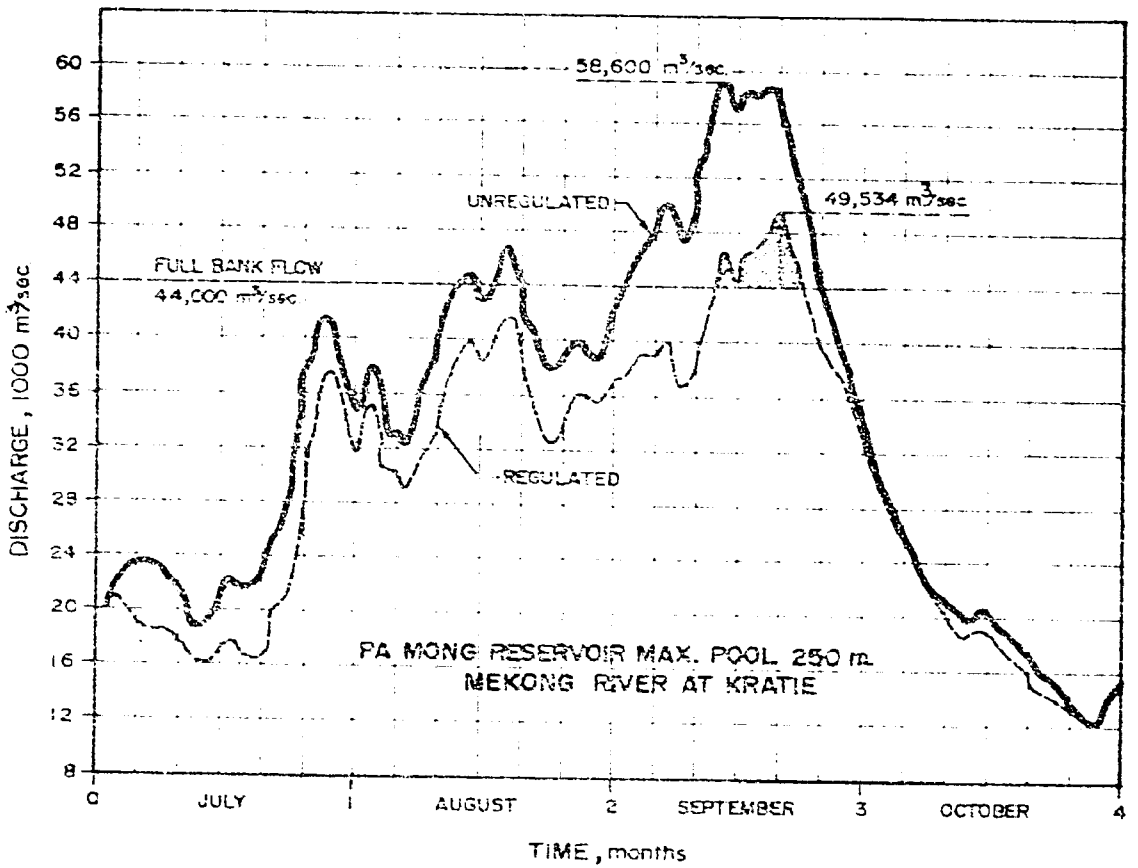


FIGURE 3D

COMPARISION OF REGULATED AND UNREGULATED HYDROGRAPHS OF 1966 FLOOD FOR MEKONG RIVER AT SELECTED STATIONS

( From Reference 27 )

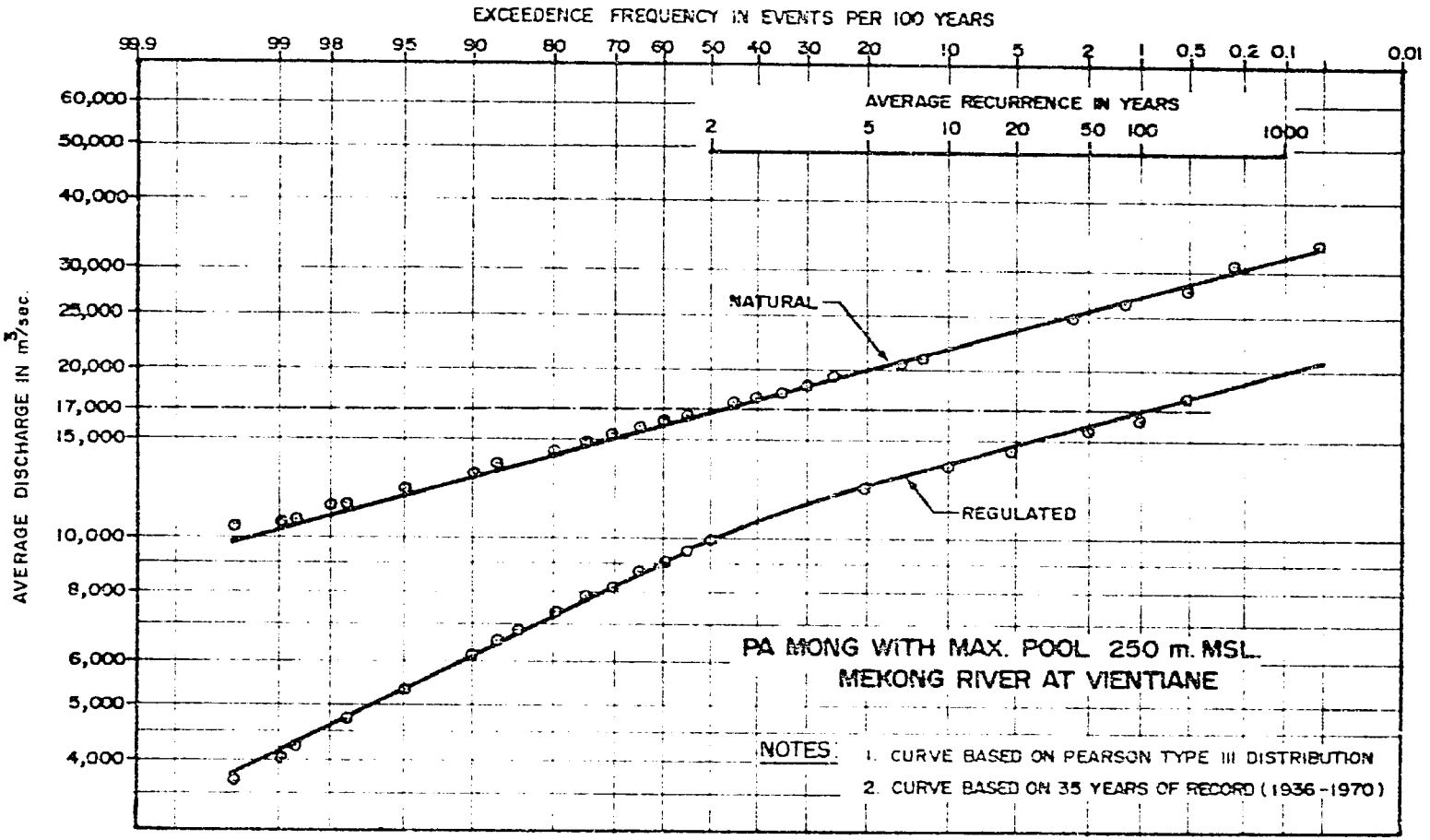


FIGURE 4A

COMPARISION OF FREQUENCY CURVES OF REGULATED AND UNREGULATED MAXIMUM DAILY DISCHARGES OF MEKONG RIVER AT SELECTED STATIONS

( From Reference 27 )

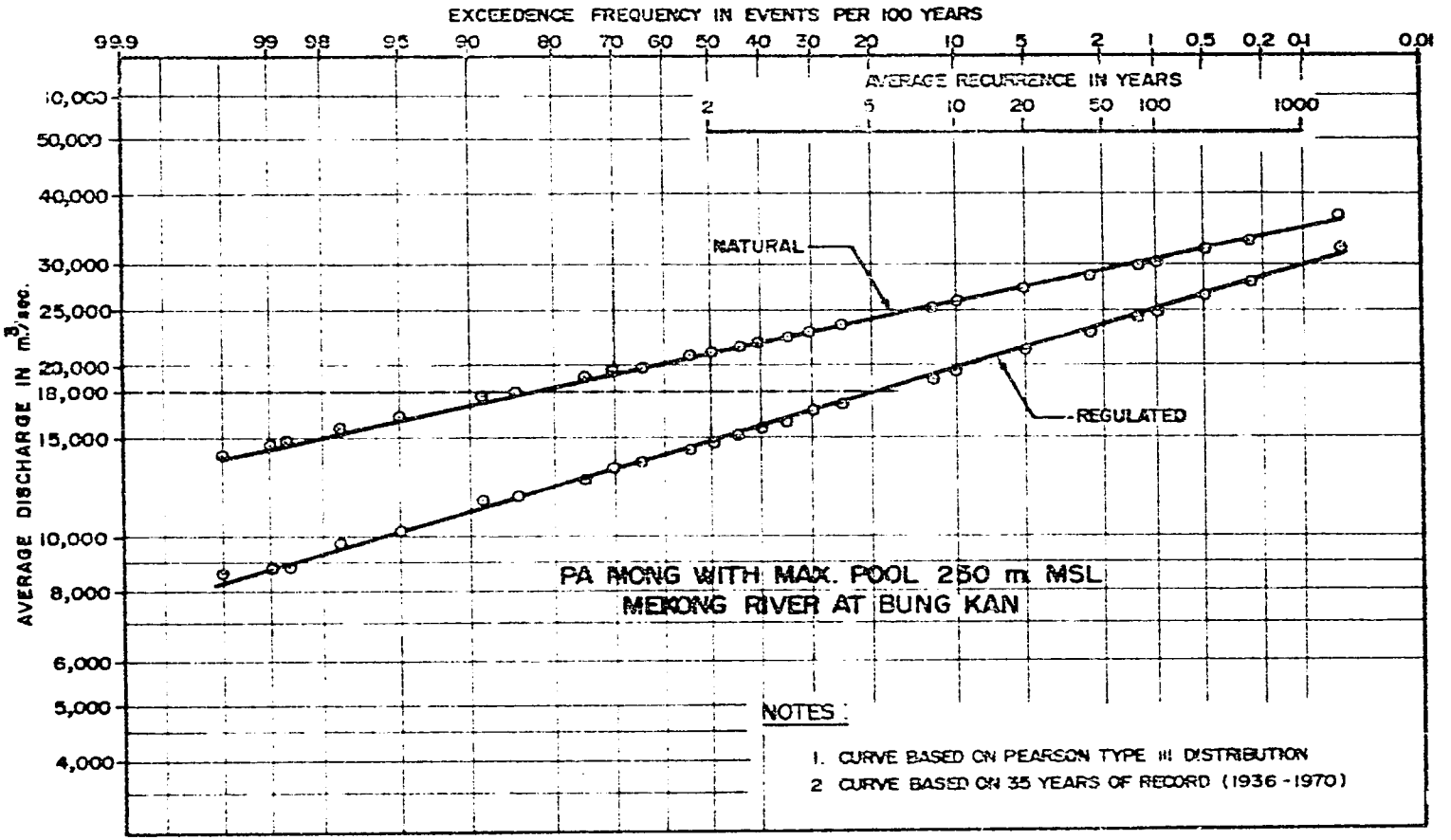


FIGURE 4B

COMPARISION OF FREQUENCY CURVES OF REGULATED AND UNREGULATED MAXIMUM DAILY DISCHARGES OF MEKONG RIVER AT SELECTED STATIONS

( From Reference 27 )

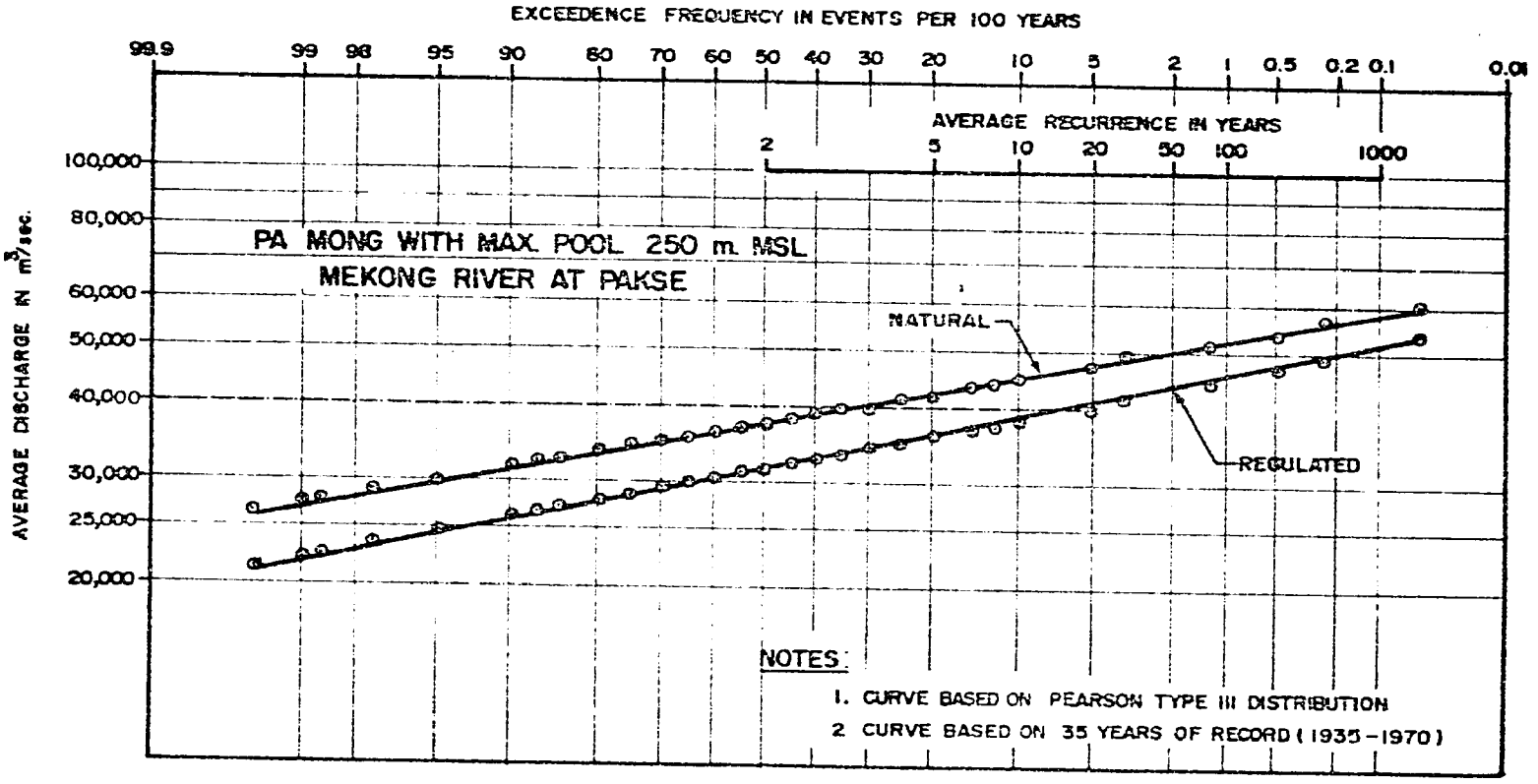


FIGURE 4C

COMPARISION OF FREQUENCY CURVES OF REGULATED AND UNREGULATED MAXIMUM DAILY DISCHARGES OF MEKONG RIVER AT SELECTED STATIONS

(From Reference 27)

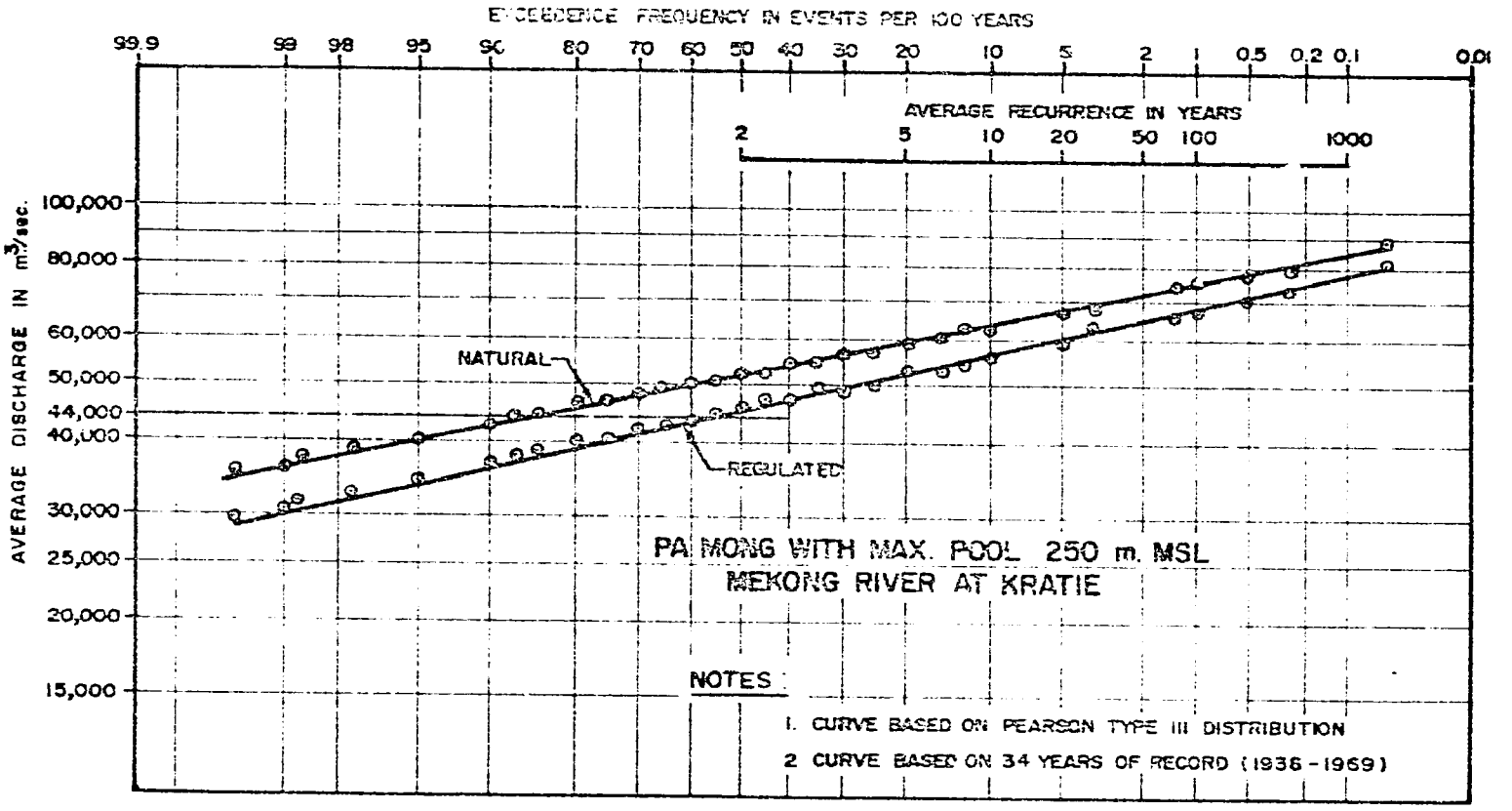


FIGURE 4D

COMPARISION OF FREQUENCY CURVES OF REGULATED AND UNREGULATED MAXIMUM DAILY DISCHARGES OF MEKONG RIVER AT SELECTED STATIONS

(From Reference 27)

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## GEOLOGY/SEISMOLOGY

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Figure 3: Location map of Pa Mong damsite, Nam Mong damsite, Nam Lik damsite, and accessory dikes

Figure 4: Nam Lik West saddle dike, photo-geologic map

# PA MONG ENVIRONMENTAL ASSESSMENT

## GEOLOGY/SEISMOLOGY

### 1. Introduction

This discussion presents a summary of the activities of the Mekong Committee in the field of geology and seismology pertaining to the Pa Mong project, as these relate to the design, construction, and operation of the project to achieve its desired objectives.

Most of the data presented are the results of engineering geologic investigations conducted from 1960 to 1975 by various agencies in collaboration with the Mekong Committee. These investigations were made primarily to obtain subsurface and surface information on foundation and construction materials for use in the preparation of preliminary designs and cost estimates for engineering structures. The various studies and reports were evaluated to obtain information relating to the integrity of the various structural components of the project, with respect to water holding capacities, structural soundness, and construction problems. Based on this information conclusions were developed on the probable effects of geology and seismology or design, construction, and operation of the Pa Mong project and on desirable precautionary measures.

Except as otherwise noted, all of this discussion has been based on information presented in the Pa Mong Stage One report (Ref. 1).

### 2. Physiography

The principal physiographic features associated with the Pa Mong project are (a) the mountain complex formed by the Phetchabun-Pak Lay range and Tranninh mountains and (b) the Khorat plateau.

The Pa Mong damsite and the major, eastern portion of the reservoir are located along the northwestern margin of the Khorat plateau in Thailand and the northern extension of this feature in Lao PDR, where it is referred to as the Sandstone Country of Middle Lao PDR. The turned-up westerly rim of the Khorat plateau forms the reservoir closure on the east, and low hills and drainage divides and the incised river canyons form the reservoir banks to the south, west, and north. The reservoir site extends upstream in the mountain complex where deep, narrow canyons are eroded in complex folded and faulted Paleozoic basement rocks that form the Pak Lay and Tranninh mountains.

## 2.1 Mountain complex

The Mekong drainage system in Lao PDR and in the upstream portion of the Pa Mong reservoir area is characterized by steep-sided valleys eroded in complex folded and faulted metasediments including phylites, limestone, shale, slate, quartzite, schist, and igneous intrusions. The alinements of the valleys are controlled by geologic structure and stratigraphy with north-south stretches of the streams oriented along the strike of softer beds or folds and faults in the basement complex.

Where the Mekong river turns easterly it forms the boundary between Lao PDR and Thailand, and crosses the basement rocks onto the younger Khorat Group of siltstone and sandstone formations. The river breaches the upturned Khorat formations and is incised in a 12-kilometre-long narrow gorge in the uptilted margin of the Khorat plateau. It is in this gorge that the Pa Mong damsite is located. The main portion of the reservoir rests on the lower Phu Kadung siltstone member of the Khorat Group and the fringe area of the basement complex where erosion has formed a long north-south trough or strike valley to the west and north of the upstream margin of the Khorat plateau. The escarpment of the plateau, which provides the easterly closure of the reservoir, is supported by more resistant upturned ridges of sandstone and siltstone.

## 2.2 Khorat plateau

The Khorat plateau and its northern extension into Lao PDR is an uplifted, basin-shaped area lying east of the Phetchabun-Pak Lay range of mountains. It is made up of a thick series of siltstone and sandstone beds (over 3,000 metres thick) called the Khorat Group. It is a relatively stable land mass overlying the more disturbed basement rocks. When the Khorat formations were gently folded into a large basin-shaped plateau, minor subsidiary cross folding occurred, forming relatively smaller anticlinal and synclinal folds. The major drainage systems have breached the plateau generally along the anticlinal cross folds. Remnants of the Khorat Group lying west of the margin of the plateau are generally the synclinal structures, which commonly have been eroded to form synclinal basins that are breached by local drainage systems. The well-established drainage systems generally are aligned on the axes of anticlines.

## 3. General geology

Most of the proposed engineering structures of the Pa Mong project are in the Khorat Group of formations. Along the western escarpment of the plateau, easterly dips range from 10° to 35°. Fault zones have been located at the Pa Mong site; however, seismic history in the vicinity of the Pa Mong project indicates that the proposed structures are located in an area that is relatively free from seismic hazards. The proposed Pa Mong dam is on thick bed of sandstones and siltstones which are lenticular, cross-bedded with wide variation in the degree of cementation.

## 3.1 Regional geology

Brief descriptions of the principal rock types in this region are described as follows, beginning with the oldest to the youngest (See also generalized stratigraphic column in Figure 1, and regional geologic map in Figure 2):

(a) Kanchanaburi series (Carboniferous and older): This series contains the oldest rock formations of the area. The Kanchanaburi rocks are commonly exposed along the Mekong river channel and generally form the western portion of the reservoir upstream from the plateau escarpment.

(b) Rat Buri series (Permian and Carboniferous): The Rat Buri series is primarily a thick, massive, crytalline, pure limestone but locally is thin-bedded and includes some interbedded shale, chort and sandstone. The limestone is exposed in the west portion of the drainage divide at the Pa Mong - Nam Mong saddle and the west Pa Mong - Nam Lik saddle and in the vicinity of the upper part of the Pa Mong - Nam Lik reservoir area. It has been extensively eroded in part by the action of surface and ground water. As a result cavernous limestone and karst topography underlie part of the reservoir area and provide a possible escape of reservoir storage between tributary drainage systems.

(c) Khorat group (Triassic-Cretaceous): The Khorat group consists of seven major formations, all of which may not be represented in the region of the project. They are described below from oldest to youngest:

(1) Nam Phong formation (Np): The Nam Phong formation (not identified in this area) is described by Ward (1964) as the sequence of siltstone and resistant sandstone and a few conglomerates overlying the pre-Khorat erosion surface.

(2) Phu Kadung formation (Pk): This formation consists of red to greenish gray soft siltstone and widely spaced, nonresistant shaley sandstone. The lower half of the formation is mostly soft, micaceous, reddish-brown and grayish-red siltstone. The middle part contains 120 metres of a pale red, fine-to very fine-grained, well-cemented calcareous sandstone. The upper part consists of interbedded and micaceous siltstone and sandstone. A conglomerate comprises the bottom of the formation which overlies the Rat Buri limestone. The Phu Kadung formation erodes more readily than the overlying Phra Wihan sandstones and occurs beneath the main body of the reservoir immediately west of the escarpment.

(3) Phra Wihan formation (Pw): The resistant sandstones of this formation cap the main western escarpment of the Khorat plateau. The thick cross-bedded, clean sandstone usually occurs with siltstone units above and beneath it. The Phra Wihan formation occurs as the main ridge of the escarpment and in the low gaps will serve as the bank rock for the reservoir along its eastern margin.

(4) Sao Khua formation (Sk): The Sao Khua formation is primarily siltstone with occasional sandstone units. It is about 500 metres thick and underlies the strike valleys between the Phra Wihan and Phu Phan formations, is mottled red, gray and brown. It is soft and easily weathered. The sandstone members are yellowish-gray to brown or pale red.

(5) Phu Phan formation (Pp): The formation consists of bright-colored coarse-to fine-grained sandstones which are massive and cross-bedded with a wide variation in the degree of cementation. Siltstone is interbedded with the sandstone in the lower portion of the formation. The top of the formation is a very-thick-bedded unit of variably cemented, conglomeratic sandstone that occurs as isolated ridges along the trend of its outcrop.

(6) Khok Kruat formation (Kk): This formation is composed of soft siltstone and sandstone that overlies the Phu Phan formation. It does not occur at any of the major engineering sites but may occur in the vicinity of pump and diversion structure sites.

(7) Salt formation (S): This formation is interbedded sandstone, siltstone and claystone containing gypsum and rock-salt deposits. It underlies some of the project area considered for irrigation.

(8) Igneous-Andesite and Phyolite Porphyry: Large bodies of andesite prophyry and rhyolite porphyry occur as intrusions in the Kanchanaburi rocks west of the plateau escarpment. These rocks along with some granite are particularly common along the Mekong river upstream from the southern arm of the Pa Mong reservoir and along the Nam Loei. They are not involved with the foundations at any engineering sites.

(d) Tertiary-recent (Igneous rocks, alluvium): Deposits of unconsolidated materials occur throughout the dam-site and reservoir area consisting of transported gravel, sand, and clay deposits which are remnants of former flood plains of streams and recent accumulations of stream deposits and slope-wash debris, and of residual soils from inplace weathering of the rock formations.

## 3.2 Seismology

A review of seismic data indicates that the Pa Mong project is not in an active seismic belt. The faults are old and inactive. Recommendations have been made for establishment of a seismic station in the vicinity of Pa Mong reservoir to give an indication of any activity that may result from loading the area with the huge body of water to form the reservoir, and also to measure the performance of engineering structures in response to imposed seismic stresses.

There are two seismorgraph stations, which are part of a worldwide monitoring system, located in Thailand at Chiang Mai and Songkhla. Together with an additional station near Pa Mong, these should be sufficient for purposes of project design.

## 4. Stage One report

The engineering geology evaluations presented in the Stage One report (Ref. 1) deal with the geologic and engineering aspects of proposed structure sites. The major or basic geologic problems are concerned with the water-holding capability of the reservoir, the suitability of foundation materials to support the engineering structures, and availability of construction materials.

Geologic investigations of the Pa Mong project had been conducted since 1960 up to the preparation period of the Stage One report (Ref. 2, 3, 4, 5). The possible desirability of dam structures higher and larger than originally envisioned raised questions on the foundation capability to support the load of the larger structures. Hence, a consulting board of geologists was convened to review the available data and to make recommendations for future explorations, which were submitted in 1968 (Ref. 5). The recommended programme for obtaining the necessary geological data for preparing feasibility grade designs and estimates was performed and the results included in the Stage One report.

### 4.1 Reservoir

The geologic conditions of major importance in considering the water holding capability of Pa Mong reservoir are (a) the occurrence of cavernous limestone which might provide escape routes through open solution channels, and (b) those parts of the Phu Phan ridge which are low and narrow and where the percolation paths through joints or fractures in sandstone and siltstone would be relatively short. Also, limestone occurs at the divides between the Mekong and Nam Mong and between the Mekong and Nam Lik, raising questions on possible leakage problems (See Section 6).

The reservoir pool basically will be retained by Pa Mong dam, Nam Mong dam, and Nam Lik dam and by accessory dikes needed to close the reservoir. Figure 3 shows the location

map of the stated damsites and the necessary dikes for a high pool level of 250 m MSL. Reservoir closure on the north and south ends of the storage pool will be provided by low ridges of siltstone and sandstone of the Phu Kadung formation, with earth dikes to close the gaps in the low saddles below elevation 250 m MSL. The bedrock materials at the Nam Lik-Nam Ngum saddle and the Nam Mong-Nam Pong saddle are sound and impermeable, hence, leakage and stability problems are not anticipated.

Low gaps in the long north-south Phu Phan ridge of sandstone and siltation, that forms the easterly rim of the reservoir, will be closed by the Pa Mong, Nam Lik, and Nam Mong dams and by earth dikes at the Chong Khao San gap and the Huai Sai gap. Long sections of the narrow ridge extending beyond the earth dikes will require special reservoir rim treatment such as grouting, blanketing (soil cement), or riprap to provide protection from wave erosion and possible leakage at the upper of higher elevations of the reservoir.

The sandstone and siltstones of the Phu Phan ridge dip eastward under the Khorat plateau. The rocks are quite dense and of relatively low permeability except in the weathered surface exposures along open joints and fractures. They support a relatively high groundwater table in the unweathered rock. Along portions of the sandstone rim, where the rim is thin, moderate leakage is anticipated in the downdip toward the east. Such leakage is expected to result in minor springs along the east side of the reservoir rim.

4.2 Foundations conditions for dams and dikes

Most of the engineering structures for closing the reservoir will be in the Khorat group of sedimentary rocks consisting of alternating beds or siltstone and sandstone. These engineering structures are the Pa Mong, Nam Mong, and Nam Lik dams and some accessory dikes to retain the reservoir surface at the designated elevation. Topogeologic information on these engineering features is presented in Table 1. In addition to the drill holes for subsurface investigations, an electric logger which made gamma ray, resistivity, and self-potential logs of drill holes was also used as an aid in classifying rock types and in detailing the characteristics of bedrock material. Designs and estimation were based on the subsurface investigations.

(a) Pa Mong damsite: The damsite is within the narrow canyon where the Mekong river breaches the Phu Phan ridge of siltstone and sandstone beds forming the Khorat plateau. Following study of numerous alternatives, a site was selected (sometime referred to as the "lower damsite") which meets the requirements for a large dam with adequate space for spillway, powerplant, and other engineering facilities.

The general regional dip of the sandstone and siltstone is to the east, or downstream. The abutments are generally in competent sandstone layers and the main foundation for the dam is in siltstone. The deep accumulations of overburden and weathered bedrock materials are needed for the cofferdam-diversion structures during construction of the dam. Excavations for powerplants on both sides of the river will be deep, and the structures will be deeply keyed into fresh rock where inplace shear and compressive strength of bedrock material are adequate to support them.

The fresh sandstone at depths from 6 to 17 m is quite uniform and sound. The siltstone is more variable as to general strength and soundness, with some layers susceptible to rapid air-slacking and disintegration when exposed. This characteristic will require special attention during construction to insure that newly exposed surfaces are immediately covered and protected from extended exposure. Jointing in the sandstone is a prominent feature and surface exposures show much separation and slumping of the sandstone on the surface. Drill cores and percolation tests indicate that the joints generally become tight below the weathered zone at depths of 10 to 17 m.

There are many minor shears but only one major fault, referred to as the Ban Ang fault, which has been located in the dam foundation area. As previously noted, this fault is inactive and it is not believed to present any problem.

Sand and gravel bars along the Mekong river channel will provide a sufficient quantity of concrete aggregate in sizes ranging from fine sand to 5-inch gravel. Tests of samples indicate a satisfactory quality of aggregate material, if used with low-alkali cement, including limestone, granite, and various types of matamorphic rocks that may be suitable for crushed aggregate and riprap. If material larger than 5-inch is needed and if no other sources are found, good quarry sites are located in the reservoir area 20 to 40 km upstream from the damsite. Rock quarries can be developed and the material can be transported to the damsite by river barges.

Additional preconstruction explorations will be required for the preparation of final construction designs of the engineering structures.

(b) Nam Lik damsite: The Phra Wihan formation, which consists predominantly of sandstone members, forms the narrow part of the river gorge. Structural weakness is not evident at the site, and the abutment areas

have stable slopes. A rather deep accumulation of slope wash with some large sandstone blocks covers most of the abutment areas. Unstable slopes are present in the stream channel upstream from the damsite area.

The alternating beds of siltstone and sandstone and lenticular bedding will prevent excessive seepage losses, although the beds dip downstream and away from the reservoir. Grouting may be required, especially in the sandstone members, to abate seepage losses. The right abutment is preferred for the location of the diversion tunnel.

It appears that a higher percentage of sandstone exists in the foundation and abutments at an axis 200 to 300 m downstream from the one presently drilled. Field work was curtailed at the Nam Lik damsite area because of security conditions. For final design additional topographic surveys and drilling exploration will be required to select the best axis location within the damsite area.

Materials investigations were limited to obtaining gravel samples from the stream channel for petrographic analysis. Extensive gravel explorations were carried out on the Nam Lik channel near its confluence with the Nam Ngum during preconstruction investigations for the Nam Ngum dam. A review of the results of the laboratory analysis indicates the gravel is well graded but is short on the plus 3-inch fraction. An ample source of acceptable gravel can be found both upstream and downstream of the damsite.

(c) Nam Mong damsite: The Royal Thai Irrigation Department considered this site for an independent unit to store Nam Mong water for irrigation of lands downstream from the dam. A geologic map, foundation exploration consisting of 10 drill holes, and construction materials exploration for an earthfill dam were completed in 1966.

For Pa Mong HWL 250 m MSL, investigations were made for a dike structure at the Pa Mong-Nam Mong drainage divide (El. 234 m MSL). It was noted that the cavernous limestone west of the Pa Mong-Nam Mong saddle might present a potentially serious leakage problem. One solution to this problem would be to form one large storage basin, by simultaneous construction of both dams; one at Pa Mong damsite and the other at the Nam Mong damsite. However, more recent studies sponsored by the National Energy Administration of Thailand in 1971-76, including field exploration and drilling, indicate the leakage problem at Nam Mong will probably not be serious and would be readily controlled.

The upstream face of the ridge below the Phra Wihan sandstone is covered with deep talus of large sandstone blocks that have been dislodged from the ridge and litter the western or upstream slope. Below the weathered zone the rock is relatively tight and sustains a high water table. This indicates that with removal of 5 to 10 m of weathered rock in the cutoff zone and with grouting adjacent to the dam, leakage can be controlled within acceptable limits. Cutoff depths to bedrock in the valley flood plain portion of the dam foundation range between 10 and 15 m as indicated by subsurface borings.

Some of the potential embankment material consists of transported alluvium that has recently been deposited by flowing water, but for the most part the deposits are undulating uplands of residual soil and deeply weathered siltstone all of which would be classified as impervious. Previous materials would be crushed or quarried sandstone and limestone. The best quality for quarried rock is the Phra Wihan sandstone, which forms the crest and downstream portion of the dam abutments. The limestone ridge located approximately 6 km northwest of the damsite will provide the best quality rock for aggregate and riprap.

The Nam Mong damsite is considered geologically suitable for the proposed earthfill dam, and the available geologic data are believed to be adequate for feasibility grade designs and estimates. For final design, exploration will be needed to obtain more detailed data, both for structure foundations and for construction materials.

(d) Accessory dikes: In addition to the three dams mentioned above there will be accessory dikes required to contain the reservoir depending on the selected high pool level. For 250 m MSL, these would be the Huai Sai Gap dike, Chong Khao San dike, Nam Mong-Nam Pong dike, Pa Mong-Nam Mong saddles, Pa Mong-Nam Lik saddles, and Nam Lik-Nam Ngum dikes. It was decided that construction of dikes at the Pa Mong-Nam Mong and the Pa Mong-Nam Lik saddles would not be feasible because of the underlying carvernous limestone formations, which might lead to excessive leakage problems (See Section 6).

Table 2 summarized the information pertaining to engineering geology published in the Stage One report. It is visualized that no foundation problem is expected for the construction of the dikes. Some treatment of the reservoir rim including grouting may be required to remedy minor problems of reservoir leakage. The most important problem will be protection of the

natural dikes, reservoir rims, and dike structures against the anticipated reservoir waves and wave erosion. These protection measures will include stripping and placement of protection cover such as riprap.

4.3 Other engineering structures

(a) Distribution system

(1) Lao PDR: It was concluded that a bench flume in the steep portion of the canyon would not be practical and that water should be conveyed in a tunnel over the upstream portion of the route below Pa Mong damsite. The lower portion of the canal is all in excavation and no unusual construction problems are anticipated.

(2) Thailand: The distribution system will consist of gravity canals with diversion from Pa Mong reservoir by a tunnel upstream from the right abutment of Pa Mong dam. The initial portion of the canal will require a large amount of rock excavation, which will be a large item in the cost of the distribution system. Some 54 auger holes were drilled at intervals to obtain sufficient information for estimating costs for rock excavation and for planning layouts for the irrigation distribution system.

(b) Transmission lines and substations: Aerial reconnaissance studies were made along proposed power transmission line and substations. Designs and costs were based primarily upon data collected for studies made for existing transmission lines and work underway in Thailand.

5. Phase II report

Supplementary geologic investigations were conducted during the preparation of the Phase II report as needed to permit evaluation of possible additional engineering components to the Pa Mong complex not considered in the Stage One report. The additional sites considered for engineering structure and related construction material sources were mapped and explored by subsurface methods, such as core drilling, trenching, test pits, and auger holes, and samples of foundation and construction materials were analysed (Ref. 6).

5.1 Damsites

(a) Nam Ngum damsite: Enlargement of the Nam Ngum reservoir and dam was considered in the Phase II report (Ref. 7). The proposed damsite is situated at the lower part of the mountainous region and consists of sandstone, shale and conglomerate of the

Triassic Age in the Mesozoic Era. The rock strata at the damsite are resistant to erosion and cross the river forming a sharp hill ridge to create a narrow gorge. The results obtained from 13 diamond core borings indicate the river bed is of hard rock consisting mainly of sandstone beneath 2 to 3 m of gravel deposit. The drilling carried out from both banks did not encounter any serious faults.

Security reasons prevented drilling on the left bank, but a reconnaissance survey of the surface soil indicated the geological structure of the left bank is nearly the same as that of the right bank. The bedding plan and the joint plane found in the sandstone formations can be made water-tight by grouting before and after concrete placing.

There is a thick layer of weathered clay (9 m thick) in the downstream area of the right bank on the proposed route of the spillway or bypass, which covers a depth of about 10 m of sandstone where weathering is considerably advanced. Care should be taken when excavation is carried out in this area.

The foundations of the new powerhouse (near the existing one) can be placed safely on the hard rock in the river bed.

Concrete aggregates can be supplied from the thick deposits of sand and gravel found in the river bed downstream of the damsite. Also, similar deposits of aggregates can be found in the river bed further downstream. Crushed stone can be found in the mountains at elevation of 230 to 250 m MSL on the left bank immediately upstream of the damsite (Ref.7).

(b) Huai Mong diversion damsite: This damsite, located about 15 km downstream from the Nam Mong damsite on the Huai Mong channel, is underlain by alluvial fill deposits from the meandering stream activity. Nine hand auger drilled holes were made, with the soil samples tested in the laboratory. The upper portion is a clay-loam soil and at the lower depths most of the auger holes revealed a heavy clay soil. The water table is high and fluctuates with the water surface in the stream channel. The soft alluvial and fine grained soils at this site will not be very stable unless anchored by some means such as piling. These soils will erode readily and careful protection with concrete gravel and riprap will be required at the overflow weir and sluice-way portion of the structure (Ref. 6).

Earth materials suitable for compacted embankment are found in the immediate vicinity, but other construction materials are not available near the structure site. Concrete aggregate may be obtained from the Mekong river channel near Nongkhai, Thailand. Gravel for drains and the bedding for riprap can also be obtained from the Phu Phan ridge area near the Nam Mong damsite, and a limestone source in the Pa Mong reservoir basin just west of the Nam Mong damsite would provide a superior rock.

5.2 Other engineering structures

Geologic investigations were made for evaluation of additional engineering sites including the Chong Khao San canal, Kut Linchi pump inlet channel, and Sombun irrigation outlet channel.

(a) Chong Khao San canal: This site is for a proposed headwork at a saddle area of the Chong Khao San dike. The length of canal is 530 km, with a capacity of 250 $m^3$/sec. Horizontal laterite was found throughout most of the area, and it was difficult to auger through the laterite accumulation especially above the water table. About 6.5 km of the initial reach may be classified as predominantly rock excavation. Some construction problems will arise because of the saturated soil conditions and high ground water along the reach across paddy land. The excavation for the canal prism will provide a source of required earth embankment material for the canal construction. The Rat Buri limestone is a source being used to provide coarse sizes of aggregates in the area at the present time. Sand and small aggregate sizes come from natural sources found along the Mekong river channel (Ref. 6).

(b) Kut Linchi pump inlet channel: This inlet channel, 3 km long and located on the southwestern edge of the Pa Mong reservoir, is being planned to convey about 50 $m^3$/sec of water from the reservoir between elevations 225 to 255 m MSL. The canal will provide water to the upper portion of the Lam Phanieng irrigation division (Ref. 6).

Subsurface exploration was on a limited scale, including drilling of six hand auger and two rotary holes. An igneous rock consisting of andesite and rhyorite porphyry was found below the overburden, characterized as decomposed rock to a depth at least 34 m. A long slope of clayey soil derived from the weathered igneous rock poses construction hazards because of water saturation, hence drainage of this slope area will be advisable, especially in the active

drawdown portion. Construction materials can be found in the vicinity to provide sources of riprap and concrete aggregates. Rock spalls can provide the bedding for the riprap since there are no known sources of natural gravels in the vicinity (Ref. 6).

(c) Sombun irrigation outlet channel: A channel 13 km long, required to convey water through the Nam Mong-Nam Pong drainage divide was considered in the Phase II report. The invert elevation will be 225 m MSL and the maximum depth of cut will be 26 m. Excavation for this outlet channel will be in siltstone and sandstone of the Phu Kadung formation, and can probably be accomplished with heavy-duty equipment without the use of blasting. At the invert elevation practically all the excavation will be below the ground water. Gentle cross slopes with berms will be required for open-cut-excavation because of the unstable siltstone and ground water saturation condition found at the structure site. For the mid-portion of the proposed channel section, about 2 km long, it is recommended that consideration be given to driving a tunnel or use of a cut-and-over section to reduce both construction and operation and maintenance costs (Ref. 6).

Concrete aggregates are not available at the structure site. Aggregate sources can be found in the Mekong river channel area and by processing Rat Buri limestone found within 25 km. These source areas are the same as proposed for the major structures of the Pa Mong project.

5.3 Mekong river channel

Detailed descriptions of rock formations which are found along the Mekong river channel downstream are also presented in the Phase II report. Sandstone and siltstone bedrock of the Phu Phan formation is intermittently exposed in the river channel from the damsite to about 7 km downstream. The next 6.5 km of the river consists of overburden material overlying primarily siltstone of the Khok Kruat formation. From this point (about 13.5 km downstream of the damsite) the stream channel is sand and gravel, and silt and clay with some clayey gravel generally make up the river banks. These overlie soft shales and siltstone downstream to the Nam Ngum confluence (Ref. 6).

6. Nam Mong and Nam Lik saddles

Some further geologic investigations have been conducted to gain information about expected leakage problems at the Pa Mong-Nam Mong saddle area and the Pa Mong-Nam Lik east and west saddle areas (Ref. 8, 9).

(a) Nam Mong: For the Nam Mong saddle (Ref. 9), the Rat Buri limestone in the area of the Nam Mong-Pa Mong divide appears to be a shelf deposit of cryptocrystalline to microcrystalline calcureous ooze, with some argillaceous content and some thin shale layers. Possible underground water movement within the limestone is expected to be restricted because of thin shale beds, argillaceous content, and sparry calcite infilling in the limestone. However, the Rat Buri limestone has been thrust-faulted to form possible leakage paths across the drainage saddle. Also, a possible zone of fracturing may exist in connection with a fault zone at Huai Sai Gap and extending into the Nam Mong area. This zone may provide an excape route for underground waters from possible karst development to the north.

Cavern development in the area is small and appears to lack interconnections between solution areas. Solution development appears to be inactive, with some deposition in the form of speleothems. At and below the general plain level, the caves are filled with laterite-derived clays, which would restrict water movement through the caves. Solution development below the general plain of the surrounding area is expected to be restricted due to the high water table, unless the water table has been considerably lower in the past. Development of new solution channels is expected to be insignificant, and any significant leakage would be through existing caverns and solution channels.

The study concludes that the problem of reservoir leakage at the Pa Mong-Nam Mong saddle can be readily managed for reservoir elevations up to 240 m MSL, but for levels at 250 m or higher additional geologic investigations will be needed for final design. Also, a ground water tracing programme has been recommended as part of the reconnaissance level and feasibility studies.

(b) Nam Lik east: For the Pa Mong-Nam Lik east saddle areas (Ref. 9), the saddle area itself is considered to be the most reasonable location for the proposed dike. Possible alternate dike sites to the southwest delineated by the USBR could involve extensive grouting at the right abutment in the Phu Phan sandstones in the area of faulting, and would require higher dike construction. Also, extensive drainage from the area between these alternative dike sites and the saddle would have to be either pumped over the dike or channeled into the Nam Lik river.

A rolled earthfill dike will be the most suitable form of construction. A simple rolled fill cutoff should adequately control seepage under the dike, and a grout curtain at the abutments will provide a positive barrier to seepage through the abutments. The alignment of the dike should be arranged so that dike construction misses the fault at the left abutment. No drilling in the Nam Lik East saddle area is deemed necessary in order to complete reconnaissance grade dike designs and cost estimates.

(c) Nam Lik west: Field inspection of the Pa Mong-Nam Lik west saddle area was not possible due to the security problem, hence the studies were based primarily on aerial photograph interpretation. The study report (Ref. 9) concludes that some field surveying will be necessary to establish accurate elevations in this area. It appears feasible to build a dike just south of the limestone outcrops as shown in Figure 4, to keep reservoir waters away from the porous limestones at the saddle area. However, it is possible that no structure of any kind will be required. The saddle is at plus El. 270 m MSL; leakage paths in the limestones may not cross the saddle; and it may be practicable to blanket the limestones to prevent reservoir waters from reaching them.

Extensive geological investigations of the area will be required to define the precise leakage problems at the site, and to decide on the best solutions to any problems which may exist. The solution adopted in the study report is tentative and is designed to provide a reasonable estimate of the ceiling cost of preventing extensive reservoir leakage across the saddle.

7. Probable effects of Pa Mong project

(a) Landslide prone areas: Landslide prone areas are indicated along the eastern rim of Pa Mong reservoir at Nam Lik and Nam Mong and along the natural dike south of Huai Sai Gap dike. The eastern rim of the reservoir is confined by the escarpment of alternating sandstone and siltstone of the Khorat plateau. Talus of large sandstone blocks dislodged from the ridge are accumulating on the slope facing the reservoir basin resulting from weathering of the siltstone which underlies the massive sandstone bed. Measures to improve the low natural dike, that comprises over 5 km of the reservoir rim south of the Huai Sai Gap dike, will be needed to protect it from erosion by heavy wave action (Ref. 1).

For the southern rim of the reservoir, landslide prone areas are indicated at the Kut Linchi inlet channel and Sombun irrigation outlet channel. At the Kut Linchi inlet channel extensive excavation will be required in severely weathered rhyorite and andesite porphyry. The stability of the saturated slope of clayey soil dreived from the weathered igneous rock will be uncertain even with flat slopes, hence a drainage system is needed for the slope area especially in the active drawdown zone, and special attention should be paid in the design of the inlet channel. Also, the excavation for the invert elevation of the Sombun irrigation outlet channel will be below ground water, which might cause stability problems with the saturated siltstone. Gentle cross slopes with berms are recommended for open-cut excavation. Limits of stable slopes for excavation would be delineated at the design period and modified as needed during construction to suit the actual conditions (Ref. 6).

Land slides would of course be detrimental to communities situated along the reservoir bank and can cause wave attack along the shores of the reservoir. Restrictions on community development should be provided for areas subject to significant hazards.

(b) Erosion prone areas: As previously noted, erosion of the natural dike of 5 km length south of the Huai Sai Gap dike seems probable. Heavy wave attack of the reservoir water over a period of time may cut this rather low and narrow natural ridge. Stripping and preparing the slope for placement of protective cover such as riprap will probably be necessary (Ref. 1). Other erosion prone areas are the Chong Khao San dike, the Nam Lik-Nam Ngum dike areas and the Nam Lik and Nam Mong damsites. Protection measures are technically feasible and have been recommended (Ref. 1, 6).

Erosion downstream of the Pa Mong damsite is discussed separately (See sedimentation and erosion).

(c) Geologic faults and earthquake hazards: There is only one major fault, referred to as the Ban Ang fault, located in the dam foundation area. The general continuity of surface outcrops shows little evidence of any significant displacement. This fault is believed to be old and inactive. Records and traditions of earthquakes in the region indicate that any earthquakes have originated at considerable distances from the project area (Ref. 1).

Establishment of the proposed seismic station in the vicinity of Pa Mong will be valuable for indicating rock formation behavior and response under the huge body of water to be stored. As previously noted, this seismic station would be integrated as part of the worldwide system, and together with the two existing stations in Thailand at Chiang Mai and Songkhla should provide sufficient information to guide design of the Pa Mong project.

(d) Ground water problems: Effects of the reservoir and irrigation system on ground water are reviewed in the discussion on ground water.

(e) Effect of different pool elevations: Requirements for accessory dikes for different Pa Mong high pool elevations will depend on the topography of the basin. Table 1 shows the approximate lowest elevation of the accessory dikes, thus indicating which dikes would be required for each pool elevation. A major concern will be the cost of saddle dikes for the Pa Mong-Nam Mong and Pa Mong-Nam Lik saddles.

The probable effects with respect to leakage and erosion will be different for different pool levels. For the higher pool elevations under consideration (250 and 260 m MSL), the problems of leakage and erosion along the low and narrow natural dikes will be more significant and require more extensive remedial measures.

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(7) "Feasibility Report on the Multi-Purpose Nam Ngum Project, Laos (and Appendix)". Nippon Koei, Japan, 1964.

(8) "Report on Geological Investigation of Southern Part of Pa Mong Reservoir and the Proposed Pa Mong-Nam Mong Divide, Udornthani". Srisuparp, National Energy Administration, Bangkok, Thailand, 1974.

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TABLE 1

TOPO-GEOLOGIC INFORMATION FOR PA MONG, NAM LIK, AND NAM MONG DAMSITES AND ACCESSORY DIKES

(Ref. 1)

| Name | Underlying Geologic Formation | Dipping | No. of Drill Holes at Site | | No. of Auger Holes for Materials Investigation | Approx. Lowest Elev. m MSL |
|---|---|---|---|---|---|---|
| | | | Drill Holes | Auger Holes | | |
| Pa Mong Damsite | Phu Phan formation in the abutments<br>Sao Khao formation in the lower portion | Dips to east<br>Dips to east | 35 | - | 21 | 154 |
| Nam Lik Damsite | Phra Wihan formation | Dips away from the channel | 7 | - | - | 158 |
| Nam Mong Damsite | Phra Wihan formation | 25°, dips easterly | 12 | - | 39 | 165 |
| Huai Sai Gap Dike | Phra Wihan, Sao Khua and Phu Phan formations | - | 19 | 15 | 49 | 241 |
| Chong Khao San Dikes | Dominant Phra Wihan sandstone ridge | Dips nearly vertically | 6 | - | 26 | 228 |
| Nam Mong-Nam Pong Dikes | Siltstone and sandstone of the lower Khorat group and the Kanchanaburi rock series | - | - | - | - | 248 |
| Pa Mong-Nam Mong Saddle | Phu Kachung formation and cavernous limestone of Nat Buri series west of the saddle area | - | 15 | 30 | 48 | 234 |
| Pa Mong-Nam Lik Saddle | Phu Kadueng siltstone - East saddle<br>Cavernous limestone - West saddle | - | - | - | - | 220 |
| Nam Lik-Nam Ngum Saddle | Phu Kadueng formation | Dip 45° northerly | - | - | - | 207 |

TABLE 2

INFORMATION ON ENGINEERING GEOLOGY FOR ASSESSORY DIKES OF PA MONG RESERVOIR

(Ref. 1, 6, 9)

| Names | Foundation Condition | Waterholding Capability | Construction Materials | Remarks |
|---|---|---|---|---|
| Huai Sai Gap Dike | No problem | Expect some minor seepage through 5 km natural dike of the reservoir rim. | Impervious materials are available. Concrete aggregates are within 40 km, and coarser aggregate can be produced from nearby limestone outcrops. | Critical feature is the protection of a natural dike of the reservoir rim. This will require stripping and preparing the slope for placement of the protective cover. |
| Chong Khao San Dike | No problem | In doubt because sandstone is fractured and permeable. | Adequate impervious materials and rock for rock fill is available in the vicinity of the structures. | Problem of attack by huge waves along reservoir rim. Expensive to control. |
| Nam Mong – Nam Pong Dikes | No problem | Underlain by impermeable siltstone and sandstone. | Impervious material from nearby area. Rockfill and riprap material from Phra Wihan sandstone. | Expensive item will be quarried rockfill and riprap protection for dikes. |
| Pa Mong – Nam Mong Saddle | No problem | Underlain by cavernous limestone, but leakage subject to control. | – | May be desirable for Pa Mong dam and Nam Mong dam to be constructed simultaneously to form one continuous reservoir. |
| Pa Mong – Nam Lik Saddle | No problem | Underlain by cavernous limestone at west saddle | – | Advantageous to combine the storage areas of the Pa Mong and Nam Lik to eliminate leakage problems. |
| Nam Lik – Nam Ngum Dikes | No problem anticipated | Grouting may be necessary to alleviate underseepage along the strike of steeply dipping beds. | Earth materials are available in the vicinity area. Gravel at 3 to 8 km hauling distance from the sites. | Wave action protection to the structure is critical. Some shoreline protection might be required to curtail excessive erosion. |

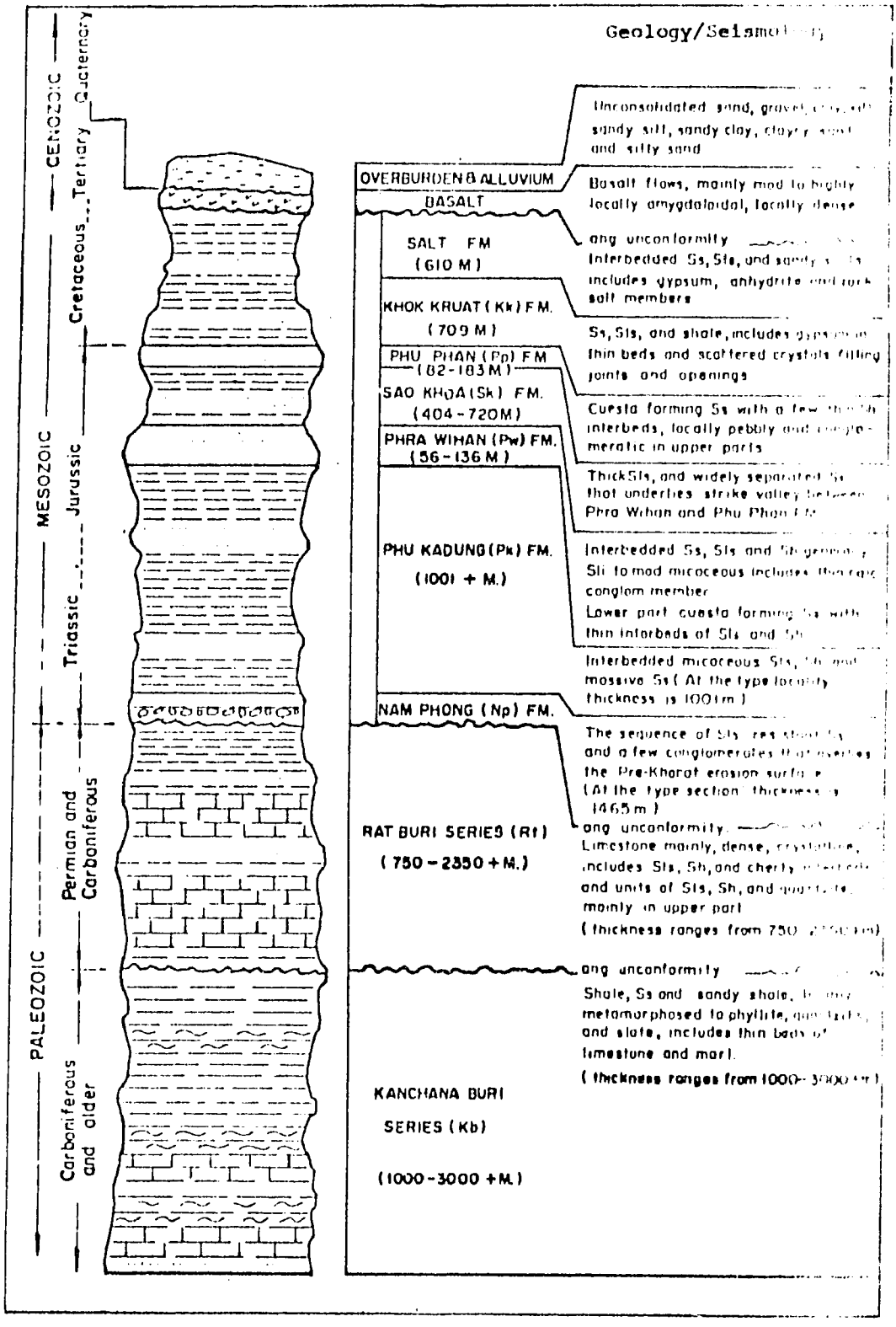
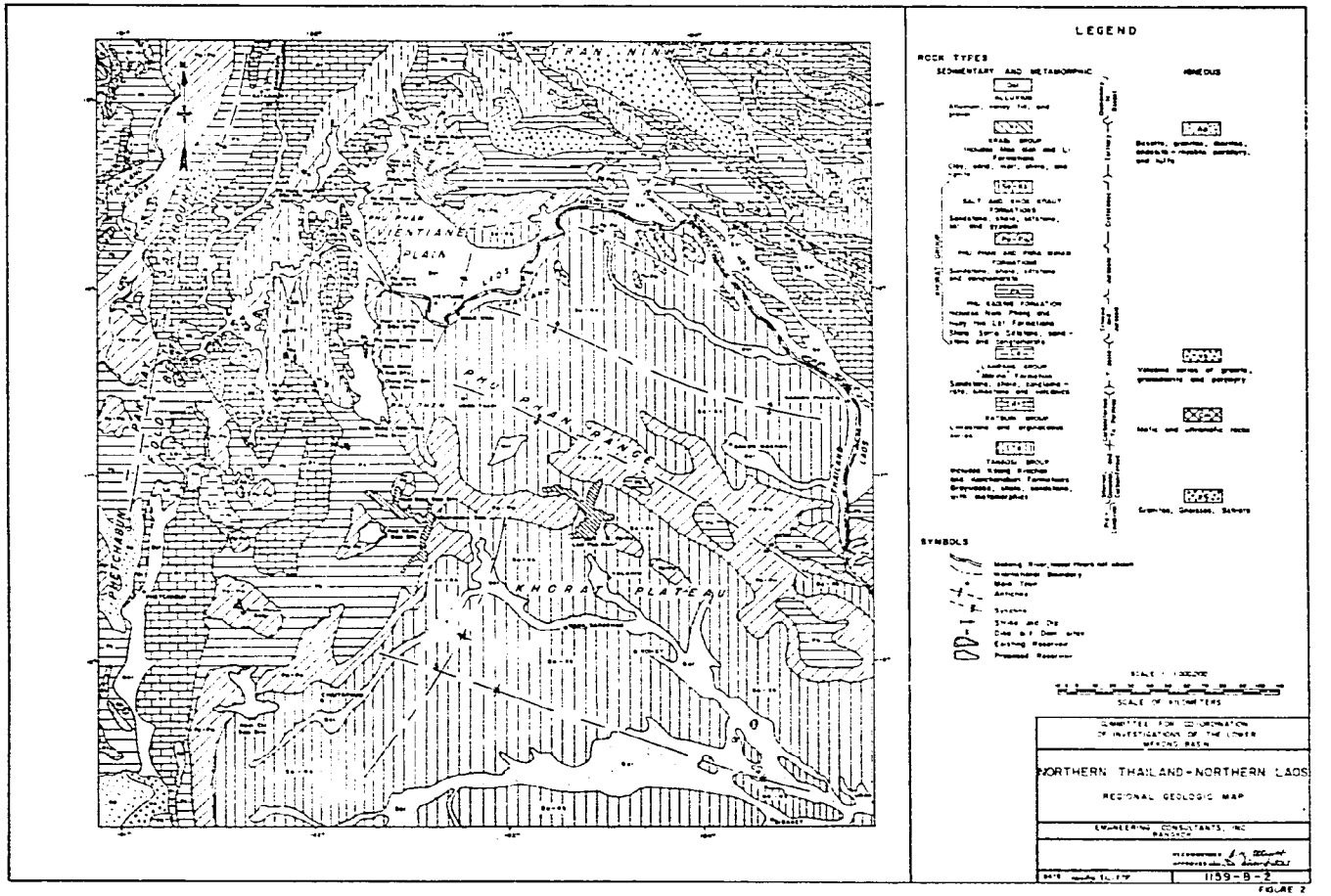



FIGURE 1

GENERALIZED STRATIGRAPHIC COLUMN NORTHEAST, THAILAND
(Ref. 1)

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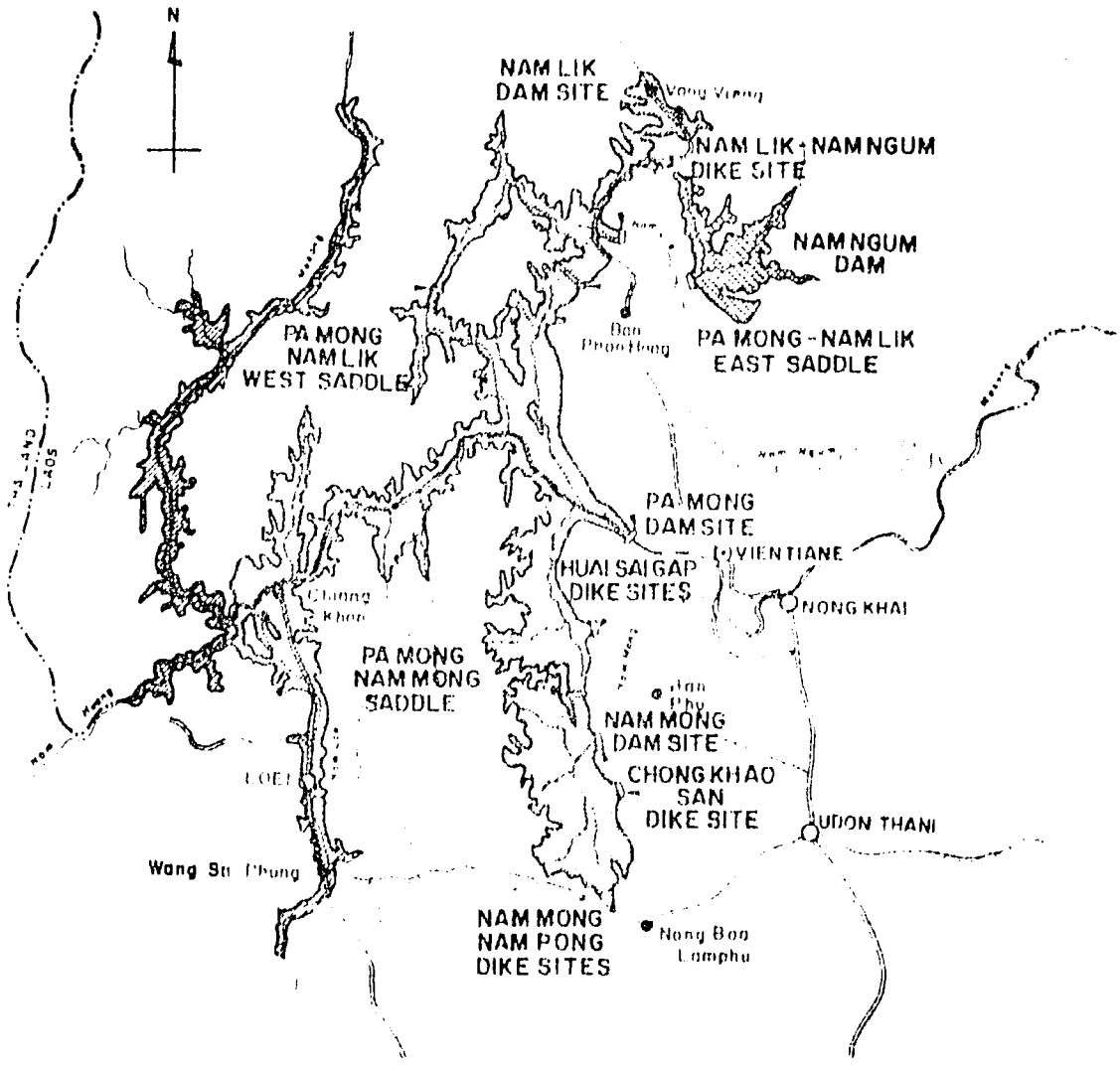


COUNTRY BOUNDARY

RESERVOIR EXISTING

RESERVOIR PROPOSED

0 10 20 30 40 50
SCALE KM

MEKONG COMMITTEE

LOCATION MAP

PA MONG DAMSITE, NAM MONG [illegible]
NAM LIK DAMSITE, AND ACCE[illegible]

FIG 3 DATE

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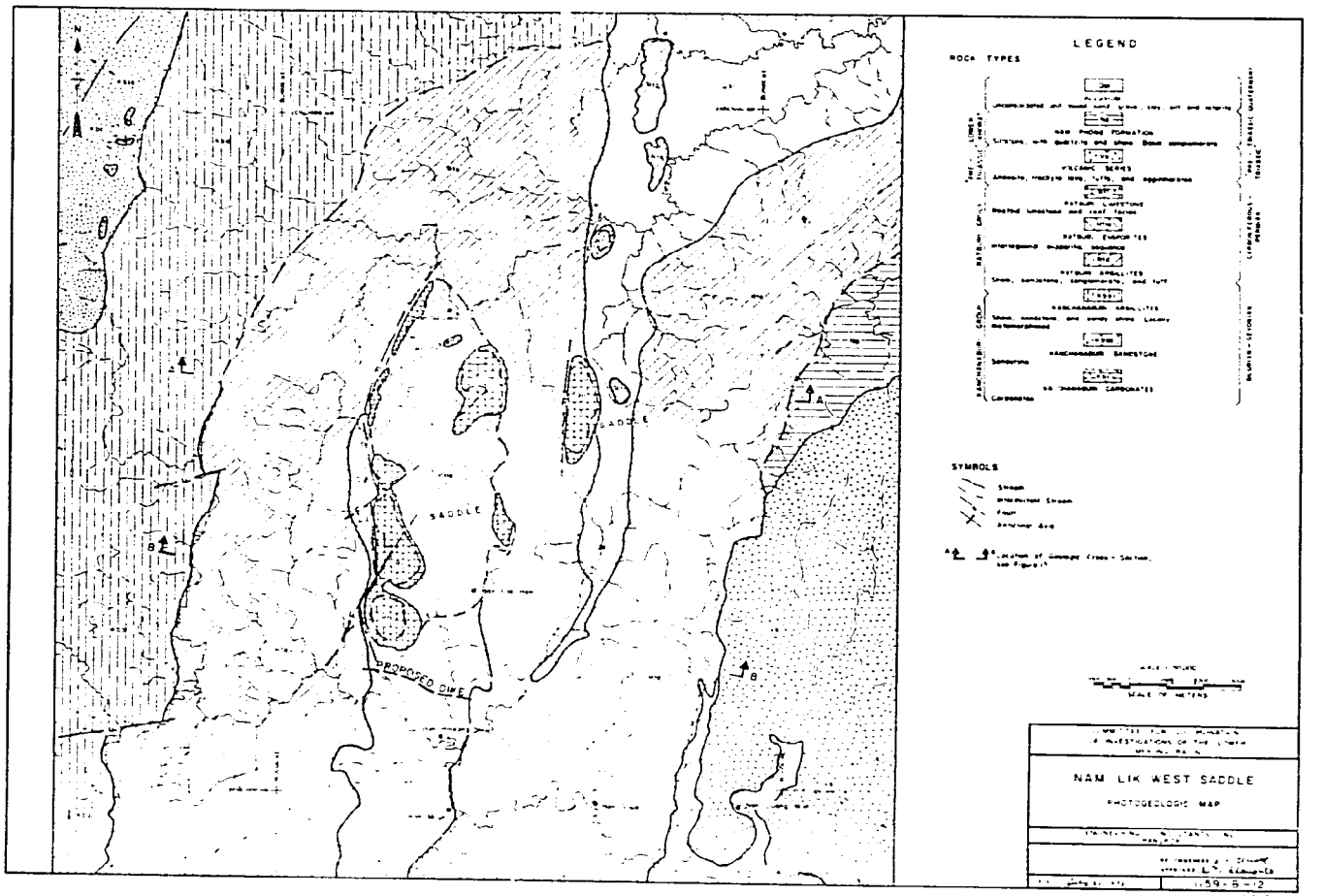


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# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## GROUND WATER

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Table

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# PA MONG ENVIRONMENTAL ASSESSMENT

## GROUND WATER

### 1. Existing situation

Ground water is environmentally important in the lower Mekong basin because of the many uses dependent on water from wells and springs, and because discharge from ground water aquifers comprises most of the dry season base flow of streams. However development of ground water resources in the lower basin is still quite limited, amounting to only about one per cent of the total safe annual yield of the basin estimated at approximately 70 billion $m^3$. Present use of ground water is limited mainly to domestic and community water supply in rural and in some urban areas. Ground water has not been significantly used for irrigation primarily because in areas where ground water is plentiful, surface water is also usually plentiful and of more reliable quality and useable at lower costs.

For the reasons noted above ground water exploration has been very limited in most parts of the lower basin, so that precise information is generally lacking on the extent and nature of ground water resources in most areas. However a number of studies conducted by or for the Mekong Committee do permit a general assessment (References 1 through 18, 19, 22, 23).

Construction of unlined reservoirs and extensive use of water for irrigation can significently change water table characteristics and ground water movement. In some instances, water resources development projects may create unanticipated serious local drainage problems, as well as ground water quality problems. Geology has a greater effect upon the quality of ground water than any other factor. Assessing the nature and extent of ground water aquifers in the basin is important both for estimating the availability of ground water and for determining potential environmental effects of proposed actions. Detailed knowledge on ground water requires field measurement of water tables and the piezometric surface, and estimation of permeabilities from pumping or infiltration tests (Ref. 19).

### 2. Probable effects

Construction of Pa Mong dam will probably affect the ground water resources of the lower basin only to a very limited extent, and it is likely that this will be more beneficial than detrimental. Generally the effects will be greater for the areas close to the dam site, and will gradually diminish proceeding downstream. The anticipated effects therefore may be significant in the upper part of the basin, but are bound to be minimal in the delta area.

(a) Reservoir vicinity: The creation of Pa Mong reservoir will affect the ground water table in the upstream area aquifers which are in contact with the reservoir. These aquifers will receive some recharge from the reservoir, causing the water table to rise. The extent of this effect will depend primarily on the hydrogeological conditions, the water level of the reservoir, and distances from the reservoir. Generally this will improve the availability of water from local wells.

The terrace alluvials in contact with the reservoir will accept recharge from the reservoir causing temporary bank storage. The water levels in these deposits will fluctuate with the reservoir water level. This extra storage will be beneficial in serving to increase the total reservoir storage capacity.

(b) Leakage from reservoir: The Pa Mong Stage One report notes the existence of cavernous limestone in the saddles separating the Nam Lik and Nam Mong basins from the Mekong basin, and that serious leakage through these saddle areas might occur if diking were attempted at these sites, especially at pool levels of 250 m MSL or higher. An evaluation of this problem, including subsurface borings at two of the saddle areas (Ref. 21), notes that rolled earth-fill will be the most feasible form of construction for the dikes, and developed the following conclusions:

(1) Nam Mong saddle: The reservoir leakage problem can be solved by practicable engineering methods (e.g., outoff curtains) for pool levels up to 260 m. Additional subsurface geological investigations will be needed to obtain more detailed information prior to design of the control system, and a system of ground water observation wells should be installed for monitoring of ground water levels.

(2) Nam Lik east saddle: A simple rolled fill cutoff should adequately control seepage under the dike, and a grout curtain at the abutments will provide a positive barrier to seepage through the abutments.

(3) Nam Lik west saddle: Although subsurface borings could not be made at this site, photogeological interpretation indicates it is feasible to build a dike approximately one kilometre north of Ban Hinkang-Na to keep the reservoir waters away from the porous limestone at the saddle area. However, it is possible no dike need be built because the saddle is

above El.270 m, and leakage paths do not cross the saddle. Also, it may be feasible to blanket the limestones to prevent reservoir waters from reaching them. Geological investigations of the area will be required to delineate the leakage paths and to develop the best solutions.

(c) Downstream riverine areas: Below Pa Mong dam, the reservoir operation will cause significant changes in the historic streamflow patterns of the Mekong river (Ref. 9). This will, in turn, affect the ground water recharge and discharge, particularly for the river bank areas close to the river and its tributaries. During the wet season, the surface water recharge to the ground water aquifers will be reduced in proportion to the reduction in the Mekong river flow. However, the increase in flow during the dry season may result in a significant decrease in the ground water discharge to the river. The effects in changing the normal flow regime will likely be more in the dry than in the wet season. The overall impact of the bank storage during the dry season will be to augment the total dry season flow, with significant benefit to agriculture and other beneficial uses of the river water.

(d) Pa Mong irrigation areas: After the start of Pa Mong project operation, the reservoir will provide about 13,900 million $m^3$ of surface water annually for irrigation, fishery and municipal uses in the service areas (Ref. 9). Utilisation of ground water in these areas will be limited mostly for domestic water supply for a limited number of people. Therefore excessive extraction of ground water will not occur in the service areas, and the ground water resources in these areas will be conserved.

Because of irrigation, seepage from local storage, and seepage from distribution canals, the ground water levels in the irrigation service areas will probably rise. Subsurface drainage systems will be used as needed to maintain a salt balance and otherwise as needed for successful cropping of both rice and upland crops. A special problem is the possible increase in ground water salinity in areas overlying salt formations in the Khorat plateau. Some aquifers might be inter-connected and the water may move horizontally and thus transfer salt from one aquifer to another (Ref. 17). In view of this, the probable effect of irrigation of lands overlying the salt beds in northeastern Thailand and adjacent areas of the Lao PDR was investigated in 1973 with the following conclusions (Ref. 4):

(1) In areas where the proposed irrigation will be mainly for wet-season crops, as supplement to natural rainfall, there will be little change in the present ground water levels or movement.

(2) In other areas where year-around irrigation is proposed, the additional water applications can be expected to cause a rise in average ground water levels, which can be expected to be 1 to 2 metres in low-lying areas and floodplains, to as much as 3-5 metres beneath uplands.

(3) Adequate drainage will have to be provided in the irrigation developments to prevent water logging and possible salinization of soils.

(4) Ground water discharge, which presently comprises the dry season base flow of all streams, will increase as a result of increased irrigation (probably ranging from 10 to 15 per cent or more of the water diverted for irrigation).

(5) The underlying salt deposits will have no effect on the proposed developments nor will the future irrigation result in solution of the salt beds.

(6) Harmful deterioration in ground water quality will not result from the planned irrigation development.

(7) Increase of ground water discharge, together with surface runoff from irrigation and regulation by existing reservoirs (excluding Pa Mong) in the area will significantly increase the dry season base flow of most streams.

(8) The return flows from irrigation that eventually return to the Mekong river will not have any significant effect upon ground or surface water quality.

A follow-up study was made in 1974 (Ref. 20) to ascertain the causes of "local seasonal salinization" of surface soils, which is a common phenomenon in northeast Thailand. It was found this salt originates from ground water emanating from salt-bearing strata which still contain some residual salt even though the strata are close to the surface and subjected to continuing leaching.

(e) Mekong delta: Intrusion of saline water from the sea affects many rivers and canals in the lower part of the delta, especially in the dry season when the Mekong river discharge and local rainfall are small (Ref. 13). The quality of ground water in this area is also affected by the saline water

intrusion (Ref. 2). However, the storage water releases from Pa Mong during the dry season will have a signicant effect in augmentation of dry season flow. Also, tidal gates and other barriers will be used to help minimize intrusion. Consequently the overall effect of the planned irrigation system in the delta should result in some lessening of intrusion and in a corresponding improvement in the quality of both surface and ground water affected by intrusion.

(f) Summary: A rough preliminary assessment was attempted of the extent of both detrimental and beneficial effects on ground waters resulting from Pa Mong, based on the available information given in Reference 1 to 18. A summary of this assessment is presented in Table 1, which shows the net environmental effect on ground water is likely to be much more beneficial than detrimental. However, the studies to date have not been carried out sufficiently to permit quantified assessment of the magnitudes of effects in individual areas. Therefore, it is not now possible to predict specific environmental effects.

3. Effects of different pool levels

With respect to different pool levels at Pa Mong reservoir, the probable effects should be of a similar nature regardless of pool level selected. The magnitude of effects will of course be greater for greater reservoir depths, but in any case the magnitude will be small.

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TABLE 1

SUMMARY OF ASSESSMENT OF EFFECTS OF PA MONG ON GROUND WATER

| Ground Water Parameters | Benefit or Detriment | Reservoir Vicinity | Downstream Riverine Areas | Pa Mong Project Service Areas | Mekong Delta |
|---|---|---|---|---|---|
| Water Level | + | 2 | 2° | 1 | 0 |
| | - | 0 | 1°° | 0 | 0 |
| Water Quality | + | 0 | 0 | 0 | 0 |
| | - | 0 | 0 | 0 | 0 |
| Seawater Intrusion | + | 0 | 0 | 0 | 1° |
| | - | 0 | 0 | 0 | 0 |

Notes: (1) 0 : insignificant effect or no effect, 1 : limited extent of effect
2 : significant effect.

(2) ° : during dry season, °° : during wet season

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## HUMAN ECOLOGY

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# PA MONG ENVIRONMENTAL ASSESSMENT

## HUMAN ECOLOGY

### 1. Introduction

As in evident from a review of evaluations of environmental impacts in regions throughout the world, most adverse effects resulting in losses of environmental resources stem directly or indirectly from human development - from growing populations and their associated community, industrial, and agricultural activities. The development of cities in effect replaces the natural ecology with an urban environment. Even traditional farming practices are vastly disruptive of natural ecologies, replacing a varied biota of high diversity with low-diversity systems.

The lower Mekong basin, like many other developing regions, is experiencing unprecedented deterioration of natural resources, not so much, yet, due to population explosion, but due primarily to gross use and application of modern tools and technology without suitable controls. In agriculture in northeast Thailand, for example, the new technology has permitted rapid development of production of large quantities of cassava and kenaf, but the process is more akin to "mining", with respect to soil fertility depletion, rather than cropping on a sustained yield basis. In the forests, exbraction of logs by mechanical means has accelerated the pace of deforestation. Again, with respect to wildlife, the ready availability of very efficient guns has placed the survival of virtually the entire wildlife of the region in jeopardy, even in the highest hills and mountains. It is this rapid utilization and deterioration in natural resources, rather than development of water resources and similar developments, which poses the greatest threat to environmental values in the lower basin. Exacerbating this threat is the continuing exponential growth of population.

### 2. Human ecology in the lower Mekong basin

Recognizing the importance of the population factor, and its key relationship to impact on environment in the future development of the lower basin, the Mekong Committee has sponsored a preliminary evaluation of the long-term population problem in the basin, which was completed in 1974 (Ref. 1). The findings of this study may be summarized as follows:

(a) The desirability of achieving a balance in human population and the consumption of renewable resources in the long run is self-evident. The only alternative is a series of uprecedented catastrophes along with a partial destruction of the overall carrying

capacity of the environment. A major watershed area such as the lower Mekong basin appears to be an especially suitable region for carrying out the necessary planning.

(b) The carrying capacity of the lower Mekong basin was crudely estimated to be 123 million persons as compared to about 33 million population in 1974. The assumptions were that intensified methods of cultivation and ensuing yields would be raised to the highest levels obtainable today on all land presently cultivated, and extended to almost all the land in low-lying areas that can be irrigated. A several-fold increase in the cultivation of plateaus and hilly lands that are more lightly yielding was also assumed. (This degree of intensification and extension would probably be regarded as highly optimistic by agricultural scientists).

(c) Irrespective of carrying capacity limitations, the estimated lowest population at which "steady state" could be reached is from 130 to 170 million, depending upon conditions in neighbouring basins, and assuming the acceptance of fertility controls proceeding as rapidly as any rates that have been experienced in recent Asian history. The higher side of the range allows for use of Mekong water by growing metropolitan areas just outside the basin that are accommodating settlers from the Mekong and more denely settled basins nearby.

(d) The likelihood of population exceeding carrying capacity noted under (b) above suggests that unprecedented measures must be taken both to enhance carrying capacity and to accelerate acceptance of fertility limitation. In both instances it means depending upon knowledge that already exists and has already been reduced to practice in Asia, but only on a very small scale. Thus twenty years or more would probably be required to fit such controls to the needs of the lower basin peoples after the necessary studies and experiments were undertaken. A dietary plan needs to be prepared which would identify the periods and the dimensions of the prospective shortages; the appropriate region must be larger than the Mekong basin.

(e) More imaginative efforts must be made to hold down the growth of population. One feature neglected everywhere in the world should be looked into more fully, namely, using the social changes effected by valley development to reinforce the acceptance of family planning and fertility control. There are four identifiable stages: (1) the resettlement of people now living in areas to be flooded, (2) the workers mobilized for

large scale construction, (3) the population affected by the extension of the electrification of villages and towns, and (4) the agriculturists receiving the new water for irrigation. Experience accumulated in many societies has shown that family size preferences do not change significantly until the climate of opinion and the flow of social communications have both changed, and the control of population cannot be accomplished by mandate or through the use of police powers. However, quite a few countries have been successful in influencing rates of change toward new family size norms.

(f) The structural characteristics that can be deduced for the steady state at a minimum adequate level of living, maintaining a rural-urban equilibrium, suggests that the labour force would need to raise productivity several times over current levels. For the rural areas this means a labour force roughly equal to the present (with a total population somewhat less) but getting more crops from a larger area per worker. It also means that all added population henceforth can only find productive employment in urban areas. At steady state the population is expected to be 80-90 per cent urban.

(g) Intensive use of water and energy in the urbanized regions requires the introduction of recycling of water, fixed nitrogen, phosphorus, and scarce materials. The simplest solution is to produce the perishable foods within the extended metropolis. Energy saving can be accomplished with that aid of telecommunications, and electrified rail network, and a combination of light vehicles. The latter might be combined very effectively with canal transport in the largest forseeable urban aggregations.

(h) On the whole, perhaps because the Mekong has had a head start, the possibility of achieving a steady state without intervening massive catastrophe seems to exist, but there is likely to be either a close squeeze or an "overshoot" about three generations from now.

3. Impact of Pa Mong

While the Pa Mong project is critically needed for, and would be financed essentially from, power revenues, the Pa Mong project is perhaps even more critically needed as the most feasible approach to increasing agricultural productivity to meet the projected food needs of the region, especially in northeast Thailand. The increased productivity would be mostly in rice and upland crops and also in fish (both from the reservoir fishery and from fish farming) to help meet protein needs. The necessary water for enabling this increase, by

permitting cropping during the dry season, by improving cropping during the wet season, and by permitting fish farming on a continuing basis, must come essentially from mainstream storage projects.

The possible total system of water resource project development identified by the Mekong Committee would furnish, with present-day methodology, new food supplies over non-project levels to support approximately an additional 100 million people (Ref. 2).

The Pa Mong project, as the logical first major mainstream impoundment, is the key first big step in implementing the overall system plan. As noted in the discussion on agriculture, Pa Mong will make it possible (a) to virtually eliminate flooding along the middle course of the Mekong river from Pa Mong to Khone Falls, which are densely populated riverine lands, and to develop these lands by low lift pump irrigation on both sides, particularly on the Lao PDR side in the Vientiane and Savannakhet plains, (b) to irrigate up to 1,000,000 ha in northeast Thailand and the Lao PDR, and through the irrigation system to supply thousands of villages with domestic water, (c) subject to international agreement, to transfer 5,000 million $m^3$ or more of surplus water in the dry season to the central plain of Thailand, (d) to reclaim up to 200,000 ha in Democratic Kampuchea through flood control, thus utilizing lands not now usable, and to convert up to 200,000 ha from floating rice culture to other rice varieties of higher yields and quality, (e) to make available for use in the dry season in the Mekong delta some 30,000 million $m^3$ of extra fresh water, and (f) to engage in year-around fish farming throughout the lower basin.

Using the general rule of thumb that a cubic metre of irrigation water will yield at present about 0.5 kg of rice (and more of upland crops), the potential extra rice yields from the improvements noted above could support at least 25 million people in northeast Thailand and the Lao PDR alone. The additional benefits in extra food supply further downstream would be even larger because of the very large land areas which could become subject to cropping or extra cropping either through flood control or irrigation. Hence the extra food to result from Pa Mong should meet the needs of at least an additional 50 million people.

An additional very important potential which may be realized from Pa Mong will be the opportunity to demonstrate on a mass scale, especially in the irrigation service areas in northeast Thailand and the Lao PDR and in the delta, how to transform existing agricultural practices by using new concepts and methodologies which take full advantage not only of continuing improvements in agricultural technology but of the unique combination of the year-around sunshine,

year-around water available through water control, and a highly competent people. This combination represents a special asset to Southeast Asia, and if these resources can be mobilized in the lower Mekong basin, it is realistic to believe that for a long time to come the lower basin can meet its own food needs and realize major export revenues as well.

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# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## IRRIGATION AND DRAINAGE

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# PA MONG ENVIRONMENTAL ASSESSMENT

## IRRIGATION AND DRAINAGE

### 1. Introduction

The Mekong river is one of the world's largest rivers with an average annual flow more than 475,000 million $m^3$. Most of this annual flow is not utilized but passes through the Mekong delta into the South China Sea. The lower Mekong basin covers an area of more than 600,000 $km^2$ with a population in 1970 of about 30 million (Ref.1). Consumptive use of the basin waters for irrigation and water supply currently amounts to only 0.6 per cent of the total available flow. The total cultivated area in the lower Mekong basin is now approximately 10 million hectares, or 15 per cent of the total area of the basin. Of the total cultivated lands, only 213,000 hectares, or about three per cent, are currently irrigated. Several irrigation projects now under construction, or likely to be completed before 1980, will increase the irrigated area of the basin by at least 550,000 hectares to a total of over 750,000 hectares.

Planning of irrigation projects for enhancing agricultural productivity in order to meet the food requirements of growing population and also to provide a surplus for export has been carried on by all the riparian governments for the past several decades as well as by the Mekong Committee. Irrigation has been one of the major aspects of the Mekong Committee's programme for the orderly development of the water and related resources of the lower basin, including both the mainstream and tributaries, for the benefit of all the people of the basin, without distinction as to nationality, religion, politics, or other differences.

Since the formation of the Mekong Committee, 17 projects situated on the mainstream of the Mekong river and in the vast Mekong delta, and more than 90 projects situated on tributaries, have been identified as possible developments (Ref. 1, 4). Some of the mainstream projects are true alternatives competing for use of the same reach of the river. These projects have been investigated in varying degrees of detail ranging from complete study, design, and implementation for some of the tributary projects, to simple "desk studies" of some of the remote and inaccessible sites. Table 1 summarizes the major investigations of the mainstream projects for irrigation development. Tributary projects included with irrigation which are in operation or under construction are listed in Table 2. Table 3 describes those tributary projects which have been investigated at reconnaissance and feasibility levels.

Within the context of the overall planning of the Mekong Committee for development of irrigation potentials

throughout the lower Mekong basin, this discussion will evaluate the role of Pa Mong as the first mainstream project in the overall plan, from the irrigation engineering point of view. The programmes of the Mekong Committee for orderly development of the basin with respect to irrigation comprise numerous activities, carried out by the Mekong Secretariat divisions. The programme of the agricultural division includes three major categories of planning, namely (a) experimental and demonstration farms, (b) pioneer agricultural projects, and (c) regional irrigation planning. The economic and social studies division has been concerned with the socio-economic aspects of irrigation development. Detailed activities of the agricultural division and economic and social studies division to guide the continuing development of agriculture of the basin are discussed in other sections of this chapter.

## 2. Irrigation and agriculture development potential of lower basin

### 2.1 Existing conditions in lower basin

The lower Mekong basin drains an area of about 605,500 $km^2$. It includes almost the whole of the Lao PDR (202,400 $km^2$), the northern tip and northern area of Thailand (184,240 $km^2$), nine-tenths of Democratic Kampuchea (154,730 $km^2$), and the western flank and southern tip of Viet-Nam (65,170 $km^2$). As previously mentioned, a population of about 30 million lives in the basin (1970), which is not considered to be densely populated compared with most other Asian river basins, hence resources of land, forests, and water are still relatively plentiful. Historically, food production has not only kept pace with the rapidly increasing population but has provided an export surplus. As a result of continuing expansion the cultivated area now amounts to about 10 million hectares, or 15 per cent of the total area of the basin. Further increases in production by areal expansion will be progressively more difficult to obtain, and can much more easily be procured by irrigation development (Ref. 1,5).

In the past, wet-season rice cultivation was sufficient and there was little or no need to provide for multiple cropping and dry season irrigation.

The value of agricultural production in the lower basin was approximately US$ 1,000 million a year in 1970 (Ref. 1). This is roughly half of the total produced by the four riparian countries. Three agricultural zones can be identified within the basin. Table 4 shows the gross area of the basin and those areas under cultivation separated by zones and in relation to population in 1970 (Ref. 1).

Although rainfall is quite heavy during the wet season, there is insufficient rain the rest of the year to produce more than one crop in the basin. However, the temperature and other meteorological conditions are

favourable for plant growth all the year round, but the limiting factor is water supply. As mentioned previously, continuous irrigation is not extensively practised in spite of the wide expanse of suitable land; emphasis so far has been on supplementary irrigation. There has been as yet little need for multiple-cropping as increasing food requirements have been traditionally satisfied by increasing the area of single-crop cultivation.

The major dam projects completed and under construction for irrigation as well as for other purposes in the tributary basins are listed in Table 2 and are shown in the location map of Figure 1. In addition to these projects, there are a number of small tank irrigation systems in the tributary basins. In Thailand, a programme of tank construction has been in progress since 1951. The 154 tanks built for irrigation, flood control and water supply served a total irrigated area of 65,403 ha in 1970, and this total is expected soon to reach 70,923 ha. In the Lao PDR, except for the Nam Ngum project completed in 1971, irrigation has so far been confined to small tank projects. The 167 tanks constructed as of 1970 supplied 24,500 ha. The Nam Ngum project is planned to supply substantial power for pump irrigation on the Vientiane plain and the Nam Ngum valley, for more than 100,000 ha (Ref. 4). In 1969 a study commissioned by the Asian Development Bank (ADB) identified eight priority irrigation projects, totalling some 33,500 ha, within the framework of the overall development of the Vientiane plain (Ref. 20). These projects have been planned and developed under the programme of the agricultural division of the Mekong Committee. The current activities for implementation of these projects include the construction of the Casier Sud pioneer agricultural project of 5,100 ha and Tha Ngon irrigation project of 800 ha. The other projects are being planned within the context of overall development planning for the Vientiane plain.

In Democratic Kampuchea, the Bovel project will eventually service an area of 45 000 ha. The Western Baray project of 13,000 ha is the next largest single-purpose scheme in the country. Thirty-five smaller projects service an additional 29,675 ha. The multipurpose Prek Thnot project now under construction will increase the irrigated area by 7,000 ha.

In Viet-Nam, the cultivated areas are located in the Mekong delta. In the delta drainage is a key and limiting factor as well as water supply. More than 90 per cent of the delta land is heavy clay soils which are more suitable for rice than other crops. Very acid soils are common in some parts of the delta. Most of the delta soils have a low to moderate fertility level, hence more fertilizer will be needed to maintain higher production levels. Salt water intrusion also is a factor in the coastal zone.

Except in a few isolated areas the annual overflow onto the flood plain, supplemented by rainfall, is sufficient to raise a single rice crop and sometimes an additional crop as well. Within most of the delta, in both Democratic Kampuchea and Viet-Nam, it is difficult to distinguish between works undertaken for irrigation and those for drainage and navigation. Large areas in Viet-Nam are criss-crossed by canals serving all three purposes simultaneously.

## 2.2 Need for irrigation development

The development of water resources for irrigated agriculture will provide benefits to a larger area of land and to a wider section of population than any other component in the Mekong development programme. The need is to expand the output of agricultural products to meet the requirements of a growing population and to provide a surplus for export in order to finance essential imports. In attempting to meet this need, the four riparian countries could choose one of the three options (Ref. 1): (a) they could continue to utilize present agricultural practices on the existing land resources; (b) they could improve technology and cultivation methods, but without introducing water control; or (c) they could supplement such technological improvements with full control and development of the water and related resources of the Mekong and its tributaries. Analyses indicate that if either the first or second of these choices is taken, agricultural production will fail to keep pace with the rising demand. Table 5 shows the estimated food crop requirements, production possibilities without additional irrigation, and likely dificiencies, for each country in the lower Mekong basin (Ref. 1). Over the study period, production measured in tons of paddy equivalent would have to be expanded from about 12.7 million tons in 1970 to about 37 million tons by the year 2000. Calculations of alternative methods for meeting this production target indicate that the maximum possible increase obtainable without irrigation but with a 50 per cent increase in the cultivated area, would not raise production to the required level. Accordingly, irrigation is positively essential to the achievement of these production targets.

The amount of land to be brought under irrigation during the 30 year period from 1970 to 2000 will depend on various factors, including agricultural technology, the crops chosen, and the production levels likely to be achieved with irrigation. Assuming that the lower Mekong basin should meet its own food requirements (at an improved nutritional level), that it should be self sufficient in agricultural raw materials for domestic industry, and that it should continue to export food and non-food produce, then the estimated total area under irrigation will have to increase to between two and three million hectares during the 30-year period. This will require many inputs in addition to irrigation. The achievement of this goal will require a much improved

agricultural technology including the expansion of agricultural research, improvement of livestock, expansion of fish production, and a general diversification of farming systems away from the monoculture of rice. Together with those changes, there will be a need for improved institutional arrangements, particularly in the fields of land tenure, marketing, training and extension, credit, communication, and farmers' organizations.

## 2.3 Indicative basin plan

In order to plan for the orderly development of water and related resources of the basin, the Mekong Committee prepared an Indicative Basin Plan in 1970 which describes the infrastructure and services to be needed including facilities for irrigation and drainage. The Indicative Basin Plan includes (a) a short-range plan, for the decade 1971 to 1980, comprising independent projects which can satisfy the needs in rather localized areas; (b) a long-range plan, extending to the year 2000, comprising several sequences of mostly mainstream projects; and (c) a plan covering complementary programmes of research, training, and the development of infrastructure and facilities, needed to achieve the objectives in a reasonable time.

### 2.3.1 Short-range plan

The short-range plan provides for the successive implementation of independent tributary projects in the four countries to fill localized needs and meet the development objectives of the countries. It is anticipated that during the decade 1971 to 1980 the demand for additional irrigated lands capable of full double cropping will amount to 62,500 ha in Democratic Kampuchea, 15,000 ha in the Lao PDR, 144,000 ha in northeast Thailand, and 320,300 ha in Viet-Nam. These requirements can be met by a number of tributary projects including two projects (Prek Thnot and Battambang) in Democratic Kampuchea; one project (Nam Ngum) in the Lao PDR; six projects (Nam Pong, Lam Nom Noi, Lam Pao, Lam Pra Plerng, Nam Takong, and Nam Oon) in Thailand; and two projects (Upper Se San and Upper Sre' Pok) and several developmental projects in the Vietnamese delta including polderling at Cai San, An Troung, Pong Thap, and Ba The, and protecting coastal areas against seawater instruction at Tiep Nhut, Go Cong, Kien Hoa, and Vinh Loi. The locations of these projects included in the short range plan are shown in Figure 2. Table 6 lists these projects and the areas to be served including the planned commissioning period (Ref. 1).

### 2.3.2 Long-range plan

The increase in irrigated area required to meet the increasing need for agricultural production in the lower basin over the period up to the year 2000 was estimated to be 1,863,000 ha for full double cropping, as shown in Table 7. Tributary projects within the basin could service an area of about 1,212,100 ha, only 65 per cent of this requirement.

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In Viet-Nam, thirteen tributary projects, all located in the plateau area, have an aggregate capacity of 97,000 ha and represent no more than 21 per cent of the demand. These would satisfy the national development up to 1983 if the plateau alone were chosen for development. However, in planning for expansion of irrigation in Viet-Nam emphasis is being placed on the development of the delta including the coastal areas, and this is dependent on an adequate supply of fresh water during the dry season, as well as the regulation of flood flows by mainstream projects in association with the establishment of a system of dikes and control works to prevent flooding from the river and sea water intrusion. In northeast Thailand the situation is similar; the capacity of tributary projects is far less than the requirement to be met by increased irrigation. In the Lao PDR, the potential tributary projects can easily satisfy needs to the year 2000. The situation in Democratic Kampuchea is also favourable, i.e. the potential tributary projects could service 576,000 ha which is more than sufficient.

Irrigation, particularly during the dry season, will necessitate considerable regulation and storage of flood water in reservoirs during the wet season to conform with the principle adopted by the joint meeting of the lower Mekong riparian countries in 1957, that (a) the existing low water discharge of the Mekong would not be reduced in any way at any site; and (b) the supplies to be diverted for irrigation purposes would be made by storage of flow during the high stages of the river. In formulating the mainstream projects for the long-range plan of development, the Pa Mong, Stung Treng, and delta development projects are the key projects for irrigation development in the integrated plan. The Sambor project is included mainly for hydropower.

The three major multipurpose projects, Pa Mong, Stung Treng, and Sambor, have been estimated to have a capacity for full double-cropping of about 5 million ha (Ref. 1). Pa Mong, with an estimated potential of 1,630,000 ha could satisfy the requirements of the Lao PDR and northeast Thailand. Stung Treng and Sambor, with potentials of 1,287,000 and 84,000 ha respectively, could satisfy the requirements of Democratic Kampuchea, and Pa Mong and Stung Treng together would furnish sufficient dry season water to permit farmers to harvest a second crop on at least 2,050,000 ha in Viet-Nam.

### 2.3.3 Complementary programme

The Indicative Basin Plan report (Ref. 1) also outlines the complementary programme of ancillary investments needed to achieve full realization of benefits from development in the lower basin. With respect to irrigated agriculture, many activities would be involved including agricultural research, extension services, farm credit, marketing, storage institutional structures, and social development (see discussions on agriculture and on socio-economics).

## 3. Pa Mong project/irrigation and drainage

The Pa Mong project is the major mainstream project of the lower Mekong basin. Investigations on this project have been undertaken for more than 15 years for multipurpose development of which irrigation has been one of the primary objectives. The Pa Mong Phase 1 investigations included subreconnaissance characterization of 2,037,000 hectares of lands in the general area to be considered for irrigation development (Ref. 6). The objective of the Phase I studies was to determine whether there was enough land of quality suitable for irrigation development to warrant further investigation. Based on review of existing data plus an extensive soils characterization survey conducted in the field and supported by laboratory analysis, the conclusions regarding land resources were generally favorable.

The Stage One feasibility studies (Ref. 7) published in 1970, demonstrated that an initial stage of development of the Pa Mong project consisting of dams, reservoirs, and powerplants, and an initial stage of irrigation, would be an attractive project. A feasibility land classification survey was made for a total of 17,800 ha in the Lao PDR, designated as the Vientiane division, and for 78,000 ha in Thailand, designated the Huai Mong division. Selected irrigation areas of 11,420 and 31,580 irrigable hectares respectively in the Lao PDR and in Thailand were planned with feasibility layouts of irrigation and drainage facilities.

The Phase II studies (Ref. 8), issued in 1972, revised the Stage One irrigable area to be 39,990 hectares including 10,620 hectares in the Vientiane division and 29,370 hectares in the Huai Mong division, and changing the design criteria so that canals with bed width less than one metre would be unlined. Included in the Phase II studies are possible irrigation development increments to the Stage One project and the proposed inclusion of farm fish culture development on the nonarable lands. Reconnaissance investigations were made for nine irrigation divisions in addition to those considered in Stage One. It was stated that the use of a greater portion of the project water supply for irrigation and fishery uses would not significantly impair the feasibility of the planned Pa Mong power development. The development of nearly 1,000,000 hectares of lands for irrigation and farm fishery would provide development opportunities over a period of at least 50 years. Figure 3 shows the location map of the Pa Mong service area considered in the Phase II studies. The Phase II studies also outline a possible plan for transbasin diversions from the Mekong basin into Thailand to increase water supply for irrigation in the Chao Phraya basin.

The Pa Mong Optimization and Downstream Effects study includes refinement and identification of potential irrigation areas to be serviced and affected by Pa Mong including the Phase II project area, downstream areas along river banks,

and the delta area; refinement and estimation of agricultural demands and total water requirements for irrigation; and irrigation cost and benefit evaluation for both project and downstream areas.

## 3.1 Existing conditions in Pa Mong project area

### 3.1.1 Land resources

(a) Present land use: Of the total arable land in the Pa Mong project service area, about two-thirds is presently being cultivated. The present land use within the different irrigation divisions of the Pa Mong project are summarized in Table 3. About 90 per cent of the cultivated land in the Lao PDR is devoted to rice production, 2 per cent to diversified crops, and the remaining 8 per cent to fallow. In Thailand, there has been more of a shift to diversified crops. Approximately 85 per cent of the cultivated land is devoted to paddy rice and 15 per cent to diversified crops with a negligible amount to fallow and idle. Production of these lands can be increased by clearing existing trees from partially cleared fields, levelling termite mounds, and implementing improved technology to increase per hectare yields. However, large increases in agricultural production will not materialize unless an adequate and dependable water supply is made available.

(b) General soil characteristics: Characteristics of the soils were major factors in evaluating the suitability of lands for irrigation because of their strong influence on crop yields, production costs, and economic returns. The important landforms in the Pa Mong study area are river levees, active flood plains, old lowland surfaces, and uplands. Detailed information on the characteristics of these soils is given in the discussion on soils, hence the discussion here is limited to a brief description of the general land form categories.

The soils on the river levees are predominantly alluvial soils. Although they are of limited extent, occurring mainly along the Mekong river and Nam Ngum, the river levee soils are among the most fertile soils in the region and produce a wide variety of field crops, vegetables and tree crops. The soils of the active flood plain area are mainly alluvial soils and hydromorphic soils, and are used mostly for broadcast or transplanted paddy rice production in the rainy season. For this use, they are quite productive and relatively high yields are obtained when flooding is not destructive. The soils of the lowland surfaces have undergone intensive weathering and

leaching and show genetic horizon development. Paddy rice is grown on practically all of these soils, and for this use they are moderately productive, with yields being generally lower than on most active flood plain and river levee soils. A significant portion of the old lowland surfaces in some areas have laterite soils. These contain high proportions of gravelly ironstone concretions at depths less than 50 cm, and are mostly used for paddy rice culture, although their yields are usually quite low. The extensive upland areas contain a wide variety of soils, the Alfisols being the most fertile. A significant proportion of the upland soils are cultivated, especially in the areas with higher populations and good access roads. The native vegetation in most areas is rather sparse low open vegetation. The Inceptisols in upland areas are soils having very coarse texture to depth greater than 50 cm. Most attemps to cultivate these soils are unsuccessful and most areas remain under a sparse low open forest cover.

(c) Soil salinity problems: Salt-affected soils are those which contain amounts of soluble salts or of exchangeable sodium high enough to adversely affect crop production. Although they occur on less than 0.1 per cent of the total Phase II service area, they may occupy as much as 4 per cent of old lowland surfaces in semiclosed basin areas such as those in the vicinity of Udorn and Kamphawapi. The salt-affected soils are often adjacent to or intermixed with soils containing low amounts of salts in areas used for rain-fed or flood-fed paddy rice. Salt-affected soils appear to be limited to areas where saline ground water is found at shallow depth, especially where local surfaces are elevated slightly above the surrounding lands; hence relatively little leaching occurs and the salts accumulate near the surface. In active flood plain and other areas that undergo prolonged inundation, soluble salts and exchangeable sodium may be high in subsoil layers in some places, suggesting accumulation through downward displacement. Although most of the lowland and flood-plain areas east of the Phu Phan ridge are underlain by salt-bearing strata and shallow saline ground water, the total area of salt-affected soils in these areas has remained low and essentially stable. Because of their small extent and the apparent equilibrium that has been attained, the salt-affected soils are not considered to represent a problem in the region except in a few local areas.

### 3.1.2 Water resources

(a) Surface water: The main surface water runoff for the Pa Mong project is the Mekong river above the damsite. The Pa Mong water supply, supplemented by tributary runoff from the two adjoining basins of Huai Mong and Nam Lik, will be about 153,000 million $m^3$ on an annual average basis. The Mekong river begins to rise slowly in April and May and reaches its peak during the wet season months of August and September. The streamflow then recedes slowly during the ensuing dry season. The low flow seldom drops below 1,000 $m^3$/sec in April, and the high flows normally peak between 13,000 and 26,000 $m^3$/sec in August and September. The runoff of the tributary basins is subject to great seasonal variation. Most of the annual runoff, about 90 per cent, occurs in the monsoon season from May to October, and on the average about 70 per cent of the annual total is produced during the period from the beginning of September to the end of October (Ref. 9, 10). During the dry season, the runoff from the tributary rivers is very low and dries out in some the small tributaries.

(b) Ground water: Various studies (Ref. 7, 8, 11, 12) indicate that deep ground water in the Pa Mong project service area is generally not a reliable source of water. It is not unusual for deep wells to have low yields or poor quality or both. Some wells have provided satisfactory service for domestic water supply; however, hand dug wells (2 to 10 m) are still the primary source of domestic water supply in the service areas.

(c) Water quality: Surface water quality has been tested periodically on the Mekong, Nam Lik, and some small streams in the project area (see discussion on water quality). Generally, the water quality was found to be excellent (Ref. 7, 8, 11) with low dissolved solids and no harmful concentrations or adverse ratios of individual constituents. The total dissolved solids generally increases in the dry season when most of the water in the stream channel is derived from ground water. Even at very low flows, however, the water quality is satisfactory.

### 3.1.3 Drainage

The existing surface drainage network in the Pa Mong study area is typical of that found on a mature erosion surface. Although the principal outlet channels are deep (usually greater than 10 metres) and well defined, they have very low gradients with many oxbows and meandering reaches along their courses. The broad active flood plains, and old

lowland surfaces, which comprise a large portion of the study area, have many shallow channels (1 to 2 metres deep) which generally parallel the main outlets and serve as floodways during the rainy season. These channels form a braided pattern in the lowland areas and also have very low gradients. Many of the older channels and oxbows have been cut off from the better defined drainage ways so that water which collects in these shallow depressions during periods of high runoff has no outlet when the high flows recede. The main outlet channels (i.e. Mekong river, Nam Ngum, and Nam Chi) in the project area have flows for the entire year but are at low levels during the dry season. Most other drainage ways carry flows only during the rainy season.

The natural channels which carry runoff from uplands and high lands adjacent to the project area flow only during the periods of high precipitation. These channels are usually well defined in the higher lands but are normally obliterated by rice paddy development when they enter the valley floor areas. As most of these drainage ways are not connected to outlet channels, but end after reaching potential project service areas, their main effect would be concentration of runoff from higher areas to the project lands.

Runoff from adjacent higher elevated lands together with local rainfall often exceeds the capacity of the existing natural drainage network during high precipitation periods. The excess flows spread over the lowland and flood plain areas as sheet flows. While considerable use is made of this flooding in wetland rice culture, very often it is of sufficient magnitude to cause damage to the crops. Large areas are inundated to depths of two or more metres during the peak of the rainy season.

The main natural drainageways have a maximum water surface elevation of one or two metres above the lands to be drained, due to the levee system. This precludes maintaining a continuous drainage outlet for surface runoff from some lands immediately adjoining the levee system. These conditions exist primarily along the Mekong river and the Nam Ngum, and to a lesser extent along the other main drainage outlets.

Subsurface drainage conditions in the project area are considered to be generally poor. The soil profiles of the old lowland, flood-plain, and river levee areas have slow to very slow hydraulic conductivities, with low permeable materials being 1 to 3 metres in depth over barrier zones. Upland areas have moderate hydraulic conductivities with 3 to 10 metre depths of permeable materials. Low gradients and lack of outlets together with low hydraulic conductivities and shallow drainage barriers result in poor subsurface drainage conditions.

## 3.2 Land and water studies

The Pa Mong Phase I investigation undertook sub-reconnaissance characterization of 2,037,000 hectares of lands

in the general area on the Vientiane plain in the Lao PDR and in northeast Thailand. This area was subsequently covered in the Phase II studies at the reconnaissance level, except for portions of lands in the Huai Mong and Vientiane irrigation divisions. The lands in these two divisions, designated as the Stage One area, have been investigated at the feasibility grade level, and are to be included for the first stage of development of the Pa Mong project.

### 3.2.1 Land classification

The purpose of the land classification carried out by the Mekong Committee is (1) to determine the location, extent, and suitability of those lands suitable for irrigation, i.e. capable of economical production of sustained high yields of climatically adapted crops througnout the life of the project, and (2) to provide basic data essential to solving agronomic, economic, and engineering problems associated with project plan formulation. Land suitability for irrigation was measured in terms of anticipated relative net income.

The Pa Mong land resources survey area consists of lands in the northwest part of the Korat plateau in northeast Thailand and adjacent areas in the Lao PDR. The project area was divided into divisions with boundaries drawn mainly along natural features such as drainage divides or large streams. The locations of the survey area and the various divisions are shown in Figure 3 together with the types of land classification survey. In the Stage One area, the Stage One feasibility survey was conducted for the total area of 95,800 hectares, with 17,800 hectares in the Vientiane division and 78,000 hectares in the Huai Mong division. During the Phase II studies, the entire area, comprising 214,000 hectares in the Lao PDR located in the Vientiane plain and 1,944,400 hectares in Thailand including the Stage One area, was investigated (Figure 3).

Land classification hectarage summaries for the arability surveys are presented in Table 9 for the Lao PDR and Thailand divisions (Ref. 8). The arable area comprises about 52 per cent of the total 2,148,800 ha in the survey area. Classes used for land classification are based on those developed by the USBR (Ref. 6, 7, 9, 10). Less than 2 per cent of the total arable area is classified as diversified crop land and this is mainly of Class 2 quality. Class 1R and 2R lands comprise 21 and 77 per cent of the arable area, respectively. From these arable lands, the selection of potential service area and irrigable lands were made. The basis for selection was location, extent, and relative suitability of arable lands in relation to practical project canal locations which were governed mainly by relief and physiography. Table 10 shows land classification summaries by hectares for the potentially irrigable lands selected within the Lao PDR and Thailand divisions (Ref. 7).

### 3.2.2 Soil salinity

As previously mentioned, most of the Pa Mong service area is underlain by salt-bearing strata and shallow saline ground water, and salt-affected soils are found in some of the areas proposed for irrigation development. In the Phase II service areas, it is expected low salinity levels would be maintained in the soils of irrigated uplands and river levees because of their substratum permeability and gradient conditions permit the required leaching. Because of the very slow subsurface drainage in the old low land and active flood plain areas, salinity control over most of these areas would be maintained through the periodic downward displacement and diffusion processes that would continue to occur with irrigation. Irrigation water applications are expected to result in displacement of the salts initially in the soils, plus the small amounts added in the irrigation water, below the shallow root zone of rice. During the period of submergence, a certain amount of diffusion into the surface would occur. Salts that might move upward into the root zone will be removed by rainfall and irrigation preceding the next crop. Through these processes, both soluble salts and exchangeable sodium are expected to be maintained at low levels and there would be no significant reduction of rice yields (see discussion on water quality for additional details). Although favourable conclusions have been drawn in the Phase II studies, it was also recommended that a comprehensive programme for refinement of geological information and for collection of ground water, surface water, and soils data be implemented to enable more precise analysis of the effects of project development and to provide a basis for development of specific project and farm management practices to assured continued land productivity.

Another study on soil salinity problems of the Pa Mong project area was carried out in 1972 (Ref. 1[illegible]). The study objective were to evaluate the probable effects of the year-around irrigation of lands overlying the salt beds in northeast Thailand and adjacent areas of the Lao PDR upon the salt content of the surface waters and of adjoining ground water aquifers, as well as the probable effects of return flows from such irrigation on water quality of adjacent streams. Based on review of data from previous investigations and field inspections, together with field sampling and analysis of return flows in irrigated areas overlying the salt beds, several important conclusions were drawn relating to Pa Mong irrigation and drainage planning as follows:

(a) The salt deposits, which underlie approximately one-half of the area proposed for irrigation development, will have no effect on the proposed developments nor will the future irrigation result in solution of the salt beds. These deposits, when present, are at considerable depth and overlain by relatively impermeable strata. Ground water circulation resulting

from heavy rainfall or from irrigation development is at shallow depths. Present extensive irrigation in areas overlying salt beds (generally for only one crop annually) shows no problem attributable to the presence of deep-lying salt. Conversion from single crop to year-around irrigation would not change this situation.

(b) Thin efflorescent salt films now appearing on the ground surface over significant areas of the plateau during the dry season are the result of concentration and evaporation of shallow ground water, and occur primarily where local relief and soil permeabilities are such that adequate flushing is not accomplished in periods of heavy rainfall. Areas where there is widespread are generally not irrigated now nor are they planned for future irrigation. Year-around irrigation, with proper drainage facilities, will not result in an increase in the area of these efflurescent salt films and in fact should prevent their formation in some areas now producing only rainfed crops.

Further details are given in the discussion on salinity.

### 3.2.3 Drainage

Extensive surface and subsurface drainage studies were made during the Stage One and Phase II investigations. With respect to the influence of drainage on crop adaptation with irrigation, the natural subsurface drainage and barrier conditions of the Pa Mong service area are favourable for wet land rice production in most of arable lands, but only a very small percentage of lands have natural drainage conditions that are highly suitable for upland crops with irrigation. This is because diversified upland crops require an aerated root zone as well as a soil surface free from flooding or ponding, in contrast with wetland rice production which requires soil conditions with surface submergence and reduction of water requirement through control of deep percolation. The drainage investigations showed that maintenance of an aerated root zone for upland crop production through installation of artificial subsurface drains would be prohibitively expensive in most areas. Under the economic conditions expected during the planned life of the project, there are no climatically adapted upland crops that, when grown over extensive areas, will produce the extra returns necessary to justify the high cost of such drains. It is expected that upland crops will be successfully grown under irrigation on some lands without construction of subsurface drains.

With year-around irrigation, the additional water applications can be expected to cause a rise in average ground water levels. This rise can be expected to be of the order of 1 to 2 m in low lying areas and floodplains to as

much as 3 to 5 m beneath uplands. Seasonal fluctuations can be expected to be somewhat less than at present (Ref. 11). Adequate drainage will have to be provided in the irrigation developments to prevent water-logging and possible salinization of soils. Ground water movement can be expected to continue to be parallel to the land slopes, at shallow depth, from the irrigated areas to the adjacent natural or artificial drainage ways. The increased groundwater discharge together with surface runoff from irrigation will significantly increase the existing dry season base flow of most streams.

### 3.2.4 Irrigation water requirements

In the Pa Mong Stage One and Phase II studies, estimations of irrigation water requirements for the service area were based on empirical methods using information from published studies in Thailand, Philippines, Malaysia, Taiwan, the Lao PDR, and the United States. The estimates of irrigation water requirements included the following steps: (1) estimation of irrigated crop consumptive use by the Blaise - Jensen method with an assumed cropping schedule; (2) estimation of crop water requirements, which is the total water needed to obtain optimum production, by taking into account the constant cultural water requirement and average consumptive use on a percentage-of-area basis for the first and last transplanting of rice crops; (3) estimation of crop irrigation water requirements, which is the amount of irrigation water needed to supplement the effective rainfall, using 75 per cent and 76 per cent of total annual rainfall for the annual effective rainfall for the Stage One and additional Phase II areas, respectively; (4) estimation of service unit irrigation requirements, which is the crop irrigation requirement times the farm efficiency, with an assumed 70 per cent farm efficiency; and (5) estimation of irrigation diversion requirements including losses from irrigation diversion requirements including losses from irrigation canals and laterals and from project operation. The average annual diversion water requirements for irrigation of the Stage One area (initial development) and for the total area considered in the Phase II studies, for the period 1951 to 1969, are 632 and 13,673 million $m^3$ respectively (Ref. 8).

### 3.2.5 Return flows

For the Stage One development (initial stage), it was assumed that return flows from irrigation water use would not be reused in the project area. The return flows from the Vientiane division in the Lao PDR will be drained to the Mekong and Nam Ngum rivers. Part of return flows from the Huai Mong division in Thailand would be drained into Ubolratana reservoir on the Nam Pong river. In the Phase II studies, the return flows from irrigation and fishery diversions from the irrigation areas including both Stage One and the Phase II expansion were estimated to average about 4,000 million $m^3$, of which 2,500 million $m^3$ were planned to be reused in downstream divisions.

With respect to quality of return flows, the study on effects of proposed irrigation on water quality and return flows (Ref. 11) indicates that the quality of existing return flows from irrigated areas will be satisfactory, even in areas underlain by salt beds as well as where brackish to saline ground water and salty soils are most prevalent. The available data for the study are not sufficient to predict accurately the minor changes in water quality to be expected at a particular point on individual streams or tributary, but are adequate, however, to indicate that there will not be harmful deterioration in water quality as a result of the planned irrigation development. The average annual concentration of dissolved salts will increase slightly in all surface flows, because of the net depletion resulting from irrigation. However, the present quality of water in streams during low flows in the dry season months would in fact be improved as a result of proposed development. Hence, it is expected that there will be no problems of water quality of return flows from irrigation and their reuse for downstream divisions (see discussion on water quality for details).

### 3.2.6 Water utilization for irrigation

Water utilization studies for the Pa Mong project were made for the case of a high pool level of 250 m MSL, which combines storage of the Mekong river at Pa Mong together with the Nam Lik and Nam Mong, with a total reservoir capacity of 90,000 million $m^3$. For irrigation development, the initial plan includes only the Stage One service area assuming no reuse of return flows. As noted previously the Stage One area includes 10,540 and 29,250 productive hectares in the Vientiane division (the Lao PDR) and Nam Mong division (Thailand) respectively. The ultimate development after year-50 was also studied assuming a total service area of 326,320 hectares for irrigation and fishery development, and reuse of return flows where possible. The reservoir operation studies were made using the monthly flows from a 40-year period from 1930 to 1969. Table 14 presents the average allocation of water from Pa Mong reservoir for the 40 years of operation for the initial plan and for the year-50 plan. The average annual irrigation diversions were estimated at 0.4 and 7.3 per cent of the average annual inflow for the initial plan and the year-50 plan, respectively.

## 3.3 Plan of development

### 3.3.1 Distribution and drainage systems

The plan of irrigation development includes the systems of distribution and drainage networks. In the Stage One feasibility study, the distribution and drainage facilities were laid out and sized to the meet the service unit requirements. A service unit is the basic irrigation unit wherein resident farmer organizations exercise control over the distribution of water and drainage provided by the project. Topographic maps

at a scale of 1:10,000 with 1 m contour intervals were used for locating canals, laterals, and sublaterals down to the service unit turnout. Canals and laterals were located based on topography, land classification, and existing physical, boundaries such as roads, villages, dikes, ditches, etc. In the Stage One feasibility study, all canals and laterals were assumed to be lined with concrete. However, based on additional information on soil conditions, these were revised in the Phase II studies so that the canals with bed width less than 1 m were considered to be unlined. All irrigation and drainage ditches within the service unit would be unlined. A standard service unit size of approximately 60 hectares was selected mainly on the basis of judgement and water management experience in the United States and Taiwan. In the Stage One area, a distribution system with a total length of 462.5 km was planned for the project development.

Drainage studies show that precipitation during the rainy season is more critical in terms of drainage requirements than for irrigation application. This applies to both surface runoff and deep percolation to the water table. A surface drainage system will be necessary to protect the irrigation works and project lands from drainage due to flooding during the rainy season. A system which controls and removes excess water is planned for all project lands. Subsurface drains were considered for transitional lands between the paddy lands and uplands to maintain ground water tables at sufficient depths to allow for production of upland type crops. The net returns from upland crops on transitional lands when compared to the returns from rice, which could be grown without subsurface drains, were not sufficient to justify the investment required for subsurface drains. Therefore, subsurface drains are not planned for the transitional lands.

The irrigation divisions considered for later stage development potential were planned in the Phase II studies. Due to the limited information and the accuracy of available topograhic maps, the distribution and drainage networks were not as extensively laid out as those for the Stage One area. Only the main canals and some important laterals were located on the topographic maps.

### 3.3.2 Project organisation/administration

It was assumed in the Stage One and Phase II studies that all of the Mekong project features, except the irrigation, power transmission, and distribution systems, would be operated by a single international agency. For the irrigation projects, it was assumed that the responsible governmental agencies of Thailand and the Lao PDR would engage in the operation. The irrigation projects would be operated by a superintendent who would be in charge of a staff responsible for operation and maintenance of the irrigation system, and all associated f features. An agricultural section, which will perform research

and give technical advice and assistance to the farmers, will also be required. It was also assumed that the "common irrigator" concept will be practiced and the responsibility for operating and maintaining the irrigation system within a service unit will be borne by the individual farmers within the unit under the direction of the common irrigator selected by the farmers. Training the common irrigator in operation and maintenance activities as well as giving advice on irrigation farming would also be required.

The Pa Mong project will be considerably different from projects the average Thai or Lao farmer is familiar with, and he will have to become knowledgeable about the new system through communications, training, and various other means. He will have to be assured that he will receive an adequate supply of irrigation water for year-around agriculture. The government agencies of Thailand and the Lao PDR will have the responsibility of providing information and educational assistance to the farmers. These agencies will also be responsible for upgrading technical capabilities of their own personnel in order to assure success of the project (see discussion on agriculture and socio-economics for further details).

### 3.3.3 Irrigation development period

Factors limiting irrigation development appear to be the rate at which project works can be constructed, the rate at which farmers can develop the ability to fully utilize the expanded facilities, the ability of local and export markets to absorb increased production, and the availability of capital required to finance construction. The irrigation development of the Pa Mong project is planned to begin at a relatively slow rate and increase as more experience, resources, and technology become available. The effectiveness with which the first "blocks" of irrigation are developed will affect the rate of farmer acceptance in subsequent blocks. Therefore, it is recommended that the size of initial land development should be planned so that available resources can be concentrated in a relatively small area. This will increase the probability of an orderly and efficient land development programme. It is considered that the Stage One irrigation development programme would take five years, to complete the planned irrigation facilities. Feasibility studies and engineering investigations for the additional irrigation divisions included in Phase II should be deferred until such time as a decision is reached to build the first stage of the project and the need for further development is closer at hand.

The rate of acceptance of the Pa Mong irrigation project should be considerably more rapid than it has been for other irrigation projects in the general area, provided the assured conditions materialize. Under the conditions considered in the study (Ref. 3), it is estimated that 5 years under wet season irrigation and 10 years under dry season

irrigation, following initial delivery of water, will be required to realise full irrigation benefits.

## 4. Irrigation projects related to Pa Mong

Areas to be irrigated from Pa Mong reservoir release may be classified into three or possibly four general areas (Ref. 13) including those in northeast Thailand and the Vientiane plain of the Lao PDR to be irrigated directly by diversions from the reservoir, those along the river banks downstream to be irrigated by pumping, the Mekong data area, and perhaps at some future time the central plain of Thailand by transbasin diversion. The studies of the Pa Mong project made by the USBR (Ref. 7, 8) emphasizes the areas in northeast Thailand and in the Vientiane plain of the Lao PDR. The possible schemes of transbasin diversions from Pa Mong reservoir to the Chao Phaya plain in Thailand were also outlined in the Phase II studies.

It has been recognized that the benefits of Pa Mong on downstream irrigation would be substantial, so the Pa Mong Optimization and Downstream Effects study includes a programme for irrigated agricultural studies in order to determine the value of Pa Mong storage in increasing agricultural production in the downstream areas from Pa Mong to the Mekong delta. Brief reviews of planned irrigation projects related to the Pa Mong project including the delta development, mainstream irrigation projects, and tranbasin division plan are presented in this section (Ref. 14).

### 4.1 Delta development

The Mekong delta is a vast agricultural area of the basin covering 1.6 million hectares in Democratic Kampuchea and 3.9 million hectares in Viet-Nam. Technical development is still in an early stage and further development with water control projects can significantly enhance the agricultural productivity. The Mekong Committee together with the Netherlands Government undertook a four-year programme to draw up the basis for a master plan for agriculture development in the Mekong delta and completed the study report in April 1974 (Ref. 15). A summary of the report of this Delta Team study is presented in the discussion on agriculture.

The ultimate objective is a planned programme for long-range comprehensive development of the Mekong delta in Democratic Kampuchea and Viet-Nam. The immediate goal has been to complete a study providing the technological, agricultural and socio-economic information to enable short-term planning and to serve as the first step in long-range planning. The study included those parts of the delta in Democratic Kampuchea and Viet-Nam where security conditions permitted work to be done. This meant in effect that the team's work in Democratic Kampuchea part of the delta was severely curtailed.

For the purposes of the study, the Vietnamese part of the delta was divided into 13 regions, each with fairly uniform agricultural potential with respect to sea water intrusion, flood protection, gravity irrigation, drainage, and soil acidity. For each region a number of short-term and long-term development possibilities, including specific problems, were examined from the economic, social, and technical point of view. It appears that the greatest long-term prospects for increased agricultural production in the delta is in augmentation of dry-season flows by release of water from upstream reservoirs, although, nevertheless, a large increase would still be possible by means of better control, including salinity control, of existing water resources even without such increase in low flow. Another important conclusion was that the investments needed to increase production substantially would be relatively low for large areas in the delta, because a great number of canals and other water control structures already exist. With this study, the basic information needed to formulate realistic priorities for agricultural development in the Vietnamese part of the delta is now available.

In 1973 the Delta Team identified and formulated specific water control projects suitable for early implementation, which would be compatible with long-term development planning. The team identified five such projects, four irrigation projects and one project for salinity control, and it is proposed to implement some of these in the immediate future. The four irrigation projects are (a) Ke Sach with an irrigation area of 13,000 hectares in the first phase, to be later increased to 25,000 hectares; (b) Can Tho with an irrigation area of 12,000 hectares in the first phase; (c) Huong Ly, in Kien Hoa, with an irrigation area of 12,200 hectares in the first phase; and (d) Kien An, southeast of Rach Gia, with an irrigation area of 12,200 hectares in the first phase. Ke Sach has been selected as the first priority project, and the Netherlands has been asked to assist in developing an overall plan for Ke Sach (60,500 hectares), including designs and tender documents for the 25,000 hectares first phase.

The Netherlands Government has also agreed to continue assisting the Mekong Committee by providing experts to the Secretariat with special responsibility for delta development work in Viet-Nam. As a further contribution by the Netherlands Government, a mathematical tidal model of the Mekong and Bassac rivers with their estuarine branches is being prepared. This model can be used for studying the effects of fresh water depletion in the dry season, and the effects of low flow increases brought about by upstream storage projects, on the hydraulic conditions of the delta in general and on salinity intrusion in particular.

## 4.2 Sambor project

The Sambor project is one of the first priority projects

on the mainstream recommended by the Bureau of Flood Control of ECAFE in 1956 (Ref. 3). During the period 1961 to 1967, an investigation of this project including preliminary and detailed field investigations was made for the Mekong Committee by a Japanese team sponsored by the Japanese Government. The report of this investigation was completed in 1969 (Ref. 16). The initial study of the Sambor project was made as an isolated project without considering any upstream projects; however, with the progress of studies on Pa Mong, evaluations of the Sambor project together with other projects including Pa Mong have been made.

The Sambor project has been planned for multipurpose development for power, navigation, and irrigation. Power generation is most important with respect to the cost allocations and the benefits to be obtained. The percentage of the estimated construction cost for irrigation was about 10 per cent of the total construction cost. The irrigation area planned for the Sambor project is located downstream from the damsite, with the irrigation service area entirely in Democratic Kampuchea, including 69,000 hectares extending downstream of the damsite to the boundary of Kratie province. Investigations revealed that 34,000 hectares would be technically and economically suitable for irrigation development.

The total water requirement upon completion of the programme was estimated at 428 x $10^6 m^3$ of which 238 x $10^6 m^3$ would be supplied from the Sambor reservoir and 230 x $10^6 m^3$ from the Mekong mainstream and tributaries as well as lakes and swamps. Due to limitations imposed by topography and cost, only 45 per cent of the development area would be covered by the network of the pump irrigation system. It was considered suitable to divide the area into 12 districts based on irrigation, drainage, and farm management considerations. Also, flood protection and drainage were considered; however, provision of flood protection and drainage systems for the entire development area could not be justified without upstream reservoirs such as Pa Mong and Stung Treng. Hence, the drainage improvement was planned only for 2,845 hectares.

The studies for the Sambor project which consider the availability of upstream storage from Pa Mong and Nam Ngum have mainly focused on the effects of the upstream projects on increased power production. However, the increase in runoff in the Mekong river during the dry season and the low-cost power supplied by the Sambor project together would be a major contribution to the development of up to three million hectares of delta lands, in addition to the 34,000 hectares downstream of Sambor dam.

The current investigations related to the Sambor project by the Mekong Committee are in connexion with the Pa Mong downstream effects studies. Consideration is being given to both power and irrigation possibilities in a system operation with upstream storage at both Pa Mong and Stung Treng (Ref. 4, 14).

## 4.3 Irrigation along river banks

As mentioned previously, a potential irrigation area which can benefit from the Pa Mong project is the land along the river banks downstream from the Pa Mong dam to the delta which can be irrigated by pumping (Ref. 16, 24). This stretch, with little interruption along both banks of the river from Vientiane to the Vietnamese border, while not extensive in area, is well suited to diversified cropping and is heavily populated. The extent of river bank lands economically irrigable by pumping is being identified and evaluated by the Mekong Committee under the irrigated agricultural studies programme of the Pa Mong Optimization and Downstream Effects study (Ref. 14).

## 4.4 Transbasin diversions

Pa Mong Phase II studies outlined the possible schemes of transbasin diversions from Pa Mong reservoir to the Chao Phraya river basin located in the central plain of Thailand. It was pointed out that the diversions would greatly benefit Thailand as the available water resources of the Chao Phraya basin would be limited with respect to the development potential. International agreements among the riparian countries would be necessary for such development. To determine the amount of water to be diverted it will be necessary to consider the following factors: (a) inventory of existing and potential storage available to regulate diverted water; (b) estimate of the amount of water needed to supplement the present water supply to develop potential land resources; and (c) determination of the amount of Mekong river allocated to Thailand for export from the Mekong basin. Based on review of the available information (Ref. 17, 18, 19), the irrigation diversion requirements for wet and dry season irrigation both for present and potential projects were estimated and the annual supplemental irrigation requirements together with four schemes of transbasin diversions were investigated. The transbasin diversion schemes would greatly aid future development of the lower Chao Phaya basin. Approximately 2.2 million hectares could produce two crops per year and provide food for about 20 million people.

## 4.5 Vientiane pump irrigation project

During 1970 an Asian Development Bank technical assistance mission completed a report (Ref. 20) on an integrated agricultural development programme for the Vientiane plain in the Lao PDR. The report identified eight project zones suitable for irrigation development, totalling some 33,500 hectares. Because this constituted the area included in the Stage One Pa Mong feasibility report for gravity irrigation, the USBR made a further feasibility study of 10,000 hectares for USAID based upon pumped irrigation from the Mekong in the period until the Pa Mong dam is built (Ref. 21). The primary objective of the investigation is to determine whether it is possible to provide for early irrigation development of a small unit of land in the Vientiane plain of the Lao PDR

prior to construction of Pa Mong dam.

Two basic analyses were made of the Vientiane pump irrigation project. One assumed that the Stage One Pa Mong project would be built and the other assumed that it would not be built. These alternative plans were all based on the assumption that the pumping project would be put into service at least 9 years before the Pa Mong project could be built. For the analysis assuming that Pa Mong would be built, early construction of the pumping project is compatible with the plans for irrigation on the Vientiane plain presented in the Stage One report. On a reconnaissance basis, service by pumping from the river appears to be less expensive than gravity diversion out of Pa Mong reservoir for serving approximately the same lands. Furthermore, unlike the gravity scheme, water delivered by pumping would be released through the powerplant creating power benefits. Thus, even under the assumption that the Stage One project were to be built, the lands in the vicinity of the city of Vientiane could be served at lower cost by a pumping scheme.

The greatest justification for the pumping project, assuming the construction of Pa Mong, is its role as a pilot irrigation project for an early introduction of irrigation into the Pa Mong service area at relatively low cost. The pilot project would provide an opportunity for the local people to adjust their life style and work habits to intensified irrigated agriculture practices before the commitment is made to invest in full development of the Pa Mong project.

The analysis assuming Pa Mong would not be built was formulated to maximize net benefits. Three plans were formulated for pump irrigation and flood control of the irrigation area and Vientiane city. The best plan was selected for feasibility evaluation. The study showed the plan to be both technically and economically feasible. Further details are given in the discussion on agriculture.

## 4.6 Pioneer agricultural projects

As previously noted, the programme of the agricultural division of the Mekong Committee includes numerous activities for enhancing the productivity of the lower Mekong basin. Included in the programme are the pioneer agricultural projects, intended to demonstrate how a successful farming community operation can be established as promptly as possible on full-scale demonstration farming areas, so that the results can be progressively applied to implement major regional irrigation schemes like Pa Mong. The pioneer projects included in the Mekong Committee's plans represent the largest programme for agricultural demonstration for any major water resources dam project yet undertaken. At present a total of 15 pioneer projects are included in the programme. Numerous problems are being investigated and considered in planning and implementing the pioneer projects including problems on irrigation

water supply, irrigable lands, drainage, operation and maintenance, water control, and socio-economic aspects. These pioneer agricultural projects are reviewed and described in the discussion on agriculture.

5. Effects of Pa Mong on irrigation development

The probable effects of the irrigation and drainage system expected to result from the Pa Mong project are closely implicated with the environmental aspects of many other features of the project (see discussions on agriculture, surface water, water quality, salinity, ground water, socio-economics, human ecology, public health, flood control, and soils and fisheries). The probable effects of irrigation and drainage may be described as follows:

5.1 Basin water resources

Pa Mong project irrigation will affect the surface runoff of the Mekong river and tributaries in the service area, and the ground water pattern. The downstream irrigation projects will also be affected by the regulation of the Pa Mong reservoir for flood control and low flow augmentation. These effects may be summarized as follows:

(a) Under the plan of development considered in the Phase II studies (Ref. 8), approximately 13,900 million $m^3$ of surface water would be annually diverted from Pa Mong reservoir to the irrigation service areas for irrigation, fish farming, and domestic, municipal and industrial water supply, of which 13,700 million $m^3$ would be for irrigation. The net return flows were estimated at 1,500 million $m^3$. Hence, the total annual depletion of Mekong river runoff for the above mentioned purposes would be 12,200 million $m^3$. This is not a significant amount compared with the total average annual runoff of the Mekong river, combined with Nam Lik and Nam Mong, of 153,000 million $m^3$. This diversion also would not affect the principles of the agreement between the countries on the use of mainstream surface water.

(b) The existing ground water resources in the Pa Mong service area will be affected by the additional water from the Pa Mong reservoir applied for irrigation. An analysis of effects of proposed irrigation on ground water (Ref. 11) concluded that year-around irrigation with additional water applications could be expected to cause a rise in average ground water levels of the order of 1 to 2 m in low-lying areas and flood plains, to as much as 3 to 5 beneath uplands. Seasonal fluctuations would be somewhat less than at present. Adequate drainage will have to be provided in the irrigated areas to prevent water logging and possible salinization of soils. The ground water discharge will increase as a result of

irrigation. Approximately 10 to 15 per cent or more of water diverted for irrigation will reappear as the ground water discharge component of the total return flows and many smaller streams that are now intermitent would flow perenially. The increased ground water discharge, together with surface runoff irrigation, will significantly increase the existing dry season base flow of tributary streams.

(c) The proposed irrigation development might affect the quality of natural waters. Pollution of natural water with pesticides, herbicides, and other residual chemicals in a universal problem and large-scale and continuing research programmes in the developed countries are aimed at developing the best practicable control procedures. Also, because the Pa Mong irrigation area is underlain by salt deposits, studies have been made to evaluate this effect on the quality of return flows (Ref. 1[illegible]). The conclusions made by the studies are that the salt deposits will have no effect on the irrigation, i.e. will not result in solution of the salt beds, because these deposits are at considerable depth and overlain by relatively impermeable strata and the ground water circulation resulting from rainfall and irrigation is at shallow depth. The quality of water of Pa Mong reservoir is excellent. Study of the quality of return flows from the existing irrigated areas is good, even in areas underlain by salt beds. It was concluded that there will be no harmful deterioration in water quality as a result of the planned irrigation development, and in fact the quality of water in tributary streams will be improved because of the increase in dry season flows. However, continuous monitoring of surface water quality is needed to alleviate any problems that might occur.

(d) The planned drainage system for the irrigation area together with the operation of Pa Mong reservoir will beneficially affect irrigation development. The surface drainage system will reasonably protect lands from damage due to flooding caused by rainfall and runoff, and would also help prevent reduction in crop yields due to ponding of excess water on the lands. Under the operation of Pa Mong reservoir, flooding caused by overland flows from the Mekong river will be much reduced thus benefitting both irrigation and drainage. The drains discharging to the Mekong river will also be provided with flap gates to prevent back-up of water from the Mekong river into the lowland irrigation area.

(e) The regulation of the Pa Mong reservoir will certainly increase the low flows of the Mekong river downstream from the damsite. The system seasonal power regulation study of Pa Mong reservoir (Ref. 22) shows that

Pa Mong dam will contribute additional flow during the dry season (November to January) ranging from 2,170 $m^3$/sec for a high pool level of 260 m MSL to 970 $m^3$/sec for a 230 m MSL high pool level. This increase of dry season flow together with flood control regulation by Pa Mong will achieve major benefits in agricultural productivity in both Democratic Kampuchea and Viet-Nam (see discussion on agriculture).

## 5.2 Land resources and soils

(a) Presently, the lands in the Pa Mong project area are used mostly for single-crop production. With irrigation development, these lands will be fully utilized for year-around irrigation. The major land-related problems which might be adversely affected by year-around irrigation are the impairment of the qualities of productive soils and soil salinization. Except for the river levee and flood plain soils, available and reserve supplies of most plant nutrients appear to be low or very low in soils of the project area (Ref. 7). However, there is still no evidence to indicate that the proposed irrigation will impair the qualities of productive soils. Although the soil fertility may be depleted under intense cultivation with application of irrigation water, correction of this problem could be met by fertilizer inputs and good farm management practices. Although there are small but conspicuous areas of salt-affected soils in the study area, control of soluble salts and exchangeable sodium at favourable levels in the soils is expected with irrigation development. Thin efflorescent salt films now appearing on the ground surface over some areas during the dry season, are the result of concentration and evaporation of shallow ground water and occur primarily where local relief and soil permeabilities are such that adequate flushing is not accomplished in periods of heavy rainfall. Areas where this is widespread are not generally planned for irrigation. Year-around irrigation with proper drainage facilities, will not result in an increase in the area of these efflorescent salt films.

In the Phase II studies (Ref. 8), some 1,000,000 hectares of lands were identified as suitable for irrigation. It was mentioned that these lands would provide development opportunities for more than 50 years. However, other land areas of the lower basin may offer equal or better opportunities for irrigation development. Hence, future planning for irrigation from the Pa Mong project should consider these lands along with other land areas so that environmental effects associated with irrigation could be minimized.

(b) The construction and operation of distribution and drainage systems may involve soil stability, erosion, and sedimentation problems. Water depths in the canals might vary from flowing to static conditions over a short period of time, and hydrostatic pressure from bank storage behind canal linings will be high under these conditions. The distribution systems within the service units will also be subject to severe conditions caused by water storage within the paddies, resulting in ponding against the lateral banks during periods of heavy rainfall. Torrential rainstorms, together with high velocity winds, will introduce debris and foreign material into the channels which could cause plugging and resultant system delivery stoppages or failures. Surface drain channels may also be adversely affected by the sudden changes in flow, especially during the initial years following construction before the banks have had a chance to become stabilized. However, these effects are localized and may be alleviated by careful design, construction, and maintenance and operation.

## 5.3 Ecological effects

The Pa Mong project includes fishfarm development on nonarable lands in the Pa Mong service area, with water furnished by the irrigation distribution system. Hence fish production in the project area will increase greatly (see discussion of fisheries). Also, the presence of aquatic weeds may pose a serious and costly treat to project facilities (see discussions on aquatic biology and on reservoir ecology). It should be noted that careful water quality control will be required to control pollution to maintain minimum water quality levels needed for uses such as fish propagation and community water supply.

## 5.4 Agricultural production

The Pa Mong irrigation project will greatly increase the agricultural production of the region. As stated previously, the irrigation areas to be benefited from Pa Mong project include (1) the Pa Mong project area of about 1,000,000 hectares in the Lao PDR and northeast Thailand, by gravity diversion from Pa Mong reservoir; (2) areas along river banks downstream from Pa Mong dam, by pump irrigation; (3) the Mekong delta area of some 3 million hectares; and possibly (4) transbasin diversions for irrigation of 2.2 million hectares in the central plain of Thailand. It is estimated that the annual increase in rice production in the Pa Mong project area alone would be about 3.7 million tons (see discussions on agriculture and on human ecology).

## 5.5 Community water supply and public health

One of the beneficial aspects of irrigation will be the availability of a dependable potable water supply for

communities and industries in the service area. The mineral quality of water from the Pa Mong reservoir is excellent for such purposes. The availability of an assured community water supply will greatly improve community public health and contribute greatly to reduction in communicable diseases now prevalent in the areas to be serviced. Also, benefits will also come indirectly from irrigated agriculture through the production of higher protein foods to improve levels of nutrition.

More detailed discussion of the public health effects to result from irrigation development, including consideration of malaria and other water-oriented diseases, are presented in the discussion on public health.

5.6 Socio-economics

The Pa Mong irrigation development will have major impacts on socio-economics of the basin (see discussion on socio-economics).

5.7 Summary of probable effects

The probable effects of Pa Mong project on irrigation development listed above are mostly beneficial to the basin population. Some minor detrimental effects might also be anticipated; however, these effects can be corrected by continuous monitoring, additional research and investigations, and effective planning and management. In summary, the Pa Mong irrigation system should have few adverse effects on environmental values in the lower basin but should contribute immensely to the welfare of the region.

5.8 Different pool levels

With respect to different pool levels at Pa Mong reservoir, the probable effects should be a similar nature regardless of pool level selected. The magnitude of effects will of course depend primarily on the extent of the land areas to be irrigated.

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TABLE 1

SUMMARY OF INVESTIGATIONS OF MAINSTREAM PROJECTS FOR IRRIGATION DEVELOPMENT

| Project Name | Project Location | Stage of Investigation | References | Description of Activities |
|---|---|---|---|---|
| Pa Mong | Thailand, the Lao PDR | Stage One development | 7 | Feasibility planning of Stage One irrigation covering an area of 40,000 hectares. |
| | | Share II extension | 8 | Reconnaissance planning of irrigation extended from Stage One development covering 800,000 hectares of irrigation lands including Stage One. |
| | | Optimization and downstream effects | 13 | Determination of value of Pa Mong storage in increasing agricultural production to meet the estimated demands by regions including downstream irrigation areas to be irrigated by releases from Pa Mong. |
| Sanbor | Democratic Kampuchea | Feasibility planning | 16 | To justify the technical and economical feasibility of the project for multipurpose development including planning for irrigation development of 34,000 hectares downstream from the damsite to the boundary of Kratie. |
| Delta Development | Democratic Kampuchea, Viet-Nam | Master planning | 15 | Comprehensive studies for agricultural development; identification of development potentials including improved water control; and planning for delta development |
| | | | 4 | A follow-up action of delta development with identification and formulation of five projects suitable for early implementation. |

TABLE 2

TRIBUTARY IRRIGATION PROJECTS IN OPERATION AND UNDER CONSTRUCTION

| Project Name | Country | Source of Finance | Year of Inauguration | Description of Irrigation Activities |
|---|---|---|---|---|
| (A) Projects in Operation | | | | |
| (1) Bovel | Democratic Kampuchea | Democratic Kampuchea, France | 1969 | Irrigation is serviced by a canal network using water diverted from Stung Mongkul Borey, for irrigating 30,000 hectares and could be expanded to 45,000 hectares. |
| (2) Nam Dong | Lao PDR | France, Lao PDR | 1971 | Main purpose for power generation with minor diversion for local irrigation. |
| (3) Nam Ngum | Lao PDR | Nine countries and Lao PDR | 1971 | Main purpose for power generation but will supply power for pump irrigation in Vientiane plain and Nam Ngum valley. |
| (4) Nam Pung | Thailand | Thailand | 1965 | For power generation with power output for pump irrigation in Sakon Nakhon and Nakhon Phanom. |
| (5) Nam Pong | Thailand | Thailand, Germany | 1966 | First-stage irrigation area of 85,000 hectares on the left bank is under construction in 1974 and the ultimate irrigation development scheme will cover 53,000 hectares. |
| (6) Lam Pra Plerng | Thailand | Thailand, USA | 1967 | The total service area is about 10,500 hectares, of which the whole can be irrigated in wet season and about 60 per cent in dry season. In 1974, the whole area was serviced in wet season, but only 10 per cent in dry season. |
| (7) Lam Pao | Thailand | Thailand, USA | 1968 | The project is designed for irrigating 54,000 hectares in wet season and 40,480 hectares in dry season. By the end of 1974 about 50 per cent of total project work was completed and about 18,000 hectares has been irrigated in wet season. |

TABLE 2 (Cont'd)

| Project Name | Country | Source of Finance | Year of Inauguration | Description of Irrigation Activities |
|---|---|---|---|---|
| (8) Lam Takong | Thailand | Thailand | 1970 | The total service area is about 38,000 hectares in wet season and 27,000 ha in dry season. In 1974 about 16,000 hectares has been irrigated in wet season. |
| (9) Lam Dom Noi | Thailand | Thailand, Japan | 1971 | The project is designed for irrigation area of 33,000 hectares. The irrigation work is under construction of which 13 per cent of work was completed for pumping station and 21 per cent for irrigation system in 1974. |
| (10) Nam Oon | Thailand | Thailand, USA | 1974 | The project is designed for irrigating 32,480 hectares in rainy season and 10,080 hectares in dry season. In 1974 about 1,000 hectares received water for irrigation. |
| (B) Project Under Construction | | | | |
| (1) Prek Thnot | Democratic Kampuchea | Twelve countries and Democratic Kampuchea | | The ultimate scheme will supply water for irrigation of 70,000 hectares included with pioneer agricultural programme and on-farm development. |

TABLE 3

TRIBUTARY IRRIGATION PROJECTS/RECONNAISSANCE AND FEASIBILITY STUDIES

| Project Name | Country | Co-Sponsors | Date of Completion | Type of Study | Description of Activities |
|---|---|---|---|---|---|
| (1) Battambang | Democratic Kampuchea | UN | 1964 | Feasibility | The project study made by SOGREAH recommended four stages of development for power and irrigation of some 68,000 hectares. The first stage includes irrigation development of 23,000 hectares and the third stage covers additional irrigation area of 45,000 hectares. |
| (2) Stung Treng | Democratic Kampuchea | Japan | 1971 | Feasibility | The investigation carried out by OTCA envisage construction of a dam on the Stung Chinit to provide irrigation for 25,400 hectares and power generation. |
| (3) Nam Theun | Lao PDR | France | - | Reconnaissance | Desk studies indicate that Nam Theun 2 could provide low flow increase to irrigate up to 70,000 hectares in the lower Se Bang Fai and another 200,000 hectares further downstream in the Lao PDR, Democratic Kampuchea and the Mekong delta. Reconnaissance by SOFRELEC will start as soon as circumstance permit. |
| (4) Nam Mae Kok | Thailand | Germany | 1973 | Pre-feasibility and feasibility | A feasibility study for a multipurpose project on the lower Mae Kok is being carried out and is schedule for completion in 1975. Pre-feasibility of the Fang basin, a tributary of Mae Kok, for irrigation completed in 1973, recommended two priority projects, Nam Mae Sao and Nam Mae Na Wang. |
| (5) Nam Mae Ing - Mae Lao | Thailand | Switzerland | 1972 | Reconnaissance | Study was made for ground water and surface water resources in the basins. Five projects, irrigating up to 71,000 hectares were selected for further study. |

TABLE 3 (Cont'd)

| Project Name | Country | Co-Sponsors | Date of Completion | Type of Study | Description of Activities |
|---|---|---|---|---|---|
| (6) Nam Mun | Thailand | USA | 1971 | Feasibility | Investigations of Nam Mun project south of Nakorn Ratchasima was made by USBR for irrigation development of up to 19,500 hectares by gravity flow and for domestic, municipal, and industrial water supply. |
| (7) Nam Chi | Thailand | USA | 1972 | Feasibility | Investigations of Nam Chi project on the upper reach near Chaiyaphum was made by USBR to irrigate more than 30,000 hectares. |
| (8) Upper Se San | Viet-Nam | Japan | 1966 | Reconnaissance and Feasibility | Reconnaissance study carried out by Nippon Koei for the overall development potential of upper Se San basin for power and irrigation. Feasibility studies for three small irrigation schemes for 6,900 hectares and for initial-stage for run-of-river power project and for pump irrigation were also carried out. |
| (9) Krong Buk | Viet-Nam | Japan | 1966 | Reconnaissance | Investigations were carried out by OTCA of Japan on a tributary of the upper Sre Pok river for irrigation serving 6,500 hectares in the central highlands of Viet-Nam. |

TABLE 4

CULTIVATED AREAS IN LOWER MEKONG BASIN IN 1970[a/]

(from Ref. 1)

| Zone | Gross Area (million ha) | Cultivated Area (million ha) | Per Cent Cultivated | Rural Population (millions) |
|---|---|---|---|---|
| Hills | 16.0 | 0.6 | 3.7 | 2.4 |
| Plateaux[b/] | 41.6 | 6.3 | 15.1 | 15.0 |
| Floodplains[c/] | 6.9 | 3.0 | 43.5 | 8.4 |
| All zones | 64.5 | 9.9 | 15.3 | 25.8 |

a/ Mekong Secretariat estimates based on 1965 data.

b/ By "plateaux" is meant the Korat plateau, the Vientiane plain, various tributary plains and the northern plains of Democratic Kampuchea.

c/ By "floodplains" is meant the lower Mekong floodplains, below Kompong Cham, extending to the sea.

TABLE 5

PROJECTED FOOD REQUIREMENTS, PRODUCTION, AND DEFICIENCIES IN LOWER MEKONG BASIN FOR YEAR 2000
(Quantities in thousands of metric tons of paddy equivalent)
(from Reference 1)

| Region | Year | Planted Area (000 ha) | Production (without irrigation) | | Requirment | Deficiency | |
|---|---|---|---|---|---|---|---|
| | | | Upper Estimate | Lower Estimate | | Based on Upper Estimate | Based on Lower Estimate |
| Democratic Kampuchea | 1963-68 | 2,719 | 3,109 | 3,109 | 3,121 | 12 | 12 |
| | 1970 | 2,867 | 3,567 | 3,543 | 3,600 | 33 | 57 |
| | 1975 | 3,023 | 4,090 | 4,038 | 4,187 | 97 | 149 |
| | 1980 | 3,176 | 4,699 | 4,589 | 4,917 | 218 | 328 |
| | 1985 | 3,340 | 5,376 | 5,219 | 5,831 | 455 | 612 |
| | 1990 | 3,495 | 6,160 | 5,916 | 6,980 | 820 | 1,064 |
| | 1995 | 3,664 | 7,070 | 6,718 | 8,430 | 1,360 | 1,712 |
| | 2000 | 3,825 | 8,089 | 7,607 | 10,295 | 2,206 | 2,688 |
| Lao PDR | 1963-68 | 908 | 774 | 774 | 842 | 68 | 68 |
| | 1970 | 967 | 928 | 916 | 1,016 | 88 | 100 |
| | 1975 | 1,027 | 1,116 | 1,086 | 1,227 | 111 | 141 |
| | 1980 | 1,086 | 1,343 | 1,283 | 1,481 | 138 | 198 |
| | 1985 | 1,146 | 1,606 | 1,510 | 1,783 | 177 | 273 |
| | 1990 | 1,205 | 1,902 | 1,766 | 2,129 | 227 | 363 |
| | 1995 | 1,266 | 2,245 | 2,061 | 2,536 | 291 | 475 |
| | 2000 | 1,316 | 2,646 | 2,404 | 3,073 | 427 | 669 |
| Northeast Thailand | 1963-68 | 2,878 | 3,339 | 3,339 | 3,339 | - | - |
| | 1970 | 3,046 | 3,871 | 3,827 | 3,964 | 93 | 137 |
| | 1975 | 3,229 | 4,495 | 4,387 | 4,757 | 262 | 370 |
| | 1980 | 3,420 | 5,222 | 5,029 | 5,759 | 537 | 730 |
| | 1985 | 3,611 | 6,040 | 5,731 | 7,024 | 984 | 1,293 |
| | 1990 | 3,807 | 6,932 | 6,514 | 8,569 | 1,637 | 2,055 |
| | 1995 | 4,006 | 7,929 | 7,381 | 10,444 | 2,515 | 3,063 |
| | 2000 | 4,208 | 9,042 | 8,340 | 12,843 | 3,801 | 4,503 |
| Basin area Viet-Nam Secretariat estimates a/ b/ | 1963-68 | 1,705 | 3,554 | 3,554 | 3,647 | 93 | 93 |
| | 1970 | 1,841 | 4,006 | 3,962 | 4,134 | 128 | 172 |
| | 1975 | 1,988 | 4,525 | 4,423 | 4,737 | 212 | 314 |
| | 1980 | 2,097 | 5,098 | 4,926 | 5,485 | 387 | 559 |
| | 1985 | 2,238 | 5,752 | 5,499 | 6,410 | 658 | 911 |
| | 1990 | 2,396 | 6,508 | 6,157 | 7,565 | 1,057 | 1,408 |
| | 1995 | 2,570 | 7,346 | 6,909 | 9,014 | 1,668 | 2,105 |
| | 2000 | 2,765 | 8,325 | 7,784 | 10,843 | 2,518 | 3,059 |
| Basin area Viet-Nam Alternative estimate c/ | 1963-68 | 1,924 | 4,028 | 4,028 | 4,100 | 72 | 72 |
| | 1970 | 2,038 | 5,020 | 4,450 | 4,890 | 0 | 440 |
| | 11975 | 2,133 | 5,430 | 4,820 | 6,190 | 760 | 1,370 |
| | 1980 | 2,205 | 5,740 | 5,135 | 7,350 | 1,610 | 2,215 |
| | 1985 | 2,287 | 6,070 | 5,435 | 9,250 | 3,180 | 3,815 |
| | 1990 | 2,348 | 6,330 | 5,690 | 11,160 | 4,830 | 5,470 |
| | 1995 | 2,408 | 6,550 | 5,915 | 13,500 | 6,950 | 7,585 |
| | 2000 | 2,445 | 6,700 | 6,050 | 16,300 | 9,600 | 10,250 |

a/ Covers sixteen deltaic provinces within the lower Mekong basin.

b/ Est. by Mekong Secretariat in 1969 as part of estimates for all four riparian countries.

c/ Based on alternative estimates furnished March 1971 by Government of Viet-Nam

TABLE 6

IRRIGATION PROJECTS CONSIDERED FOR THE SHORT RANGE PLAN (1970-80)

(from Reference 1)

| Country | Name of Project | Area to be Served | Recommended Commissioning Period |
|---|---|---|---|
| Democratic Kampuchea | Prek Thnot (under construction) | 5,000 ha in Phnom Penh | 1971-1975 |
| | Battambang (1st stage) | 23,000 ha in western area | 1971-1975 |
| | Battambang (2nd stage) | 45,000 ha in western area; Battambang - Siemreap | 1976-1980 |
| | Total | 103,000 ha | |
| | Projected area requirements (1971-1980) | 62,500 ha | |
| Lao PDR | Nam Ngum (1st stage) | 5,000 ha in Vientiane plain | 1971-1975 |
| | Nam Ngum (2nd stage) | 30,000 ha in Vientiane plain | 1976-1980 |
| | Total | 35,000 ha | |
| | Projected area requirements (1971-1980) | 15,000 ha | |
| Thailand | Nam Pong (completed) | 53,000 ha in western area | 1971-1975 |
| | Nam Pung (completed) | 14,000 ha in central area | 1971-1975 |
| | Lam Pao (under const.) | 62,000 ha in central area | 1976-1980 |
| | Lam Pra Plerng (under const.) | 13,000 ha in southwest area | 1976-1980 |
| | Lam Takong (under const.) | 33,600 ha in southwest area | 1976-1980 |
| | Nam Oon (under const.) | 32,000 ha in central area | 1976-1980 |
| | Total | 231,600 ha | |
| | Projected area requirements (1971-1980) | 144,000 ha | |
| Viet-Nam | Cai San | 60,000 ha in west of Bassac | 1971-1975 |
| | Tiep Nhut | 70,000 ha in lower delta | 1971-1975 |
| | Go Cong I | 5,000 ha near Saigon | 1971-1975 |
| | Kien Hoa, I | 27,000 ha near Saigon | 1971-1975 |
| | Upper Se San, I | 6,900 ha in Highlands | 1971-1975 |
| | Krong Buk (Upper Sre Pok) | 11,400 ha in Highlands | 1971-1975 |
| | An Troung | 10,000 ha between Bassac and Mekong | 1976-1980 |
| | Vinh Loi (Tiep Nhut II) | 30,000 ha in lower delta | 1976-1980 |
| | Dong Thap, I | 50,000 ha in Plain of Reeds | 1976-1980 |
| | Da Tha, I | 50,000 ha west of Bassac | 1976-1980 |
| | Total | 320,300 ha | |
| | Projected area requirements (1971-1980) | 320,300 ha | |

TABLE 7

IRRIGATION DEMAND VERSUS SOURCES OF SUPPLY FOR LOWER MEKONG BASIN FOR PERIOD 1971-2000

(from Reference 1)

| | Needed Increase 1971-2000 for Full Double Cropping (ha) | Potential Capability | | |
|---|---|---|---|---|
| | | Tributary Projects | | Major Projects b/ |
| | | Area (ha) a/ | Per Cent of Need | |
| Democratic Kampuchea | 493,000 | 576,000 | 117 | 1,321,000 |
| Lao PDR | 79,500 | 254,100 | 320 | 130,000 |
| Thailand c/ | 834,000 | 285,000 | 34 | 1,500,000 |
| Viet-Nam d/ | 461,500 e/ | 97,000 | 21 | 2,050,000 |
| Total | 1,868,000 | 1,212,100 | 65 | 5,001,000 |

a/ Converted to equivalent of double-cropping capability, or mean area of wet and dry season irrigation.

b/ Pa Mong, Stung Treng, Sambor and Delta development projects.

c/ Northeast Thailand.

d/ In the plateau area only.

e/ Secretariat estimate. Alternative estimate by Government of Viet-Nam is 1.3 million ha.

TABLE 8

PRESENT LAND USE FOR PA MONG STAGE ONE AND PHASE II STUDY AREAS

(from Reference 8)

| Irrigation Division | Cultivated Land | | | | | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Paddy Riceland Cleared (Prc) (ha) | Paddy Riceland Partially Cleared (Prp) (ha) | Culti-vated Upland (C) (ha) | Total | | Closed Forest (Cf) (ha) | Mixed Open Forest (Mof) (ha) | Low Open Forest (Lof) (ha) | Bamboo-Bush (Bb) (ha) | Native Grass-land (Ngl) (ha) | Total | | | |
| | | | | Hectares | Per Cent | | | | | | Hectares | Per Cent | Hectares | Per Cent |
| Stage One Divisions | | | | | | | | | | | | | | |
| Vientiane | 5,300 | 1,055 | 1,160 | 7,515 | 65.8 | 54 | 586 | 691 | 2,574 | – | 3,905 | 34.2 | 11,420 | 100.0 |
| Huai Mong | 19,572 | 2,616 | 2,043 | 24,231 | 76.7 | 171 | 1,716 | 1,843 | 3,519 | 100 | 7,349 | 23.3 | 31,580 | 100.0 |
| Total | 24,872 | 3,671 | 3,203 | 31,746 | 73.8 | 225 | 2,302 | 2,534 | 6,093 | 100 | 11,254 | 26.2 | 43,000 | 100.0 |
| Phase II Divisions | | | | | | | | | | | | | | |
| Nam Lik | 11,332 | 3,012 | 4,808 | 19,152 | 58.0 | – | – | 12,090 | 692 | 1,102 | 13,884 | 42.0 | 33,036 | 100.0 |
| Vientiane Ext. | 4,486 | 578 | 1,520 | 6,584 | 41.5 | – | 3,548 | 4,579 | 1,013 | 128 | 9,268 | 58.5 | 15,852 | 100.0 |
| Laos Pumping | 7,991 | 2,699 | 5,421 | 16,111 | 32.5 | – | 26,526 | 5,505 | 813 | 581 | 33,425 | 67.5 | 49,536 | 100.0 |
| Udorn | 93,390 | 43,732 | 3,665 | 140,837 | 70.5 | – | 14,842 | 36,420 | 6,981 | 623 | 58,866 | 29.5 | 199.703 | 100.0 |
| Kumphawapi | 21,956 | 10,076 | 1,707 | 33,739 | 94.0 | – | 652 | 1,512 | – | – | 2,164 | 6.0 | 35,903 | 100.0 |
| Lam Phaniang | 30,033 | 34,243 | 758 | 65,034 | 41.8 | – | – | 90,567 | – | – | 90,567 | 58.2 | 155,601 | 100.0 |
| Huai Pong | 92,208 | 64,710 | 4,734 | 161,652 | 71.5 | – | 16,167 | 48,007 | 281 | – | 64,455 | 28.5 | 226,107 | 100.0 |
| Khon Kaen | 40,638 | 30,429 | – | 71,067 | 92.5 | – | 3,115 | – | 2,518 | – | 5,633 | 7.3 | 76,700 | 100.0 |
| Nai Nah | 35,776 | 8,540 | 426 | 44,742 | 91.6 | – | 223 | 3,814 | 90 | – | 4,127 | 8.4 | 48,869 | 100.0 |

TABLE 9

SUMMARIES OF ARABLE LAND CLASSIFICATION FOR LAO PDR AND THAILAND DIVISIONS

OF PA MONG PROJECT PHASE II INVESTIGATIONS

(from Reference 8)

Unit: Hectares

| Category | Lao PDR Divisions | | | | Total |
|---|---|---|---|---|---|
| | Vientiane | Vientiane Division | Laos Pumping | Nam Lik | |
| Diversified crop arable | | | | | |
| Class 1 | | | 1,070 | | 1,070 |
| Class 2 | 1,690 | 750 | 3,260 | | 5,700 |
| Subtotal | 1,690 | 750 | 4,330 | | 6,770 |
| Wetland rice arable | | | | | |
| Class 1R | 3,400 | 2,130 | 11,730 | 10,780 | 28,040 |
| Class 2R | 6,900 | 12,180 | 48,940 | 20,830 | 88,850 |
| Subtotal | 10,300 | 14,310 | 60,670 | 31,610 | 116,890 |
| Arable Classes 1, 2, 1R, and 2R Subtotal | 11,990 | 15,060 | 65,000 | 31,610 | 123,660 |
| Class 5 | | 6,810 | 12,850 | | 19,660 |
| Row and Class 6 | 4,120 | 7,040 | 33,540 | 11,540 | 56,240 |
| Towns and villages | 1,680 | 300 | 2,190 | 700 | 4,870 |
| Total | 17,790 | 29,210 | 113,580 | 43,850 | 204,430 |

TABLE 9 (Cont'd)

Unit : Hectares

| Category | Thailand Divisions | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | Huai Nong | Udorn | Khumphawapi | Lam Phaniang | Huai Pong | Khon Kaen | Nai Nah | |
| Diversified crop arable | | | | | | | | |
| Class 1 | 580 | 650 | | | | | | 1,230 |
| Class 2 | 3,900 | 2,620 | 4,400 | | | | 1,830 | 12,750 |
| Subtotal | 4,480 | 3,270 | 4,400 | | | | 1,830 | 13,980 |
| Wetland Rice arable | | | | | | | | |
| Class 1R | 13,110 | 20,380 | 7,220 | 21,700 | 88,730 | 13,410 | 25,610 | 190,220 |
| Class 2R | 24,810 | 207,190 | 64,980 | 185,860 | 172,140 | 90,880 | 56,450 | 802.310 |
| Subtotal | 37,920 | 227,570 | 72,200 | 207,560 | 260,930 | 104,290 | 82,060 | 992,530 |
| Arable | | | | | | | | |
| Class 1, 2, 1R, and 2R | | | | | | | | |
| Subtotal | 42,400 | 230,840 | 76,600 | 207,560 | 260,930 | 104,290 | 83,890 | 1,006,510 |
| Class 5 | | 24,300 | 18,700 | 300 | 150 | 5,710 | 12,350 | 61,510 |
| Row and Class 6 | 33,460 | 207,440 | 155,910 | 74,180 | 121,520 | 208,220 | 32,050 | 832,780 |
| Town and villages | 2,100 | 11,120 | 5,460 | 5,630 | 13,390 | 440 | 5,410 | 43,550 |
| Total | 77,960 | 473,700 | 256,670 | 287,670 | 395,990 | 318,660 | 133,700 | 1,944,350 |

TABLE 10

POTENTIAL IRRIGABLE LANDS CONSIDERED IN PA MONG PHASE II INVESTIGATIONS

| Land Class | Area in Hectares by Divisions (Lao PDR) | | | | |
|---|---|---|---|---|---|
| | Vientiane (Stage One Area) | Vientiane Extension | Lao Pumping | Nam Lik | Total |
| 1 | | | 810 | | 810 |
| 2 | 1,320 | 290 | 1,420 | | 3,030 |
| 1R | 2,980 | 3,620 | 8,680 | 8,830 | 24,110 |
| 2R | 6,320 | 10,810 | 35,160 | 21,890 | 74,180 |
| Total | 10,620 | 14,720 | 46,070 | 30,720 | 102,130 |

| Land Class | Area in Hectares by Divisions (Thailand) | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | Huai Mong | Udorn | Kamphawapi | Lam Phaniang | Huai Pong | Khon Kaen | Nai Mah | |
| 1 | 370 | 560 | | | | | | 930 |
| 2 | 1,490 | 1,290 | 910 | | | | 1,680 | 5,170 |
| 1R | 11,280 | 22,220 | 1,010 | 18,710 | 76,530 | 6,770 | 11,260 | 147,780 |
| 2R | 16,230 | 161,650 | 31,460 | 126,000 | 133,750 | 64,560 | 32,510 | 566,360 |
| Total | 29,370 | 185,720 | 33,380 | 144,710 | 210,280 | 71,330 | 45,450 | 720,240 |

TABLE 11

ALLOCATION OF AVERAGE ANNUAL WATER SUPPLY OF PA MONG PROJECT

FOR IRRIGATION AND OTHER PURPOSES

(from Phase II Operation Studies, Reference 8)

(a) Initial Plan

| Item | Volume ($m^3 \times 10^6$) | Per Cent of Inflow |
|---|---|---|
| (1) Firm power release | 108,238 | 71.3 |
| (2) Secondary power release | 36,770 | 24.2 |
| (3) Irrigation diversion | 628 | 0.4 |
| (4) Live stream release | 36 | 0.0 |
| (5) Reservoir evaporation | 1,346 | 0.9 |
| (6) Reservoir spills | 4,801 | 3.2 |
| Total reservoir inflow | 151,819 | 100.0 |

(b) Year-50 Plan

| Item | Volume ($m^3 \times 10^6$) | Per Cent of Inflow |
|---|---|---|
| (1) Firm Power release | 93,777 | 61.8 |
| (2) Secondary power release | 38,267 | 25.2 |
| (3) Irrigation diversion | 11,800 | 7.8 |
| (4) Fishery diversion | 1,361 | 0.9 |
| (5) DM & I diversion | 1,128 | 0.7 |
| (6) Live stream release | 36 | 0.0 |
| (7) Reservoir evaporation | 1,331 | 0.9 |
| (8) Reservoir spills | 4,119 | 2.7 |
| Total reservoir inflow | 151,819 | 100.0 |

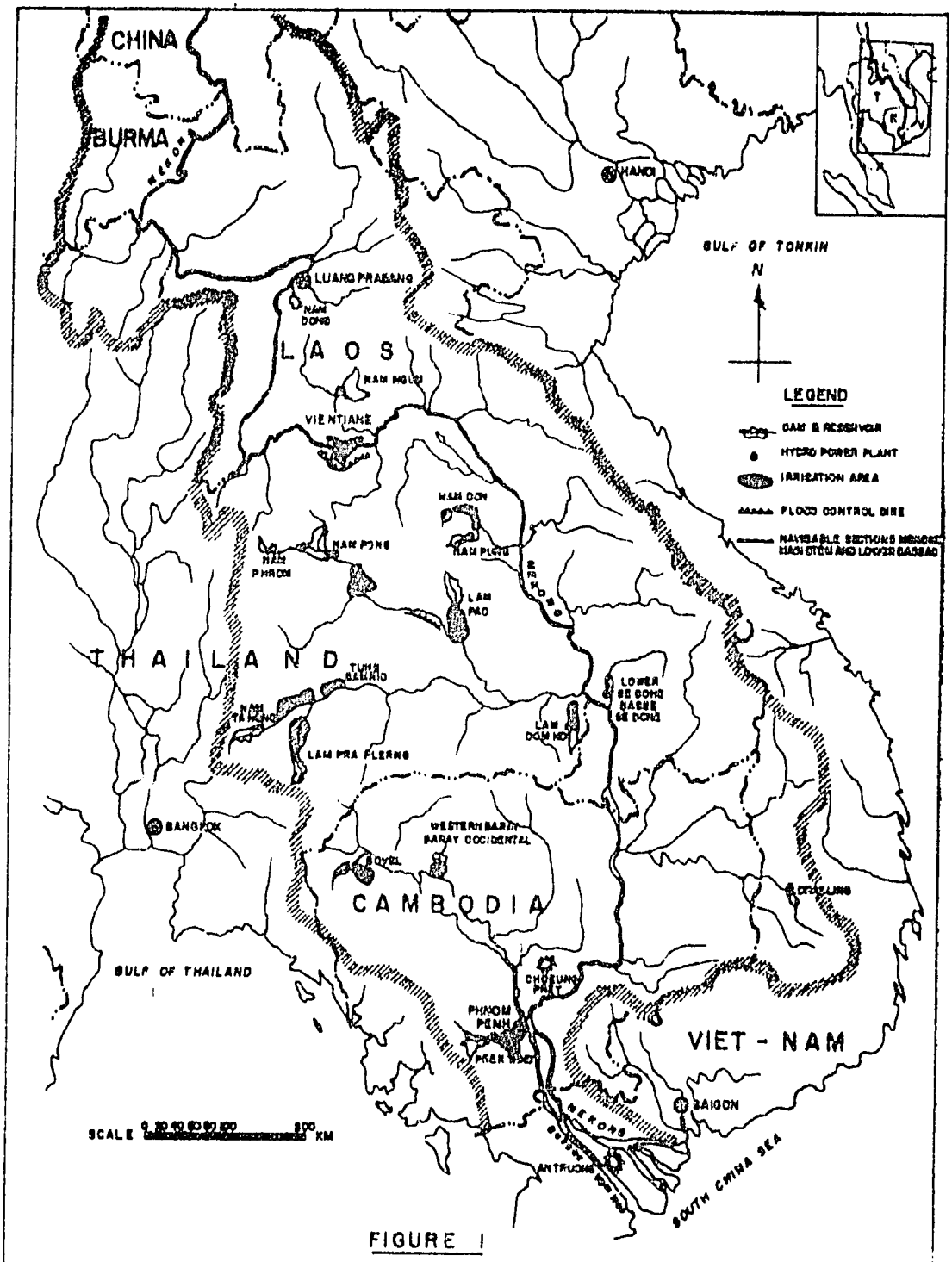



FIGURE 1

LOCATION OF WATER CONTROL PROJECTS COMPLETED OR UNDER CONSTRUCTION

( From Reference 1 )

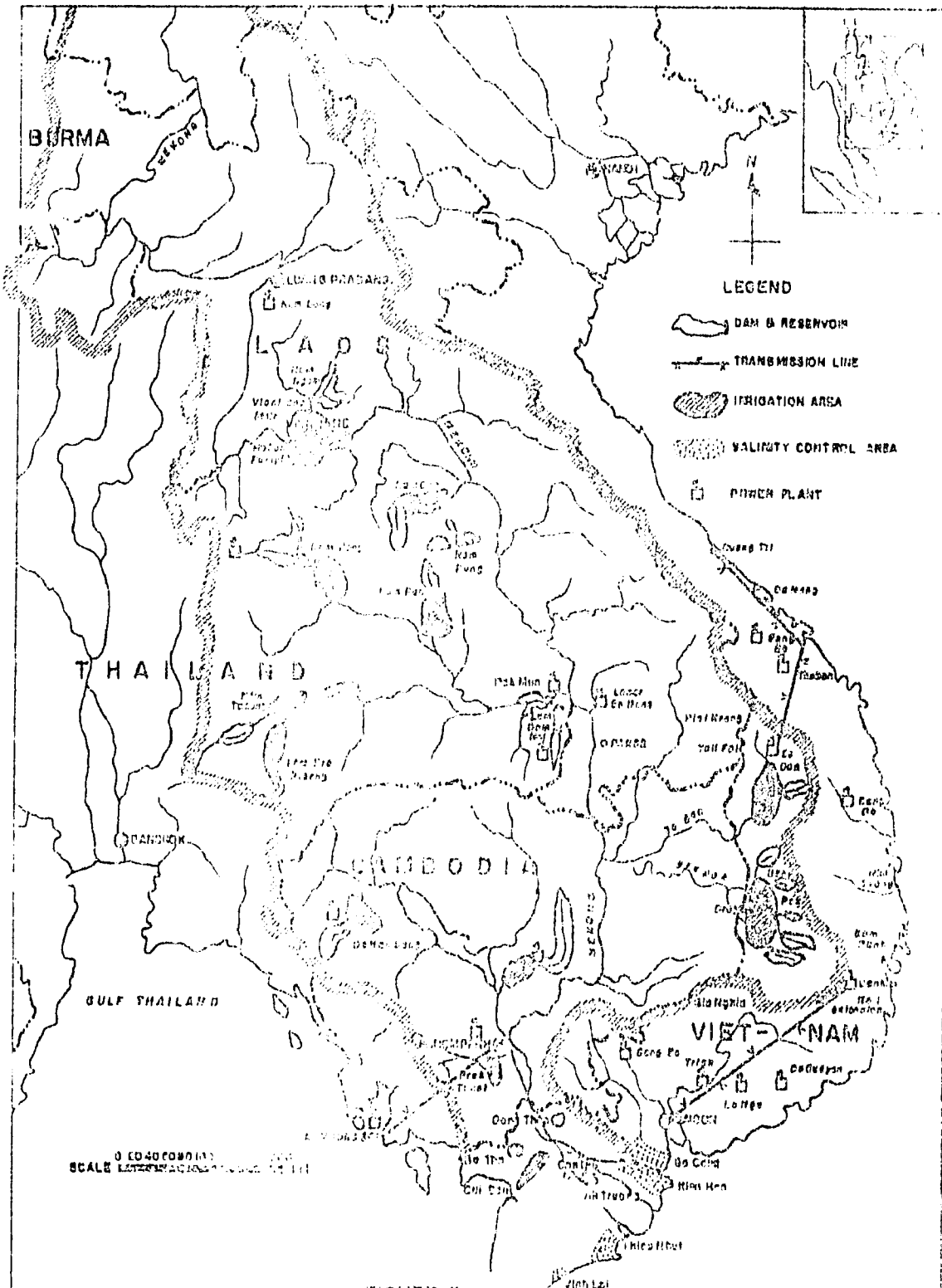
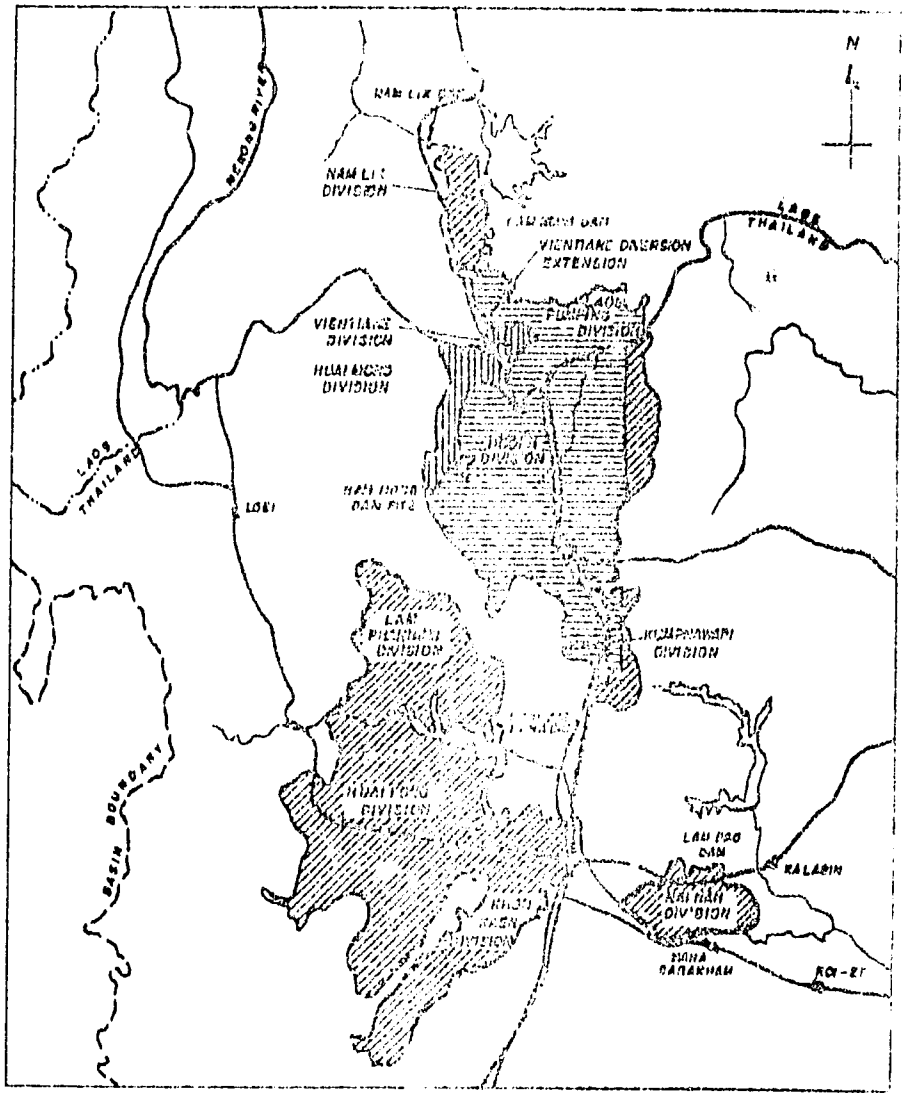



FIGURE 2

LOCATION OF WATER CONTROL PROJECTS IN SHORT RANGE PLAN, 1971-1980

( From Reference 1 )




EXPLANATION

IRRIGATION DIVISION BOUNDARIES

FEASIBILITY (STAGE ONE INVESTIGATIONS 1:10,000 TOPOS)

RECONNAISSANCE (1:10,000 TOPOS)

RECONNAISSANCE (1:50,000 TOPOS)

0 10 20 30 40 50 60 70 80

SCALE OF KILOMETERS

FIGURE 3

LOCATION OF PA MONG IRRIGATION SERVICE AREAS SHOWING IRRIGATION DIVISION BOUNDARIES AND LAND CLASSIFICATION SURVEYS

( From References 6 )

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## MINERAL DEVELOPMENT

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# PA MONG ENVIRONMENTAL ASSESSMENT

## MINERAL DEVELOPMENT

### 1. Introduction

An integral part of the Mekong Committee's programme for industrial development in the riparian countries, taking advantage of the benefits made available from water resource project development (plentiful power and improved river transportation), has been in the field of mineral resources. The programme activities include (a) field explorations for locating and evaluating the extent of mineral resources, (b) evaluations of specific industry potentials, including the possibilities for carrying out metal refining operations with imported ores where the availability of plentiful power might be a sufficient incentive, and (c) training to assist the riparian countries in strengthening their professional and technological capabilities for developing mineral resources. The programme has been basinwide, but has given primary attention to the areas of northeast Thailand and northern Lao PDR, which could be readily furnished with power from Pa Mong as well as from existing tributary power projects.

The key activity of the programme has been field surveys and explorations for locating and delineating the extent and nature of mineral deposits. In cooperation with the riparian governments, various UN affiliates, and various donor nations, an impressive number of surveys and studies have been completed since startup of these activities in 1963(Ref.1-50).

### 2. Policies on mineral development

Mekong Committee policies on mineral development may be summarized as follows (Ref. 18, No. 27):

(a) The objectives of the Mekong Committee's mineral development programme, in addition to creating a basis for establishing local industries and for use of hydroelectric power, is development of valuable mineral exports which could help finance hydroelectric projects.

(b) Mining and metal processing operations need not necessarily be integrated with power usage. It may be desirable to export ores for processing elsewhere, to import ores for processing with local power, and to export power for processing ores mined elsewhere.

(c) The main problem in evaluating mineral resources in the lower basin has been lack of fundamental detailed geological knowledge needed for appraising mineral potentials and for planning for field surveys to obtain

maximum information on mineral deposits within limited field survey budgets. The Mekong Committee therefore has promoted geological surveys and the collection and correlation of data and information on minerals from every available source.

3. Results of surveys, explorations, and studies

Table 1 presents a tabulation with brief descriptions of the various field surveys and explorations, studies, and compilations carried out under the Mekong Committee's programme relating to development of mineral resources in the lower basin. The main results and contributions of the programme may be summarized as follows:

(a) For the areas of northern Lao PDR, and to a lesser extent, for northeast Thailand - both areas in proximity to Pa Mong - development of a substantial base of information on the geology of this region, which will greatly assist in planning of future mineral exploration surveys, including a completed set of photogeological maps for northern Lao PDR. Also, a beginning effort toward preparing a geologic/mineral resources map of the entire lower basin.

(b) For the northern Lao PDR/northeast Thailand region, completion of preliminary mineral surveys in selected areas with the objective of locating valuable mineral deposits, especially certain key industrial minerals including iron ore, base metals, coal, and fertilizer raw materials. For all of these categories deposits with economic potential are known, but they all require further exploration and evaluation.

(c) Very rich deposits of potash have been confirmed in the northeast Thailand/northern Lao PDR region, which appear to be so vast and adapted to ready mining that exploration of this resource can be expected to capture a sizeable share of the market for potash throughout southeast Asia. The deposits in the Lao PDR especially appear to be among the world's richest containing more than 25 per cent $K_2O$, and moreover the impurities in this ore are rich in boron which can be recovered in the processing operations as a valuable by-product. Exploitation of this resource could have a major impact on the economy of northeast Thailand and northern Lao PDR. While the drilling programme is only preliminary, it is sufficient to merit the conclusions stated.

(d) Because of conditions of insecurity in key areas, field surveys for locating bauxite mostly remain to be done. The preliminary indications are that the lower basin, in both Democratic Kampuchea and Viet-Nam, possesses some bauxite but at present there

are no indications of bauxite in exportable quantities. The prospects for aluminum smelting appear very good, however, even if bauxite has to be imported, on the basis that electrical power will be in plentiful and cheap supply. Such a plant could produce 120,000 tons of aluminum ingot per year and consume 250,000 kW power (practically the entire firm power generation of the proposed Sambor mainstream project).

(e) The availability of plentiful power will justify establishment of small steel rolling mills in each riparian country and of specialized steel mills serving regional needs to be located in Thailand and perhaps one additional country. It is possible that local iron ore deposits, for example, from Loei province in Thailand and from Xieng Khong in the Lao PDR, can meet these needs. The total power demand by 1985 would be about 210,000 kW.

(f) There is some prospect for eventually establishing a ferro-alloy industry in the basin, using local manganese and quartzite ores, for meeting regional needs for ferro-manganese and ferro silicon. The power usage would be about 200 million kWh annually.

(g) Another promising power-using potential is use of rock salt mined from the northeast of Thailand for generation of caustic soda and chlorine. Preliminary planning is underway for a major facility of this type to be built in Thailand with private financing.

(h) The indications are that the rock salt areas in northeast Thailand and northern Lao PDR also contain, in addition to potash, large reserves of gypsum and possibly magnesia and other metals.

(i) With respect to mineral resources in the area to be inundated, the risk of inundating valuable mineral deposits is considered slight by all parties concerned with mineral exploitation in the region (Ref. 50). Neither the Thai nor the Lao government believe the area below 250 m MSL in the proposed inundation area is worth any prospecting effort. On the other hand, creation of the lake would enhance access to regions above the waterline, including a number of known mineral deposits now difficult to reach.

4. Impact on the northeast Thailand/northern Lao PDR

Both northeast Thailand and northern Lao PDR, which could readily make use of Pa Mong power, have been long neglected with respect to mineral development. The extent of mineral exploration in the Lao PDR has been very little and in Thailand, which has had a vigorous Department of

Mineral Resources, the action has been mostly in other parts of the country. The mineral development programme of the Mekong Committee, while basinwide, by focusing on the north-east Thailand/northern Lao PDR areas, has achieved a very significant upgrading of interest in the mineral resources of the region. This is resulting in evolution of programmes by both the Thai and Lao governments which offer great promise for improving the economy of these traditionally economically-depressed areas. Thus the Mekong Committee's programme has served, in a very timely way, for catalyzing activity in mineral development which is bound to lead to improve local industry and economy as well as creating additional uses of power. The environmental impact of the programme, at the present stage of Pa Mong planning, appears to be very positive in its potentials for enhancing the regional economy.

Thus far interest in mineral development has focused on explorations and studies. When actual mining and ore processing operations are contemplated, then it will be important for the regulatory agencies of the national governments to exercise proper controls as needed for preservation of environmental values - to prevent strip-mining which devastates the landscape, and to prevent wholesale pollution of ground and surface water supplies which inevitably result when mining operations are permitted to take place without regard to environmental impact. As has been amply demonstrated elsewhere, proper controls are available and are readily affordable for virtually all mining and ore processing operations provided these controls are incorporated into the planning of the operations from the outset. Also, if not so incorporated at the outset, the costs for remedial measures will usually be relatively very high, and often so high as to be difficult if not virtually impossible to achieve.

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TABLE 1

SUMMARY OF MINERAL DEVELOPMENT SURVEYS AND STUDIES IN LOWER BASIN SPONSORED BY MEKONG COMMITTEE

| Type and Name of Project | Collaborating Agencies | References | Period of Project | Brief Summary of Findings | Follow-up Actions |
|---|---|---|---|---|---|
| (A) FIELD EXPLORATIONS | | | | | |
| (1) Survey of minerals in Northeast Thailand | UNDP, USGS, DMR Thailand | 26, 29, 41, 42, 43 | 1963-68 | Survey comprised examination of magnetic anomalies indicated by earlier aeromagnetic surveys plus explorations for rock salt at Chaiya Phus, and resulted in finding of small iron ore deposits, vast rock salt deposits, and many other mineral prospects especially lead and zinc. | Thai DMR has followed up copper findings by exploitation through private enterprise (1966-67). |
| (2) Survey of minerals in Lao PDR | UNDP, BRGM | 30, 38, 42, 43 | 1966-69 | Explorations for iron ore (based on aeromagnetic anomalies) in north-central Lao PDR and in Salakham - Pak Lay area failed to find any worthwhile ores. Similarly no valuable coal deposits were confirmed in the "coal basin" northeast of Vientiane. | Study pointed up need for basic information on geology for planning mineral exploration in Lao PDR. |
| (3) Bauxite reconnaissance | BRGM | 6, 7 | 1962-63 | Bauxite deposits established in Democratic Kampuchea, one at Haut Chlong plateau being of possible economic interest, but follow-up investigations needed. Because of insecurity the survey work could not be carried out in key areas of the Lao PDR and Viet-Nam (this remains to be done). | Follow-up explorations planned when security permits; meanwhile question of availability of bauxite remains unresolved. |
| (4) Geological and geochemical mapping in Loei province (Thailand) and western Lao PDR | IGS | 18, 31, 32, 39, 40 | 1964-68 | Work included study of lead and zinc deposits in Loei province. Explorations in Lao PDR at Salakham - Pak Lay, Sayaboury, and Ban Houei Sai were not conclusive and indicated need for assessing geology of this region with decision to proceed with photogeological mapping. | Again, better basic information on a geology needed for planning field exploration. |
| (5) Photogeological mapping of northern Lao PDR | IGS | 48 | 1969-74 | Series of 13 maps at scale of 1:250,000 prepared for northern Lao PDR (area of 110,000 $km^2$, or 47 % of country), finished in 1974, which furnish a substantial basis for planning future field mineral explorations. Work done by photointerpretation of 1:40,000 scale aerial photography from U.S. Army Map Service. | These maps to be used in planning further mineral exploration in Lao PDR. |
| (6) Potash explorations in northeast Thailand and in Lao PDR. | USGS | 25, 28, 49, 51 | 1970-75 | Drilling program has established presence of very high grade potash deposits in Vientiane plain which appear to be among the world's best with potentials for capturing much of SE Asia market. Drilling in Udorn Salt basin in northeast Thailand shows vast potash deposits in that vicinity but of lesser quality than in Lao PDR. Similar rich deposits likely exist in Savannakhet plain of Lao PDR and Khorat salt basin. | Drilling program continuing. Assistance to be given to riparian governments to exploit these potentials. |
| (B) PROJECTS FOR COLLATING/SUMMARIZING DATA | | | | | |
| (7) Summary of Mekong Committee programme (1970) | - | 18 (No. 27) | 1970 | Chronological compilation of all Mekong Committee - sponsored activities on mineral development in lower basin. | |
| (8) Summary of known information on mineral resources in lower basin | - | 18 (No. 26) | 1970 | Compilation of all known information on mineral resources of lower basin organized by 25 different categories of minerals for each of the four riparian countries. | |
| (9) Card index | ESCAP | 50 | 1969 | Joint ESCAP/Mekong Committee programme for continuing compilation of all available information on mineral resources in lower basin. | Continuing activity. |
| (10) Geological data summaries | IGS, ESCAP | 44, 45, 46, 47 | 1972-73 | Compilation/collation of known information in lower basin on stratigraphy, geology, and mineral resources. | |
| (11) Geological/mineral map | - | 18 (No. 27) | 1969-70 | Compilation partially completed of geology/minerals of lower basin comprising six sheets at scale of 1:1 million. | |
| (C) METAL PROCESSING STUDIES | | | | | |
| (12) Aluminum | - | 3, 4, 5 | 1969-75 | Studies indicate feasibility of aluminum ingot plant in Democratic Kampuchea, using local or imported ores, for meeting local and regional needs, with power consumption of 250,000 kW. | |
| (13) Iron and steel | UNDP, ESCAP, UNIDO | 1, 20, 21 | 1970-71 | Regionally integrated system of steel mills recommended comprising smaller rolling mills in each country plus specialized mills in one or two countries. Total power consumption by 1985 estimated at 210,000 kW. | |
| (14) Ferro-alloys | UNIDO | 2 | 1972 | Prospects good for electric smelting of ferro-manganese/ferro-silicon for regional market, using 200 million kWh power annually, made from local ores of manganese and quartzite. | |

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# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## NAVIGATION

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# PA MONG ENVIRONMENTAL ASSESSMENT

## NAVIGATION

### 1. Introduction

Water transport is traditional in Southeast Asia and widespread use is made of the rivers and the man-made waterways of the Mekong river system. As part of its planning for comprehensive development of the water resources of the lower Mekong basin, the Mekong Committee has since 1960 sponsored a programme of studies and projects for improving navigation throughout the Mekong river system. The Mekong Committee envisages six multipurpose dams in the river reach between Vientiane and Kratie (Ref. 3). Assuming these dams are constructed, the former non-navigation or dangerous sections in the river will be submerged and assuming adequate facilities are provided to connect the lower and upper reaches of the dams, continuous navigation would be achieved.

Construction of Pa Mong, to be the first multipurpose mainstream project, would have major effects on navigation in the Mekong river. The new reservoir itself will furnish the basis for a vast system of navigation upstream of Pa Mong, and provision of trans-shipment facilities at the dam would serve to extend the range of navigation far downstream.

The present situation on navigation on the Mekong river in the lower basin and the projected improved situation to result from Pa Mong and the proposed programme of improvements are shown in Figure 1. Navigation improvement programme of the Mekong Committee, shown in Figure 2, includes provisions for channel markings, channel improvement, bank protection, construction or improvements of ports, harbors, and shipyards, and training of riparian personnel.

### 2. Conditions of waterway transportation

#### 2.1 Conditions prior to World Water II

Until the 1950's, there was little trade and commerce between the two physical entities forming the lower Mekong basin, then known as Siam and Indo-China. The Mekong was a secondary means of transport for Thailand, only serving local transport between population centres along its course (Ref. 2).

In the riparian countries, however, the Mekong served much more important purposes. From the early nineteenth century, the river functioned as the main travel route from the South China Sea into the hinterlands of all of the countries of Indo-China including the key cities of Phnom Penh, Vientiane, and Luang Prabang. There is also a waterway link between the Mekong river and Saigon. Advantage was taken of the naturally favorable navigability of the Mekong from its mouth up to

Phnom Penh and Sambor falls in the central area of Democratic Kampuchea. Navigation upstream of Sambor was, however, limited by the presence of a stretch of rapids between Sambor (near Kratie) to Khinak (thus including Stung Treng and Khone falls), and the Khemarat rapids. The region downstream of Sambor, including the entire delta, enjoyed extensive navigation routes afforded by the river and its branches and associated network of canals.

## 2.2 Conditions following World War II

After World War II, Indo-China was divided into several independent nations. Lao PDR become an essentially land-locked country. Economically feasible access to the sea or partly by river, if this can be achieved by the Mekong programme, would be especially meaningful for the Lao PDR.

### 2.2.1 Democratic Kampuchea

Despite the development of a deep sea port at Kampong Som in Democratic Kampuchea, to supplement the port at Phnom Penh, the maritime reach of the Mekong has continued to be Democratic Kampuchea's primary access to the ocean. During high water periods ocean vessels up to 4.5 m draft can go upstream as far as Kampong Cham. Also, the waterway system includes internal channels reaching Kratie and Tonle Sap. Certain sections, such as the Khemarat rapids, Khone falls, and the series of rapids between Sambor and Khinak are not navigable or are navigable only with difficulty.

The port of Phnom Penh is located near the confluence of the Tonle Sap and the Mekong, which is also the point where the Bassac branches out from the mainstream. The river flow slackens in the vicinity of the confluence, causing much deposition of sediments making the water around the port of Phnom Penh as shallow as 3.0 to 3.5 m. This constitutes a bottle-neck in the waterway traffic to and from Phnom Penh, and annual dredging is required to keep the channel open all year round for vessels of up to 4-5 m draught. Also, bank erosion and silt deposition regularly occur from Phnom Penh to Kratie. Navigation between Kratie and Sambor during the dry season is almost prohibitive and is possible only with small craft because of the many outcrops of rock above the water surface and swift currents in the narrow and deep channels between the rock outcrops.

Major cargo transported in the Mekong waterway in Democratic Kampuchea includes timber, charcoal, rice, agricultural products, and other commodities (Ref. 3). Considerable economic benefit would accrue to Democratic Kampuchea from further improvement of the waterway.

2.2.2 Lao PDR

Lao PDR is not only land-locked but has very limited highway and railroad facilities. Imports are largely financed from external aid sources, and reach the Lao PDR mainly through Vientiane via Thailand. Almost all major population centres are along the Mekong river. Distribution of imported goods is made to the major urban areas via river boat transport or truck. Even after the highway system in the Lao PDR has been improved and extended, the Mekong river is expected to be used advantageously as a means of handling intracountry commodity shipments. There are, however, over 100 km of rapids in the Mekong reach from Vientiane to Pakse, hence waterway transportation between Vientiane and Pakse has not been possible. Upstream of Vientiane there are reaches in which navigation is hindered during low flow because of rocks, and these reaches are much in need of channel improvement. Every reason exists to improve utilization of the natural waterway for internal distribution functions.

The Mekong - Lao PDR waterway system may be briefly described as follows (Ref. 1):

(a) Chiang Saen - Houey Sai: The river stretch between Chiang Saen to Houey Sai is navigable all year round for boats up to 40 tons. From traffic surveys of the Navigation Division, Mekong Committee in 1975, it has been observed that many wood products were transported from the sawmill near Ban Houey Sai to Chiang Saen.

(b) Houey Sai - Luang Prabang: This section of the Mekong river starts from Houey Sai, a Laotian town located on the Mekong at Km 2316, and extends to Luang Prabang at Km 2010 covering a distance of 306 km. No information is available on navigation conditions in this stretch of the river; however, no major difficulties have been reported concerning the width of the channel or the depth of water during the dry season. Boats up to 50 tons can ply the river the year around.

(c) Luang Prabang - Vientiane: This section is 425 km long. Its navigability varies considerably from place to place and from season to season. There are about 20 places where navigation difficulties have been reported, the most formidable being Keng Luang which is a 10 km stretch located about 75 km downstream of Luang Prabang. Many accidents have occurred in this stretch due to the strong current, rock obstacles, and other natural hazards, and a channel improvement project is planned to reduce the navigation difficulties at Keng Luang. Elsewhere, there are various kinds of obstacles all along the Vientiane - Luang Prabang section, but many of these will be flooded out when Pa Mong is constructed. Details concerning

the widths of the navigable channel and the river and the depths of channel, at intervals of 1 km between Vientiane and Luang Prabang, are shown in Figure 3.

There is considerable difference of opinion regarding the navigability of this reach of the river. Most boat operators (Ref. 1) report that navigation between Vientiane and Luang Prabang is possible all the year around, which is confirmed by the monthly statistics of cargo movement prepared by the Direction des Douanes et Regies in Vientiane. The question involved is not so much the navigability of the river as the cost of making the journey and the risk involved. In other words, when a boat operator says that the river is unnavigable during summer, he really means he does not want to make the journey due to the relatively poor navigation conditions; however, there are others who prefer the opposite and, in accordance with the law of supply and demand, charge a high price for the journey. This seasonal price increase is not unreasonable because the travel time during the dry season is much longer than during the wet season. A round trip from Vientiane to Luang Prabang during the wet season, including loading and unloading time at the terminals, takes about 11 days whereas in summer this takes about 20 days or even longer. In addition to the greater risk of damage, the carrying capacity of the boat decreases, sometimes by as much as 50 per cent of the normal load, to enable the boat to avoid the natural hazards (Ref. 1).

(d) Vientiane - Savannakhet: This section of the Mekong river, 459 km long, is the most important route for the Lao PDR in terms of volume of freight movement. It is characterized by a wider navigable channel and a more uniform depth with the minimum, at the lowest low water level, of 1.0 m. During most of the summer, when the level of water in the river is above the lowest low, the minimum depth of the navigable channel is above 1.5 m, and the river is navigable virtually all the year. However, the magnitude of the navigation hazard is not the same during all seasons. There are a few stretches of the river where the navigable channel is very narrow and abounds with rocks, as at Keng Kabao (Km 1151), or where the navigable channel is shifting continuously as at Don Kaset (Km 1277). The navigation hazard varies with changes in the velocity and depth of the water in the channel. However, this hazard appears to have little effect on the pattern of navigation as can be seen from Figure 4, which shows the seasonal fluctuation in the volume of water-borne freight between Vientiane and Savannakhet (Ref. 1).

(e) Savannakhet - Pakse: This section of 256 km is normally navigable all year around, but with difficulty during low water periods. In high water periods the river is navigable with less difficulty. The French used this river reach all year around prior to World War II.

2.2.3 Thailand

Thailand has a rather intensive highway transportation system. There are roadways radiating from Bangkok to the northern, northeastern, southern, and central plains. The Mekong has only a marginal transportation role for Thailand. There are feeder roads extending from main highways to most communities along the Mekong river.

2.2.4 Viet-Nam

There is an extensive canals system of some 4,900 km of waterways in the deltaic arms of the Mekong river (Ref. 2). The two most important arms are the Song Cua Tieu and the Bassac. This network serves essentially as the link between Saigon, the import-export centre, and the rich agricultural areas of the Bassac and the areas west of Bassac in the delta. There are ports at Saigon, Can Tho, and along the Bassac. At present, the Song Cua Tieu, the northernmost branch, is used for navigation of ocean-going vessels. The tidal range at My Tho on the north bank of the Song Cua Tieu is 3.5 m in the spring tide and 2.9 m in the neap tide (Ref. 3). Owing to limitations at the Mekong entrance, barges or ships going to Phnom Penh are limited to about 5 m draught (Ref. 5).

The lower Bassac river presents better characteristics for navigation than the Mekong river up to Vam Nao, including a shorter aggregate length of shoals. Also, because of the importance of the industrial complex of Can Tho, the Vam Nao channel, if improved, will become an artery of vital importance for the economy of Viet-Nam (Ref. 5).

3. Navigation improvement programme of the Mekong Committee

The Mekong Committee plans for navigation improvement on the lower Mekong basin (Figure 2) include two phases, for both long-run and short-run development (Ref. 7). In the long-run many major improvements will come from the construction of mainstream dams. Each of these will include provision for cargo handling transhipment facilities, hence these dams will ultimately provide many hundred kilometres of navigation improvement upstream of the dams through creation of reservoirs or deepening the streams which will flood out rapids wherever they exist in these reaches. In addition, the increase of the low-water discharge will augment the depth in the channel downstream of reservoirs.

Without waiting for these major benefits to navigation from mainstream dams, however, certain projects can be implemented in the short-run to assist navigation by improving and marking the channel and by improving ports, shipyards, and boat design. The short-run navigation improvement policy of the Mekong Committee is set forth in detail in the 1960 publication, "Navigation Improvement Programme" (Ref. 6), which since then has been periodically revised and updated.

Listed below are the works sponsored by the Mekong Committee pertaining to short-run navigation improvement.

## 3.1 Hydrography

Basic to navigation and navigation improvement work on any river is the establishment of hydrographic survey offices for the purpose of precisely ascertaining and charting the configuration of the river bed. Hydrographic survey offices have been established in Democratic Kampuchea, Lao PDR, and Thailand, and an existing office in Viet-Nam has been strengthened with the assistance of the UNDP and several donor nations. Table 1 shows the chronicle of Mekong river hydrographic work from 1965 to 1974. These efforts represent the basic requirement for development of navigation such as channel dredging, construction of ports and ferry ramps, and preparation of navigation charts. In 1974 the Mekong Committee publication, "Technical Specifications for Hydrographic Surveys in the Lower Mekong Basin" (Ref. 18), was adopted by the chief hydrographers of the four riparian countries, to help standardize surveying procedures of the four riparian countries.

## 3.2 Channel marking and channel improvement

### 3.2.1 Channel marking

An important objective of the Mekong Committee is the establishment of adequate channel marking for all reaches of the river important to navigation. A "uniform marking system" recommended by ESCAP has been used throughout the Mekong river. The beaconing in the reaches from the delta to Phnom Penh (to be extended to Kampong Cham) comprises beacons, lightbuoys, and shorelights adapted to maritime navigation. The beaconing system upstream of Phnom Penh is suited to inland navigation. Both maritime and inland navigation systems provide for daytime navigation only. Bamboo buoys have also been used in the Lao PDR for channel marking of difficult stretches.

### 3.2.2 Channel improvement

The work on channel improvement deals with channel dredging, hydraulic modelling, and rock blasting on the difficult stretches. Dredging has been carried out on a continuing basis at the approach to Phnom Penh and in important navigation canals in the Vietnamese delta (Ref. 5).

The Mekong Committee has also proposed dredging of some parts of the Snoctrou sandbar on the Tonle Sap in Democratic Kampuchea, which constitutes the main obstacle to outgoing or incoming navigation for the Great Lake. It was proposed that the Vam Nao pass, the only natural connexion between the Mekong and the Bassac rivers, be deepened so that vessels of more than 5 m draught could, via the Bassac where the entrance is deeper, use the Vam Nao and Mekong all the way up to Phnom Penh. At present, as previously noted, owing to the limitations of the Mekong entrance, the tonnage up to Phnom Penh is limited to about 3,000 DWT. This programme would also provide transportation benefits for industrial centres such as Can Tho on the Bassac river and the inland ports on the Mekong river south of the Vam Nao pass (Ref. 5). Experimental dredging was recommended as the first step to permit an evaluation of sediment transport in the channel and thereby a forecast of recurrent dredging costs (Ref. 4, 5).

The Mekong Committee has also sponsored a programme for blasting the dangerous rock outcrops at Keng Kabao rapids, about 27 m upstream of Mukdahan, Thailand (Ref. 8). The blasting will eliminate rock outcrops as well as the submerged obstruction in a 30 m width of channel to provide a minimum depth of 2.2 m below lowest low water. It is estimated that the blasting work will require at least four annual low-water seasons from 1974, in order to clear the entire pass (Ref. 17). Also, a physical hydraulic model study of this reach of the Mekong river has been made by the Asian Institute of Technology, under Mekong Committee sponsorship, to determine the effect of removing the existing rocks on the river regime (Ref. 19). It was found that the removal of material in the channel would cause the lowest low water elevation to drop by about 15 cm. The channel will therefore need to be cleared to a minimum depth of 2.35 m below the established lowest low water level (Ref. 19, 20).

Table 2 summarizes the chronicle of channel improvement and channel marking work from 1964 to 1974.

### 3.3 Bank protection

Bank erosion is a conspicuous problem along the mainstream of the Mekong river and its tributaries. While bank protection in areas of little economic interest is perhaps of little importance, the problem is increasingly crucial in many other areas. In 1964 the road that leads to the experimental and demonstration farm in Vientiane was partly destroyed because of bank erosion (Ref. 7). Also, in 1964 it was bank erosion that caused the Moniwong bridge near Quartre Bras to collapse (Ref. 3). A report on a study of bank protection problems in Democratic Kampuchea, Thailand, and Lao PDR issued in 1969 (Ref. 21) recommended a bank protection programme including training of riparian engineers in this specialized field, preparation of a manual on river training,

and hydraulic experimentation. Experimental bank protection at Nong Khai in Thailand and many other places in the Lao PDR are being conducted.

Among the various bank protection measures carried out since 1966 are the following:

(a) Hydrotopographic surveys in 1970, especially along banks subject to heavy erosion, at the Vientiane water works between Wat Xieng Ngune and the Service Veterinaire of the Lao PDR, and between Phnom Penh and Kampong Cham and Kas-Norea (km 325-330) on the Mekong river near its junction with the Bassac river (Ref. 13).

(b) Studies by the Navigation Directorate of Viet-Nam to find a temporary solution for bank protection at Cai Bo, Cho Gao, and Vinh Dinh (Travinh) (Ref. 14).

(c) Field investigation made in 1972 on four sites in Viet-Nam subjected to erosion, namely Binh-Thuy and Vinh Thanh Trung on the Bassac and Sa Dec and My Thuan on the Mekong (Ref. 5).

(d) Riprap protection at the intake of the Tha Bo pump irrigation project on the Thai bank (Ref.15).

(e) A report on the possibilities for protecting the banks of the canals in Viet-Nam giving details of causes of bank erosion and different methods of bank protection together with their respective costs (Ref. 22). Some conclusions of this study are that there are two principal types of erosion due to wave attack and erosion due to the attack by the current. In canals subjected to wave attack only a restricted part of the bank need be protected. If the maximum flow velocity exceeds the critical flow velocity (velocity that is detrimental to the banks), protection of the entire bank slope is required. A critical flow velocity in the range of 2.20 to 1.30 m/s was recommended for the construction of the test section (Ref. 22).

(f) As part of the Pa Mong downstream effects studies, the earlier estimates of downstream bank and bed erosion and degradation to result from Pa Mong, made by the USBR, have been further reviewed with formulation of recommendations for necessary bank protection measures (See discussion on sediments and erosion).

## 3.4 Ports, harbors, and cargo handling

The introduction of cargo handling facilities to the riparian countries would be a major contribution to navigation improvement along the Mekong river (Ref. 24). In 1966 a feasibility report on ports, cargo handling, and boat-building facilities recommended a large-scale programme be undertaken on channel improvements at critical locations, construction of cargo handling facilities, and updating of vehicular ferry systems and cargo handling improvements (Ref. 23). The report showed that a series of small transportation and navigation improvement projects would benefit both existing cross-haul and line-haul traffic. These involve relatively economical and simple solutions to problems of Mekong river transport, as opposed to larger capital-intensive construction and costly equipment procurement (Ref. 24).

Figure 1 shows the existing and proposed ramps and harbors along the Mekong and the Tonle Sap rivers and also those under construction, which are included in the current planning of the Mekong Committee.

Studies have been made for development of Da Nang in Viet-Nam as a free port of entry to be paired with a port on the Mekong river at Savannakhet in the Lao PDR and an improved highway (No. 9) connecting the two ports. If this development should materialize, Savannakhet would become a key shipping point in the Lao PDR and a very large increase in transport downstream of Vientiane could be anticipated (Ref.25). On the stretch of the river between Vientiane and Savannakhet, the depth in some places in the navigable channels is as low as 1.0 m during the low water season (0.8 m during very low season), which means that ships are limited to about 0.7 m draught, allowing only very small craft of a few tons capacity (Ref.25). Regulation by Pa Mong will increase the depth of the river to about 2.4 m between Vientiane and Savannakhet, which would permit lighters of between 300 to 900 tons and motor cargo ships up to 300 tons to navigate the year around (Ref. 25). For the Savannakhet-Pakse reach there would be some increase in the tonnage of small local craft.

Studies on unimpeded navigation at Pa Mong dam (Ref. 26) have recommended that the initial stage of facilities should be ramps similar to those currently used along the Mekong river at km 1602 and 1607, downstream and upstream of Pa Mong, to handle traffic during the construction phase of Pa Mong dam. Other recommendations are for ramps to be constructed on the reservoir bank for the transfer of general cargo to be transported upstream from Pa Mong (Ref. 26), and for steel floats to be provided adjacent to the downstream ramps to accommodate the fluctuating water levels due to operation of Pa Mong reservoir (Ref. 26).

## 3.5 Boat building and navigation training centres

The Mekong Committee's navigation development programme has included establishment of boat building and navigation training centres in the four riparian countries. As a result, such centres were established at Nong Khai and Savannakhet in 1972 (Ref. 16), with courses in boat building, welding, marine diesel engine technology, and navigation. The Mekong Committee also plans to establish navigation training centres at Phnom Penh and Saigon. Also, a course on standardization in the measurement of ships in the four riparian countries was held in Bangkok in November 1974 (Ref. 17). Table 3 summarizes the training activities of the Mekong Committee in collaboration with the riparian countries.

## 3.6 Other achievements

The Mekong Committee has sponsored other activities pertaining to navigation improvement. These may be summarized as follows:

(a) Fellowships in navigation and related subjects have been provided for staff from the riparian countries. Thirty one fellowships in navigation and related subjects have been awarded to students and trainees from riparian countries for study in Europe since 1972 (Ref. 15, 16, 17).

(b) A report on rehabilitation of the inland waterway fleets in Viet-Nam and Democratic Kampuchea (Ref. 27) recommended a comprehensive work programme to be considered. The recommendations of first priority were the following:

(1) Systematic surveys of the longitudinal profiles of the canals in Viet-Nam, and of the extent of dredging needed to maintain these canals.

(2) Provision of a building, ship, and other facilities for the Saigon navigation training centre, and of a building facility for the Phnom Penh navigation centre.

(3) Procurement of prototype vessels for inland fleet development in both Democratic Kampuchea and Viet-Nam ($1.4 million for each country).

(4) Coordination of all shipyard activities in the lower Mekong region, for purpose of mutual collaboration, using the best equipped and most diversified shipyard as the focus for coordination.

(5) Establishment of a governmental agency for establishing policies regarding navigation and for coordinating navigation activities in Viet-Nam.

(6) Strengthening of the various governmental departments in Democratic Kampuchea with competent staff including necessary training.

(c) Studies on proposed bridges across the Mekong River at My Thuan and Vientiane/Nong Khai. The studies describe the expected volume, desirable sizes of waterways transport vehicles, and the required vertical and horizontal clearances of the bridges. The Vientiane/Nong Khai bridge would have a vertical clearance of 7 m above flood level and pier spacing would be 60 m (Ref. 28).

(d) Evaluation of navigation problems associated with water control structures proposed for agricultural development in the Mekong delta (Ref. 29), which could pose limitations to navigation in inland waterway transport (Ref. 30). Such water control structures would be located and designed to accommodate navigation as well as agricultural requirements.

(e) Traffic surveys along the Mekong river for the Vientiane-Savannakhet and Luang Prabang-Vientiane reaches, conducted in 1973 and 1974. Results of these traffic surveys are to be found in the annual statistical bulletins (Ref. 31, 32, 33).

## 4. Environmental considerations of the navigation improvement programme

### 4.1 Creating and maintaining navigation channels

The navigation channel schemes mentioned earlier include rock blasting at the Keng Kabao rapids, dredging of the Snoctrau sand bar on the Tonle Sap in Democratic Kampuchea, and dredging of the Vam Nao pass, the natural connexion between the Mekong and the Bassac rivers.

Rock blasting at the Keng Kabao rapids, about 27 km upstream of Mukdahan, Thailand has been underway since 1973. The total rock quantity to be blasted amounts to 4,800 $m^3$, from a stretch of river 300 m long (Ref. 19). Demolition has been performed only during the low water season. It is estimated that finishing the work will require four additional low water seasons subsequent to the work completed in 1974. Rock blasting is of course harmful to fish and other aquatic life at Keng Kabao, but this is limited to the working periods and will be temporary in nature. Regarding physical effects, it is estimated the water surface will drop not more than 15 centimetres (Ref. 19).

The dredging programme at the Snoctrau sand bar is, at the present time, still in the study phase (Ref. 4). The results of two evaluations made on the Mekong delta model

indicated that the limited dredging of the Snoctrau sand bar will not have any significant effect on the minimum water levels in the Great Lake. It is estimated that almost imperceptible decreases of a few centimetres in the Great Lake water level will result from dredging of 75 $m^2$ and 162 $m^3$ sections of sand bar (Ref. 4). The corresponding estimated total volume of dredged material under consideration is 4,200 $m^3$ and 9,100 $m^3$ respectively. No plan of disposal for the dredged material has yet been developed nor any disposal site selected. When developed, such plans should take into consideration the possible environmental effects. The primary problem in disposal of dredged material is to avoid burial of aquatic habitats.

For the dredging scheme at the Vam Nao pass in Viet-Nam, experimental dredging has been recommended to permit evaluation of sediment transport in the channel and thereby a forecast of recurrent dredging costs (Ref. 5). It appears that the delta in the region of Vam Nao has been stabilized since about 1869 (Ref. 5). Determinations of grain size distributions of fine sand and mud at the Vam Nao were made in 1972 (Ref. 5). Studies also were made in 1973 of the physical and chemical properties of the river sediment and soils of the river bank at Long Xuyen, on the Bassac river downstream of Vam Nao (Ref. 34), as part of an evaluation of the agricultural facility of the delta soils. About 200,000 $m^3$ of materials would be dredged if the full scheme is implemented. Again, disposal of this material should be planned to avoid detrimental effects on aquatic ecosystems.

It was roughly estimated that about 15-16 million $m^3$ of dredged material should be removed yearly in Viet-Nam (Ref. 27). The present capability of the dredging fleet is estimated at 4 million $m^3$ per year. With peaceful conditions in the region the working capacity can be increased to between 6 to 9 million $m^3$ (Ref. 27). It will require an investment of US$30 million to increase the working capacity of the dredging fleet to 15 million $m^3$ by 1980.

Routine dredging work at the approaches to Phnom Penh port has been carried out for many years, and appears to be efficiently planned and executed (Ref. 27). The dredged volumes are of slight quantity, no more than a few thousand $m^3$ per year (Ref. 27).

## 4.2 Navigation facilities

The development of ports and ferry ramps initiated by the Mekong Committee will have impacts not only on navigation along the Mekong but also important socio-economic effects in the four riparian countries. The development of the ferry ramp at Savannakhet will be very useful for improving the general economy of the Lao PDR. This ferry ramp will be utilized as an unloading station for goods

transported by road from Da Nang, Viet-Nam via route No.9. A plan to build a port at Savannakhet has also been initiated by the Mekong Committee. Further, these goods will be transported along the Mekong river to various population centres of Lao PDR, thus providing another sea outlet for the Lao PDR in addition to the port of Bangkok in Thailand. A road has been completed connecting Pak Beng, upstream of Luang Prabang, to the Republic of China. This road provides an alternative transportation route to Luang Prabang (Ref. 26). It can be anticipated that future development of the resources of Lao PDR will result in changes in the transportation pattern (Ref. 26).

It can be expected that provision of ports and ferry ramps will accelerate community growth at these centres. Provision of adequate storage facilities such as warehouses, sheds, and tanks at the ports and ramps, to receive products to be transhipped to sea ports or vice versa (Ref. 27), would increase local job opportunities. However use of machines for the handling of the cargo may reduce the work opportunities for laborers. Construction of these facilities will of course involve potentials for adverse environmental effects depending on the nature of the facilities. For example oil loading and storage systems pose threats of leakage and spillage.

In 1974 about 11,400 tons of cargo was transported from Vientiane to the ports above the Pa Mong damsite and the cargo received from upstream ports was about 1,880 tons (Ref. 26). About 20 per cent of the cargo transported is rice, and about 42 per cent is construction material. It is estimated about 1,500,000 tons or an average of about 150,000 tons per year of woods products will be moved by water during the construction period of Pa Mong dam (Ref. 26). Table 4 shows the estimated volume of water borne freight from Vientiane to Luang Prabang and intermediate ports.

Experience in other countries throughout the world has demonstrated the economy of water transportation systems (Ref. 26). The low requirement for fuel per ton-km becomes even more important as the world price of petroleum increases. Comparison of costs for movement of bulk materials by truck and water where paved roads are available have shown differentials as high as 20 : 1 for truck vs. water in the United States (Ref. 26). Table 5 shows a comparison of typical ton-km charges in 1974 from Vientiane to selected cities by various means of transportation.

Creation of new reservoir will, as previously noted, open up a vast area of hinterland to commerce including mineral development. As noted in the discussion on mineral development, this region is believed to be rich in numerous valuable minerals that could be exploited if economically transportation were available.

Ramps similar to those currently in use along the Mekong are recommended at Km 1602 and Km 1607 to handle traffic during the construction period of Pa Mong dam. Also ramps should be constructed on the reservoir bank for the transfer of general cargo to be transported upstream from Pa Mong dam for the initial stage (Ref. 26).

## 4.3 Navigation upstream and downstream of Pa Mong dam

### 4.3.1 Upstream of Pa Mong dam

The construction of Pa Mong dam will create a vast reservoir with water surface areas of 2,110; 2,803; 3,722; and 4,560 $km^2$ respectively for high pool levels of 230, 240, 250 and 260 m MSL. This will extend the navigable channel from Pa Mong a considerable distance upstream as shown in Table 6.

Earlier studies (Ref. 1) of soundings in the river indicate that, during the lowest drawdown of the reservoir (220 m), which would be infrequent, for the case of Pa Mong high pool elevation 250 m MSL, only one location, at Keng Luang about 75 km downstream of Luang Prabang, would be so shallow that only 1.5 m water depth would be available (Ref. 26). Also, even at this minimum drawdown level, a number of rock obstacles, of which there are many between the damsite and Pak Lay (km 1800), will be submerged. Hence, navigation in the Mekong river between the damsite and Km 1845, which is a little upstream of Pak Lay, will be substantially facilitated as a direct result of Pa Mong dam. During most of the time when the level of water in the reservoir is expected to be above the minimum level, the situation with respect to navigation will be even better (Ref. 1). Also, a large number of shoal areas will be covered by the reservoir providing extensive improvement to navigation above Pa Mong. It can be expected that multiple tows will be feasible because of the slack water conditions expected in most of the reservoir (Ref. 26).

A study by the Mekong Committee of the navigation benefits of Pa Mong (Ref. 1) concluded that the benefits to navigation in the form of increased volume of traffic due to greater navigability of the river, or of reduced cost of inland waterway transportation above the dam, will not be fully realized unless other complementary measures such as navigation channel improvements, construction of ports and ramps, establishing training centres, etc., are undertaken also. The cost saving per ton-kilometre of freight carried between Vientiane and Luang Prabang was estimated at US$0.0251 (Ref. 1).

It was estimated also that the maximum current velocity at Keng Luang, about 75 km south of Luang Prabang, will reduce to 6 km/hour compared to the existing 11 km/hour (Ref. 1). This will facilitate navigation along this reach and save fuel especially for the upstream bound trips.

4.3.2 Downstream of Pa Mong dam

(a) Vientiane-Savannakhet: As has been mentioned, during the dry season ships travelling in this reach are limited to some 0.70 m draught. The Pa Mong dam will release more water during the low water season to maintain depths varying from 1.5 m at Pakse to 3.1 m at Vientiane. Assuming the mean level of increase to be 2.4 m, this would permit lighters of between 300 and 900 tons and motor cargo ships up to 300 tons to navigate the year around (Ref. 25). Table 7 shows the estimated increase in average monthly flow during the dry period from November to June of the Mekong river downstream of Pa Mong dam, for high pool elevations of 230, 240, 250, and 260 m MSL respectively. An additional flow of at least 1,000 $m^3$/sec will be furnished by Pa Mong over the dry season.

(b) Savannakhet-Pakse: This reach of river is navigable all year around but with difficulty during low water periods due to the existence of rapids and rock obstacles (Ref. 25).

The reach includes the Khemmarat rapids which extend some 40 km. While the Pa Mong project is not expected to provide any significant improvement over the existing conditions, it is believed that an increase in stage during the low water season would permit some increase in the tonnage of small local craft.

4.4 Navigation and associated water pollution

The Mekong river traffic survey prepared in 1974 (Ref. 33) shows the main cargo transported along the Mekong river from Luang Prabang to Vientiane and from Vientiane to Savannakhet are construction materials, rice and other foodstuffs, and petroleum products. The petroleum products comprises 5 to 7 per cent of the total cargo transported.

The major cargo transported in the delta area of Viet-Nam is rice paddy. The principal other commodity is clinker which is transported from Ha Tien, the seaport of Viet-Nam where cement is manufactured, to Saigon. Studies have indicated that movement by ship is about four times more efficient than by truck, although it was found that many waterways are not now as navigable as in the past (Ref. 27). The main problem of the inland waterway fleet and its contribution to the national transport economy is the fact that the fleet capacity is partly idle because of the present waterway conditions (Ref. 27). The same report (Ref. 27) stressed the important role of the government in improving the waterways transportation system in Viet-Nam.

Commodities transported in Democratic Kampuchea include rice paddy, rubber, maize, tobacco, wood, fruits, fish, sugar, vegetables, construction materials, and minerals. Very little information is available about quantities of commodities being transported. An information system needs to be set up in Democratic Kampuchea to develop basic data on commodities transported, origin, destination, means of transportation, transportation time and cost, etc. (Ref. 27).

From the data presented above it is improbable that any significant pollution problems would arise in the future due to shipping on the Mekong, provided due care is exercised in design and operation of facilities and in the operation of ships handling oil or other pollution-sensitive materials.

## 5. Probable effects of the navigation improvement programme

The probable effects due to the navigation improvement programme mainly concern human uses and socio-economic values. Effects on other environmental values, with proper planning, will be minor.

### 5.1 Effects on land uses

#### 5.1.1 Disposal sites for dredged materials

The disposal sites for dredged materials to be removed from the Vam Nao pass and the Snoctrau sand bar have not been selected; however it has been recommended that the dredged materials be deposited on the river banks at least far enough away so the dredged material will not flow back into the navigable channel. Hence large amounts of dredged material, including an estimated 200,000 $m^3$ from Vam Nao pass, would be deposited on the river banks. With proper planning this deposition can be managed without harmful effects on aquatic biota or other environmental values and may even enhance environment through careful use for landfill. Availability of materials suitable for landfilling is a perennial problem throughout the delta.

#### 5.1.2 Commercial areas

Increased navigation along the Mekong river will stimulate community growth and increased commercial and industrial uses, hence land uses will shift from agricultural and other rural uses to urban uses. Development of navigation above Pa Mong is difficult to estimate, but could be accelerated by mineral development. However, downstream from Savannakhet there should be considerable growth in commerce should Highway No. 9 be constructed linking Savannakhet with a proposed free port at Da Nang in Viet-Nam. Development of commercial areas along the Mekong river in Democratic Kampuchea should occur in the same manner as in the Lao PDR and Viet-Nam.

In Viet-Nam the commercial areas expected to develop more rapidly following construction of Pa Mong would be My Tho, Can Tho, Long Xuyen, and Chau Doc, especially the evolving industrial zone at Can Tho. Also, the Chau Doc area is a fish production centre with about 7,000 wooden floating fish cages with a maximum fish production capacity of 35 tons/year (Ref. 27), and probably Chau Doc will become an increasingly important trade centre for fish. The navigation improvement programme should stimulate increased fish production in the Chau Doc area for distribution to other markets along the river.

## 5.2 Socio-economic effects

The Mekong Committee has concluded that the navigation benefits provided by Pa Mong dam in the region above the dam may be limited, based on purely economic aspects (Ref. 1), except for mineral development possibilities. Although navigation improvements resulting from Pa Mong will provide year around travel for people along the Mekong river from Luang Prabang to Vientiane and from Vientiane to Savannakhet, the time of travel by boat will be the main deterrent. Many passengers will prefer bus service due to the shorter time of travel. Fast passenger service along the Mekong river is under study by the Lao PDR.

Development of ports and ramps associated with Pa Mong, both upstream and downstream of the dam, will provide increased employment for laborers and technicians. Also, the training programme, including the boat building centres at Nong Khai and Savannakhet and navigation training centres at Phnom Penh and Saigon, will stimulate the four riparian countries to make use of the improved navigation channel. At least 40 persons have already been trained at the Nong Khai boat building training centre.

## 5.3 Effects of Pa Mong dam on navigation

### 5.3.1 Upstream effects

The maximum velocity at Keng Luang, about 75 km south of Luang Prabang will be reduced from 11 km/hour to 6 km/hour. The navigation difficulties at Keng Luang now increase during the dry season. With Pa Mong this problem will be eliminated when the reservoir is full (Pa Mong high pool elevation 250 m MSL would have surface water extending up to Keng Luang) (Ref. 1). However, navigability in the reservoir will depend on the season, i.e., the length of navigable reach will be least during the dry season when the reservoir is being drawn down and at a maximum at the end of the flood season when the reservoir is full. Table 8 shows the average reservoir surface elevation for Pa Mong for various high pool elevations. The average distances of flooded waterway from the damsite, based on estimations from Tables 6 and 8, are presented in Table 9.

Construction of ramps at the reservoir bank for trans-shipment of cargo is the best answer to the initial stage of the Pa Mong trans-shipment programme (Ref. 26). The ramp is recommended to be open to all users with no charges to be made for the service. It is believed that this type of facility would handle the general cargo projected for at least ten years following dam completion (Ref. 26).

A major change in trans-shipment operations would be required only in the event of extensive mineral development near the reservoir or in the area upstream from the reservoir along the Mekong.

Review of traffic projections on an approximate 5 year cycle, as recommended by a recent study (Ref. 26), will provide the bases for navigation improvement planning for further stages of development.

5.3.2 Downstream effects

Pa Mong dam will provide at least 1,000 $m^3$/sec additional water during the dry season. The average increase of depth of flow between Vientiane to Savannakhet will be about 2.4 metres, so that lighters from 300 to 900 tons and motor cargo ships up to 300 tons can be navigated throughout the year. There would be also some increases in the tonnage of small local craft in Savannakhet - Pakse reach. At the present time the maximum capacity of motor vessel travelling this reach is about 90 tons, and the maximum capacity of a motor vessel with barges is about 110 tons (Ref. 33).

The velocity of river in this reach will be slightly increased due to the increase in river discharge. The slight increase in water velocity in the low water season should not create adverse effects on downstream environmental values. Also, Pa Mong should bring about a reduction of water discharge during the flood season to an average not greater than 8,320 $m^3$/sec (Ref. 35), compared to the existing flow during the flood season of about 12,900 $m^3$/sec (average from 1913 to 1960). This reduction of about 4,500 $m^3$/sec will reduce the flow velocities during the flood period, which will be helpful to navigation.

The effects of Pa Mong on navigation farther downstream from Savannakhet are expected to be minor. Navigation improvements along the mainstream of Mekong river below Savannakhet will be achieve through future construction of downstream mainstream projects such as Sambor and Stung Treng.

It is estimated that the maximum daily river fluctuation just downstream of the Pa Mong power plant will be about 0.9 m and 3.40 m during 1983 and 1992 respectively. The time interval from the minimum to maximum river stages is about 5 hours (See discussion on power). The effect of river fluctuation

downstream of the damsite is expected to diminish at the confluence of the Nam Ngum tributary (Ref. 36). Such fluctuation of the river will affect the workability of the existing port of Vientiane in this reach of river. Also, the future ramp at Km 1602, just downstream of the damsite, will be affected by river fluctuation. It has been recommended that steel floats be provided adjacent to the downstream ramp to accommodate the fluctuating water levels (Ref. 26). Steel floats may also find application for the port of Vientiane, should the workability of the port be limited by river fluctuation.

### 5.3.3 Summarized economic benefits

The savings in tons per kilometre for each reach were estimated for the period 1981 to 2030. Based on these data, the present worth values of the savings were determined for the periods 1981-2030 and 1981-2080 by river reaches as follows (Ref. 35):

| Mekong river reach | Present worth of total annual transportation savings with 6% discount rate (US$) | |
|---|---|---|
| | 50-years | 100-years |
| Vientiane-Luang Prabang | 8,299,879 | 9,562,541 |
| Vientiane-Savannakhet | 1,282,259 | 1,477,542 |
| Total | 9,581,138 | 11,040,083 |

The total average annual savings will be $609,000 for the reach from Vientiane to Luang Prabang, and $664,000 for the reach from Vientiane to Savannakhet.

## 5.4 Other effects

Water pollution to be expected from navigation improvements should not be substantial since the majority of cargo to be transported by waterway fleet will be rich, foodstuffs, and construction materials. However, a significant volume of petroleum products will also be transported, for which special precautions need be taken.

Another effect due to the navigation improvement programme would be bank erosion along the rivers and navigation canals, especially due to use of "long tail" boats. In Viet-Nam, the navigation canals originally designed for sailing junks and low power motor vessels have not been able to withstand the turbulence caused by the powerful long tail boats now widely in use. Consequently, the banks are collapsing in many places (Ref. 37).

## 5.5 Effects of different pool levels

With respect to different levels of Pa Mong reservoir, the probable effects on navigation such as economic benefits and navigability in the lower Mekong river will be greater for higher full pool levels, particularly for the upstream reaches, although effects of a similar nature would be expected for all of the four alternative pool levels considered.

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(37) "Review of the Principle Activities of the Mekong Committee in the Field of Navigation Improvement". Mekong Committee publication WRD/MKG/INF/L.576 Rev.1, Nov. 1973.

TABLE 1

MEKONG RIVER HYDROGRAPHIC SURVEYS SPONSORED BY MEKONG COMMITTEE IN COLLABORATION WITH RIPARIAN GOVERNMENTS

| Year | Type of Work | Location | Remarks | Reference |
|---|---|---|---|---|
| 1965 | 1: 20,000 Navigation chart | Various reaches of the river | | 8 |
| 1966 | Hydrographic surveys | Nam Ngum tributary<br>The Bassac from the South China Sea to Viet-Nam/Democratic Kampuchea frontier | Reconnaissance survey | 9 |
| | Navigation charts<br>Scale 1:5,000<br>Scale 1:2,500<br>Scale 1:1,000 | Banam, Oknatey, and Kiem Chrey reaches and approach to Phnom Penh port<br>Chrui Changwar channel, Phnom Penh wharves, Phum-Chan, and Prek Anhchanh<br>Sdau pass and Rocakong | | |
| | Topo-hydrographic survey | Proposed port sites on Lao and Thai banks | | |
| | Velocities and direction of current | Quartre-Bras | Periodically | |
| 1967 | Hydrographic survey<br>1:10,000 hydrographic charts<br>Topo-hydrographic survey<br>Navigation conditions | Nam Ngum river<br>Bassac river<br>Hat Dok Keo, Lao PDR<br>The Bo, Thailand<br>Luang Prabang - Savannakhet<br>Nam Heung - Nam Mune | Reconnaissance, sounding<br>For proposed river portside<br>" " " " | 10 |
| 1967 | Navigation conditions<br>Surface current velocities and sounding survey | Entrance to the Vam Nao of the Bassac<br>Mekong mainstream | To check the alteration of navigation channel of the 1966 flood | 10 |
| 1968 | Hydrographic charts<br>Scale 1:5,000<br>Scale 1:5,000<br>Hydrographic chart<br>Navigation conditions<br>River characteristics<br>Topo-hydrographic survey | Done Kaset<br>From Chrui Changwar to Chrui Ampil<br>Keng Kabao and Kong Kapuang<br>Savannakhet - Pakse<br>Pakse - Vaun Kham<br>Luang Prabang - Savannakhet<br>Nam Mune - Vaun Kham<br>Mukdahan | Show 1966 maximum water level<br>Proposed river port | 11 |
| 1969 | Hydrographic maps<br>Scale 1:500, 1:2,500, 1:5,000 and 1:10,000<br>Hydrographic chart<br>Scale 1:5,000 | Difficult stretches on the Mekong and Bassac, Democratic Kampuchea<br>Don Kaset shallow | | 12 |

TABLE 1 (Cont'd 1)

| Year | Type of Work | Location | Remarks | Reference |
|---|---|---|---|---|
| 1969 | Hydrographic survey Scale 1:5,000 | Vientiane sandbar | | |
| | Hydrographic chart Scale 1:5,000 | Mukdahan/Savannakhet sandbar | | |
| | Hydrographic survey | Confluence of the Mekong and Mun rivers | | |
| | Hydrographic survey | Can Tho, Vam Nao | Routine work | |
| 1970 | Hydrographic survey Scale 1:500 | u/s and d/s of Phnom Penh | Routine work | 13 |
| | | Chrui Ampil (km 324-333), Manivong and Sangkum bridges | Difficult stretches | |
| | Scale 1:5,000 | Banam (km 283-288) and Peam Chor | | |
| | Survey of sandbar | Vientiane and Nong Khai | | |
| | Detailed survey, including measurement of stream flow and water plane elevation | Kong Kabao rapids | At the request of AIT for calibration of physical Model | |
| 1971 | Hydrographic survey | Approach to Phnom Penh | Routine work | 14 |
| | | Bawan pass, Chrui Changwar and Manivong bridge | Routine work | |
| | | Tonle Tauch between Peam Prapnuous and Banam | | |
| | | Done Chanh Island in front of Vientiane | Bank erosion study | |
| | | Ban Houei Sai, Tha Dona and Pakse | For ramp construction | |
| | | Dinh Tuong, Viet-Nam | | |
| | Max. and min. stages | Mekong river | | |
| | Flood chart | Nong Khai - Vientiane region | | |
| | Tailwater observation | From Pa Mong damsite to Nong Khai | Cross-section measurement | |
| | Topo-hydrographic survey | Nakhon Phanom and Mukdahan | For ferry ramp construction | |
| 1972 | Hydrographic surveys | Approach to Phnom Penh, in the vicinity of Chrui Changwar, Chrui Ampil and the Manivong bridge | Routine work | 15 |
| | | Boeung Pum Peny lake | For polder project | |
| | | Ban Houei Sai and Chiang Kong | Channel reconnaissance survey between two proposed ramp sites. | |
| | | Bac Lieu - Camau, Phu Hun - Bai Xau and Thanh Loi canals | Detail surveys for dredging work | |
| | Topo-hydrographic survey | Kong Kapheung | Large scale survey | |
| | Revision of chart datum | From Chiang Saen to Phnom Penh | | |
| | Cross-section of Mekong river | Nakorn Phnom - Thakhek, Mukdahan - Savannakhet | For EGAT's submerged cables | |

TABLE 1 (Cont'd 2)

| Year | Type of Work | Location | Remarks | Reference |
|---|---|---|---|---|
| 1973 | 10-day survey computation course | Bangkok | Attended by hydrographers of all four countries | 16 |
| | Hydrographic survey | At the vicinity of Phnom Penh | | |
| | | Keng Kabao | Before and after rock blasting | |
| | | Nam Ngum Basin | For sedimentation study | |
| | | Bane Thasano (Savannakhet) | For port site selection | |
| | | Ban Thon Pheung - Done Savanh area | For a proposed ferry ramp | |
| | | Chiang Saen | For a proposed ferry ramp | |
| | Hydrographic survey | Vam Nao passage | | |
| | Revision of chart datum | From Chiang Saen to sea | | |
| | Hydrographic map | Pa Mong damsite | | |
| | Establishment of new benchmarks | Chiang Khong and Ban Houei Sai | Checking | |
| | Tailwater survey | From Pa Mong damsite to the mouth of Nam Ngum river | Both low-water and flood | |
| 1974 | Hydrographic survey | The vicinity of Phnom Penh | Routine work | 17 |
| | | Banam pass | | |
| | | Keng Kabao | Before and after rock blasting | |
| | | Nam Ngum basin | Sediment survey | |
| | | Mekong, the vicinity of Vientiane water supply pumping station | | |
| | | Ban Thon Pheung - Done Savanh area | Repeat survey for ferry ramp | |
| | | Long An, 40 km SW of Saigon | For port development | |
| | | Rivers and canal in Mekong delta, 61 km | | |
| | Topo-hydrographic survey | Bung Kan district | For ferry ramp | |
| | Tailwater survey | From Pa Mong dam to the mouth of Nam Ngum river | Continue from last year | |
| | Care and maintenance of staff gauges | Nong Khai, Nakhon Phanom, and Mukdahan | | |

TABLE 2

MEKONG CHANNEL IMPROVEMENTS SPONSORED BY MEKONG COMMITTEE IN COLLABORATION WITH RIPARIAN GOVERNMENTS

| Year | Type of Work | Location | References |
|---|---|---|---|
| 1964 | Concrete cement reference markers and distance markers<br>Night navigation markers<br>Loading marks<br>Dredging work for ships with 4.5 m draft | From Chiang Karn to Phon Physai<br>Kratie to Phnom Penh<br>Port of Phnom Penh<br>Port of Phnom Penh | 7 |
| 1965 | Maritime beacons installation<br>Planning work for rock blasting | From Phnom Penh to Democratic Kampuchea/Viet-Nam border<br>Keng Kabao | 8 |
| 1966 | Electric lanterns installation on beacons and bouys<br>Experiment on spar bouys to replace bamboo bouys<br>Preparation of rock blasting<br>Dredging works | From Phnom Penh to Democratic Kampuchea/Viet-Nam border<br>Lao PDR and Thailand<br>Keng Kabao<br>Viet-Nam | 9 |
| 1967 | Bouys installation<br>Operation and maintenance works<br>Planning work by demolition experts<br>Dredging work by the cutter suction dredge | Bassac estuary up to Can Tho<br>Democratic Kampuchea<br>Keng Kabao<br>Viet-Nam and Phnom Penh | 10 |
| 1968 | Maintenance of navigation light beacons and reinstallation of light bouys<br>Bouys laying<br>Placing of bamboo bouys<br>Experimental rock blasting<br>Dredging works by cutter suction dredge<br>Preparing specification for aerial photography at 1:5,000 scale | Democratic Kampuchea<br>The Bassac estuary and navigable channel up to Can Tho<br>Difficult stretches of river in Lao PDR<br>Keng Kabao<br>Democratic Kampuchea and Viet-Nam<br>Difficult stretches in the upper reach between Vientiane and Luang Prabang | 11 |
| 1969 | Maintenance of light-beacons and light bouys<br>Laying bouys<br>Laying temporary bouys<br>Experimental rock blasting<br>Preparation for channel improvement<br>Routine dredging work<br>Preliminary desk study of navigation | Democratic Kampuchea<br>Can Tho on the Bassac<br>Luang Prabang - Savannakhet<br>Keng Kabao<br>Vientiane - Luang Prabang<br>Democratic Kampuchea, Viet-Nam<br>The Bassac river in Viet-Nam | 12 |
| 1970 | Kilometre markers and sounding shoremarks installation<br>Routine laying of temporary bouys | Along the banks of Tonle Tauch<br>Between Vientiane and Savannakhet | 13 |

TABLE 2 (Cont'd)

MEKONG CHANNEL IMPROVEMENTS SPONSORED BY MEKONG COMMITTEE IN COLLABORATION WITH RIPARIAN GOVERNMENTS

| Year | Type of Work | Location | References |
|---|---|---|---|
| 1970 | Second experiment on rock blasting | Keng Kabao stretch | 13 |
| | Hydraulic model of the Mekong river | Keng Kabao stretch | |
| | Photomosaic of difficult stretches for future channel improvement work | Between Vientiane and Luang Prabang | |
| | Routine dredging work | Democratic Kampuchea and Viet-Nam | |
| 1971 | Lightbouys installation, and replacement of the kilometre markers | Approach to Phnom Penh, the Banampass, Tonle sap, the Bassac | 14 |
| | Laying of temporary bouys | Between Vientiane and Savannakhet, from Luang Prabang over a distance of 50 km downstream | |
| | Starting work on new beaconing bouying | Between Cau Tieu and Sadec | |
| | Dredging work | Chrui Changwar and Chrui Ampil passes | |
| | | Inland port of Bac Lieu | |
| 1972 | Dredging works | Bac Lieu - Ca Mau, Phu Huu - Bai Xau and Thanh Loi channels | 15 |
| | | Chrui Changwar and Chrui Ampil passes | |
| | Training course in diving and under water demolition with Royal Thai Navy, three month period | Three trainees from Lao PDR, for Keng Kabao rock blasting | |
| 1973 | Dredging work | Chrui Changwar and Chrui Ampil passes | 16 |
| | | Phu Huu - Bai Xau (completed), Bac Lieu - Ca Mau (60% completed), Cay Kho - Ong Loi (50% completed), Mang-Thit and Cho-Gao (beginning) | |
| | First year of rock blasting to clear the navigation channel | Keng Kabao rapids | |
| 1974 | Dredging work | Chrui Changwar and Chrui Ampil passes | 17 |
| | 118,000 $m^3$ sediment removed | Kho-Rach Ong Lon | |
| | 82,000 $m^3$ " " | Mang Thit | |
| | 488,000 $m^3$ " " | Cho Gao | |
| | 210,000 $m^3$ " " | Cho Lach | |
| | 546,000 $m^3$ " " | Bac Lieu - Ca Mau | |
| | Second year of rock blasting | Keng Kabao rapids | |
| | Light houses | Reng Island and Vam Ky-Hou in Viet-Nam | |
| | Maintenance of concrete beacons | Between Savannakhet and Khone Island | |
| | Channel marking by bamboo floats at difficult stretches | Between Nam Houang and Savannakhet | |

TABLE 3

NAVIGATION TRAINING PROGRAMME BY MEKONG COMMITTEE IN COLLABORATION WITH RIPARIAN COUNTRIES

| Year | Description/Subject | Attending Personal | Location | References |
|---|---|---|---|---|
| 1964 | 1st Seminar on Navigation Improvement : shipyards for flat bottomed inland navigation craft; water transport equipment; the role of maritime transport in international trade. | Chief of navigation services and hydrographic survey teams from the four riparian countries, and three experts. | Phnom Penh, Democratic Kampuchea | 7 |
| 1965 | 2nd Seminar on Navigation Improvement : Keng Kabao, a narrow rocky stretch, how can it be improved; hydrojet boats, their possibilities, advantages, and uses; inland navigation and its role in economic development of the Mekong on the stretch Luang Prabang - Mukdahan/Savannakhet. | Chiefs of navigation services and hydrographic survey teams from the four riparian countries, and consultants. | Savannakhet and Vientiane, Lao PDR | 8 |
| | Pilot training by pilot expert from the Netherlands, for reach Phnom Penh - border in Democratic Kampuchea/Viet-Nam. | pilots in Democratic Kampuchea | Democratic Kampuchea | 8 |
| 1966 | 3rd Seminar on Navigation Improvement : shipyard and craft design programs, hydrographic survey, bank protection, etc. | 45 persons including 19 from riparian countries, 27 experts and observers. | Nong Khai and Bangkok, Thailand | 9 |
| | Pilot training by pilot expert from the Netherlands, for reach Kampong Cham - border in Democratic Kampuchea/Viet-Nam. | 9 pilots, Democratic Kampuchea | Democratic Kampuchea | 9 |
| 1967 | Pilot training by pilot expert from the Netherlands for reach Kampong Cham - border in Democratic Kampuchea/Viet-Nam | 13 pilots, Democratic Kampuchea | Democratic Kampuchea | 10 |
| 1968 | Pilot training by pilot expert from the Netherlands for reach Kampong Cham - border of Democratic Kampuchea/Viet-Nam. | 13 pilots, Democratic Kampuchea | Democratic Kampuchea | 11 |

TABLE 3 (Cont'd)

NAVIGATION TRAINING PROGRAMME BY MEKONG COMMITTEE IN COLLABORATION WITH RIPARIAN COUNTRIES

| Year | Description/Subject | Attending Personal | Location | References |
|---|---|---|---|---|
| 1968 | 4th Seminar on Navigation Improvement : Mekong river transportation; navigation improvement; cargo handling; ports, harbors and etc. | Representatives of four riparian countries, Mekong Committee, UNDP, and ADB. | Bangkok, Thailand | 11 |
| 1970 | Preliminary training course by British expert. | - | Nongkhai, Thailand | 13 |
| 1971 | 1st Regular training course by British expert. | 15 pupils | Nongkhai, Thailand | 14 |
| 1972 | Training course : marine engines and boat construction | 40 pupils | Nongkhai, Thailand | 15 |
| | Training course : navigation, marine diesel mechanics | - | Savannakhet, Lao PDR | 15 |
| | 13 fellowships in navigation and related fields | Students and trainees from riparian countries | Europe | 15 |
| 1973 | Training course : ship building; glass reinforced plastic (special course) | Ordinary course : 40 pupils<br>Special course : 12 Thai, 4 Lao, and 4 Democratic Kampucheas | Nongkhai, Thailand | 16 |
| | Five fellowships in navigation, hydrography, and port management | Riparian countries staff | Europe | 16 |
| 1974 | Training course : shipbuilding and workshop machinery | 19 pupils | Nongkhai, Thailand | 17 |
| | Special course : welding, marine diesel engines | 20 pupils | Nongkhai, Thailand | 17 |
| | Navigation and diesel engine mechanics | 6 skippers | Savannakhet, Lao PDR | |
| | Course on subject of standardization in measurement of ships among riparian countries. | Technicians from Democratic Kampuchea, Lao PDR, and Thailand. Viet-Nam represented by observer. | Bangkok, Thailand | 17 |

Navigation

TABLE 4

ESTIMATED VOLUME OF WATERBORNE FREIGHT VIENTIANE TO LUANG PRABANG AND INTERMEDIATE PORTS

| Year | Rate of Increase (%) | Thousands of Tons |
|---|---|---|
| 1966 | | 8.0 |
| | 7.5 | |
| 1974 | | 14.5 1/ |
| 1980 (Project year 0) | | 22.0 |
| 1981 | 5.0 | 23.1 |
| 1982 | 5.0 | 24.3 |
| 1990 | 5.0 | 35.9 |
| 2005 | 5.0 | 74.5 |
| 2006 | 2.5 | 76.4 |
| 2030 | 2.5 | 138.1 |

(Source, Ref. 26)

1/ Actual tonnage moved above Vientiane as determined by survey in 1974 was 11,369 m tons.

TABLE 5

COMPARISON OF TYPICAL TON-MILE CHARGES FROM VIENTIANE TO SELECTED CITIES, DECEMBER 1974

| Port City | River | | Road | | Air | |
|---|---|---|---|---|---|---|
| | Distance km | Rate per ton-km US$** | Distance km | Rate per ton-km US$ | Distance km | Rate per ton-km US$ |
| Downstream | | | | | | |
| Paksane | 206 | 0.016 | 150 | 0.093 | 116 | 0.763 |
| Thakhek | 390 | 0.015 | 350 | 0.066 | 240 | 0.500 |
| Savannakhet | 486 | 0.012 | 495 | 0.048 | 277 | 0.505 |
| Upstream | | | | | | |
| Paklay | 237 | 0.042 | - | - | - | - |
| Sayabouri* | 408 | 0.045 | - | - | 170 | 0.707 |
| Luang Prabang | 468 | 0.027 | 398 | 0.038 | 250 | 0.560 |

* Rate includes local drayage from Tha Deua to Sayabouri.

** Kip converted at rate of 1,200 kps per US dollar.

(Source, Mr. P. Gouye, Vientiane, Lao PDR, Ref. 26).

TABLE 6

SLACK WATER NAVIGATION PA MONG LAKE

| Reservoir Surface level m MSL | Approx. distance of flooded water-way from dam, km | Remaining distance to Luang Prabang, km |
|---|---|---|
| 210 | 175 | 250 |
| 220 | 240 | 185 |
| 230 | 280 | 145 |
| 240 | 325 | 100 |
| 250 | 345 | 80 |
| 260 | 375 | 50 |

TABLE 7

INCREASE OF AVERAGE MONTHLY FLOW

DOWNSTREAM OF PA MONG DAM DURING NOVEMBER TO JUNE

(Period of study Nov. 1929 – Oct. 1969)

| Pa Mong High Pool Elevation (m MSL) | Increase Average Monthly Flow (cms) |
|---|---|
| 230 | 970 |
| 240 | 1,500 |
| 250 | 1,910 |
| 260 | 2,170 |

TABLE 8

AVERAGE RESERVOIR SURFACE ELEVATION (FROM 1929-69) FOR PA MONG

HIGH POOL ELEVATION 260, 250, 240 AND 230 m MSL

| Scheme of development Pa Mong HWL m MSL | Average reservoir surface elevation (1929-69) end of month m MSL | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
| 260 | 255.34 | 253.83 | 251.91 | 204.96 | 248.04 | 246.93 | 249.48 | 253.62 | 258.00 | 258.06 | 258.14 | 256.86 |
| 250 | 245.67 | 244.05 | 241.92 | 239.71 | 237.33 | 235.94 | 238.78 | 243.20 | 248.63 | 249.45 | 248.65 | 247.30 |
| 240 | 237.03 | 235.46 | 233.17 | 229.86 | 226.16 | 223.19 | 227.63 | 233.02 | 239.00 | 239.94 | 239.93 | 238.55 |
| 230 | 226.29 | 224.38 | 221.98 | 219.28 | 215.41 | 212.05 | 212.25 | 223.36 | 228.40 | 230.00 | 229.96 | 229.62 |

(Source, Mekong Committee unpublished data)

Navigation

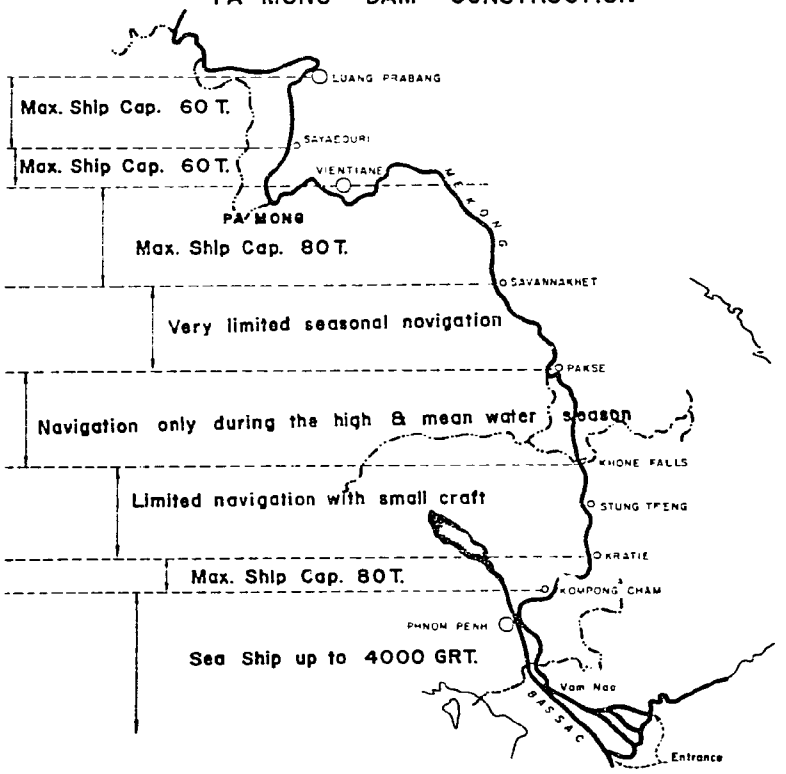
TABLE 9

APPROXIMATE AVERAGE FLOODED WATERWAY FROM DAMSITE WITH PA MONG

HWL OF 260, 250, 240 AND 230 M MSL

| Pa Mong HWL m MSL | Approx. average distance of flooded waterway from damsite, km | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
| 260 | 361 | 360 | 350 | 346 | 341 | 339 | 345 | 356 | 369 | 370 | 370 | 365 |
| 250 | 336 | 332 | 329 | 322 | 310 | 306 | 318 | 331 | 342 | 344 | 342 | 340 |
| 240 | 310 | 303 | 293 | 279 | 264 | 249 | 270 | 302 | 320 | 324 | 324 | 316 |
| 230 | 265 | 257 | 247 | 232 | 210 | 187 | 186 | 249 | 251 | 280 | 280 | 279 |

## NAVIGATION ON THE MEKONG RIVER BEFORE PA MONG DAM CONSTRUCTION




## NAVIGATION ON THE MEKONG RIVER AFTER PA MONG DAM CONSTRUCTION

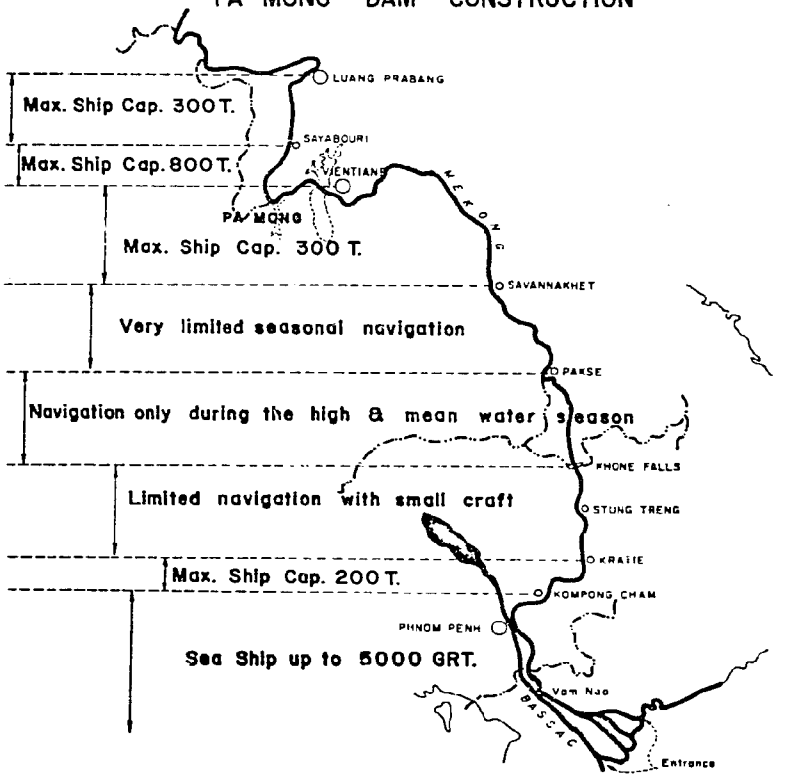



Fig. I

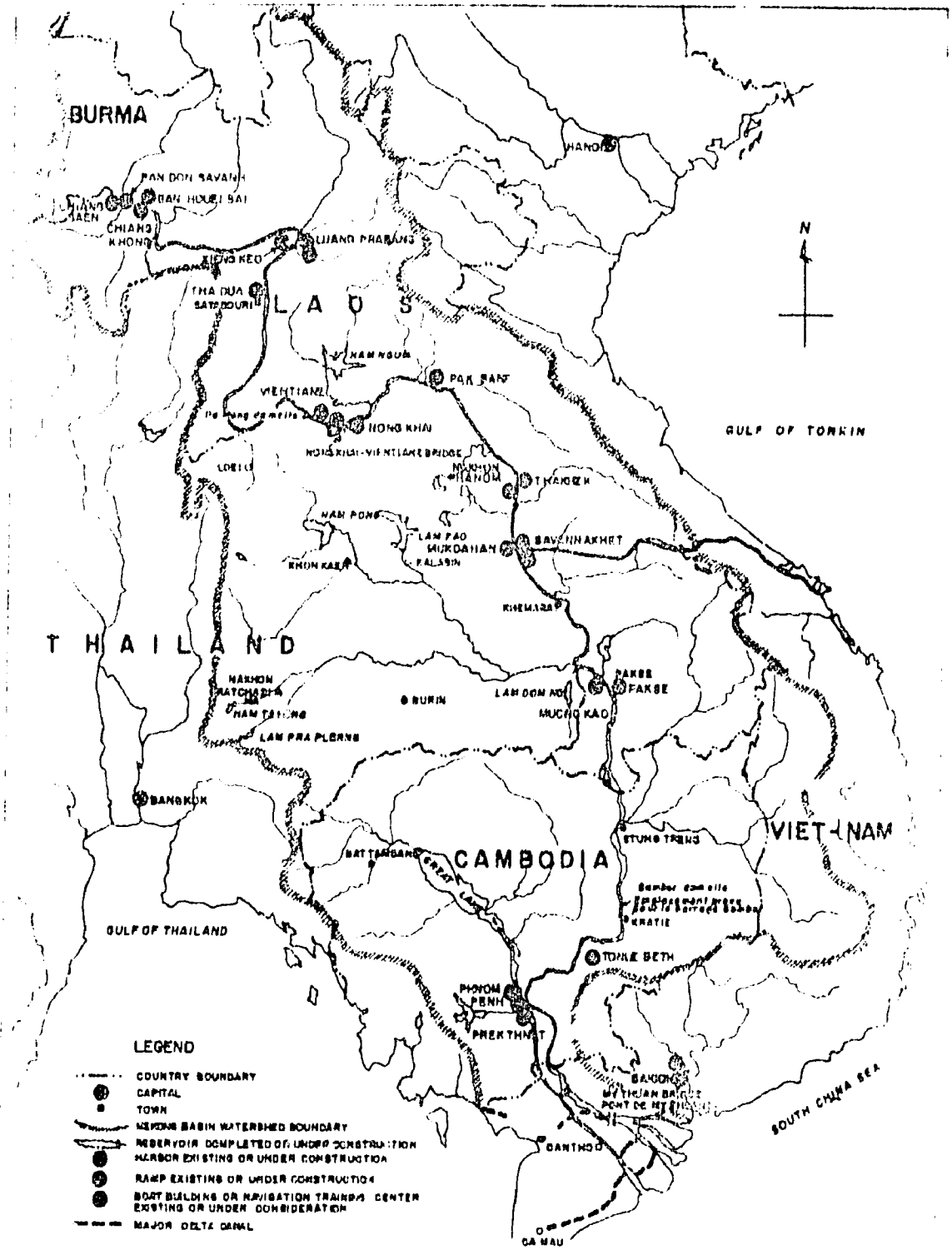
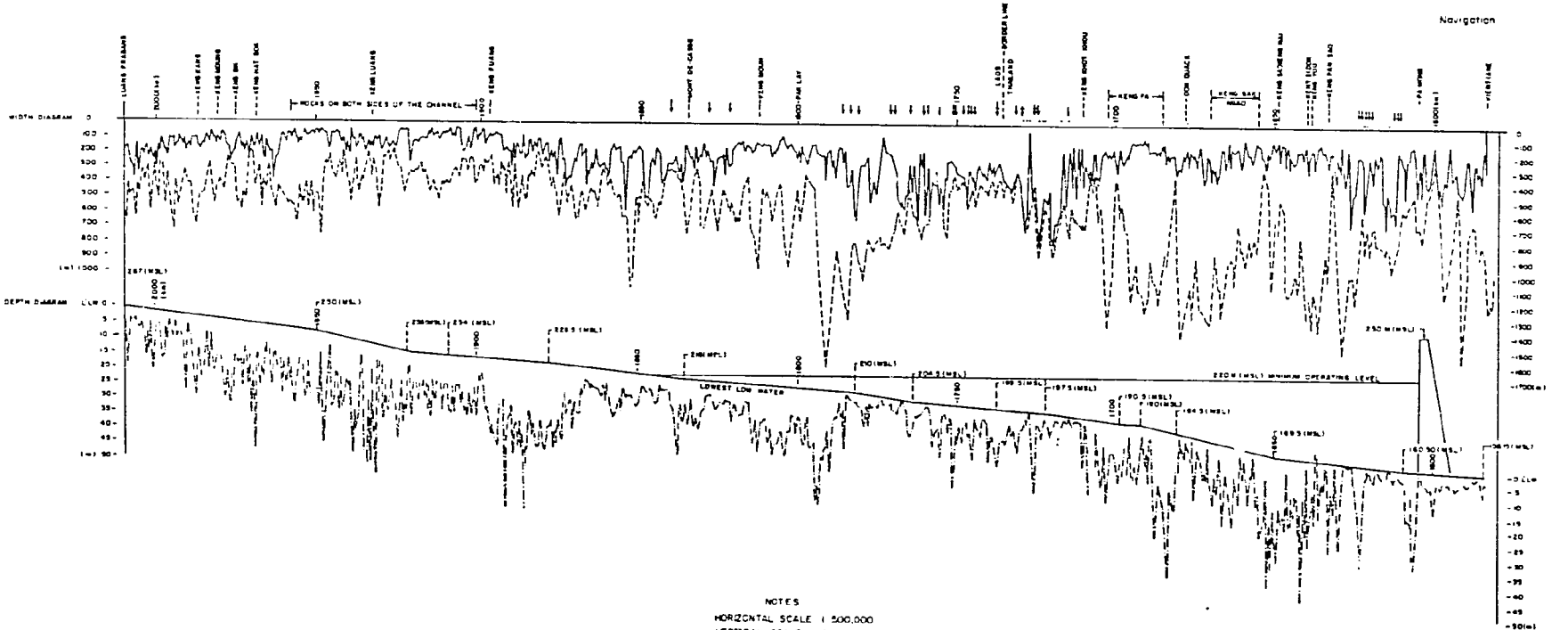



FIGURE 2

LOCATION OF NAVIGATION AND TRANSPORTATION PROJECTS PLANNED BY MEKONG COMMITTEE (AS OF 1974)

( From Reference 17 )

SCALE 0 20 40 60 80 100 200 KM




NOTES

HORIZONTAL SCALE 1 500,000

VERTICAL SCALE 1 10,000 , 1 1000 , 1 500

SHALLOW SECTION OR SHOAL (SAND)

SHARP BENDS IN THE RIVER

ROCKS

APPROXIMATE WIDTH OF NAVIGABLE CHANNEL AT LOWEST LOW WATER

APPROXIMATE WIDTH OF RIVER FROM BANK TO BANK

L.L.W. LEVEL APRIL 1,1960 BY HUNTING SURVEY CORP. LTD.

BOTTOM SOUNDED FROM LAOTIAN CHARTS SURVEYED IN 1962 - 1965

FIGURE 3

**NAVIGATION CONDITIONS ON MEKONG RIVER FROM LUANG PRABANG TO VIENTIANE**

**1958**

(Ref. 1)

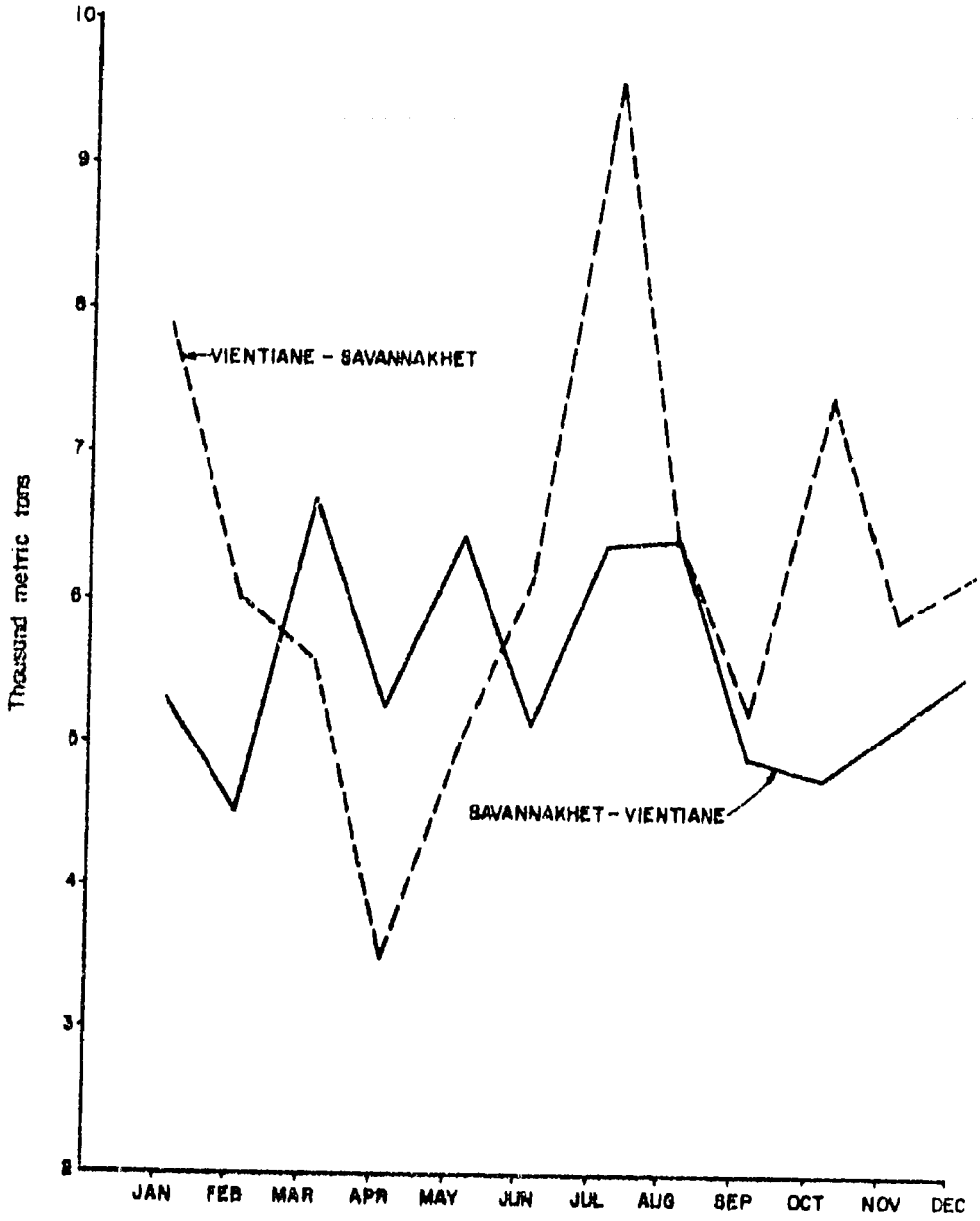



FIGURE 4

SEASONAL FLUCTUATION OF WATERWAY TRANSPORT

BETWEEN

VIENTIANE AND SAVANNAKHET

1961 - 1967

( Ref. 1 )

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## POWER

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Figure 3: Comparison of load forecast for Thailand between NEI and EGAT

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# PA MONG ENVIRONMENTAL ASSESSMENT

## POWER

### 1. Introduction

Of the multipurpose benefits expected from the Pa Mong project, power is one of the main bases of its economic and financial justification (Ref. 1). The hydrologic characteristics of the lower basin indicate that the Mekong river is by far the principal indigenous source of energy available to the four riparian countries, and that Pa Mong is the logical first mainstream project for reaping this benefit. Without Pa Mong and other mainstream and tributary hydroelectric power projects, most of the region's future energy needs might have to be met by fuel imports.

To the extent and at the rate feasible, the countries of the lower basin must industrialize for their greater prosperity, and to accelerate industrialization, they must use power. It is an accepted fact that the wealth of nations and their people is closely related to the per capita use of electricity, particularly that portion of the per capita use allocated for industrialization. However, before any decision is made to develop Pa Mong's tremendous power potential, it must be shown that the demand for power within a reasonable period will at least equal the quantity to be made available, that the cost of power production at Pa Mong will be less costly than that produced from alternative sources, and also that power production at Pa Mong will not result in serious losses of environmental resources which would be avoided if alternative sources of power were used.

All of the factors noted above have been the subject of many studies sponsored by the Mekong Committee in collaboration with the four riparian countries since 1963. These confirm that power generation at Pa Mong will be by far the most economical source of power, and with the recent increase in costs of oil and of other fuel sources including nuclear fuels, the Pa Mong power alternative commands an even higher priority than before.

It is assumed that Mekong power will be sold wholesale, at prices equal to or lower than costs from alternative sources of supply. Purchases will be the public electricity supply agencies engaged in the distribution of power to ultimate consumers and, where policy dictates, large industrial consumers. The power distribution agencies will combine Mekong power and power produced from other sources in meeting requirements within their respective service areas.

It is the purpose of this discussion to describe the environmental effects relating specifically to the power features associated with the Pa Mong project, rather than all effects stemming from construction and operation of the project. Further details on environmental effects closely associated with power operations are given in the discussions on aquatic biology, reservoir ecology, and navigation.

## 2. Load Forecasts

Using modern high-tension transmission technology, large quantities of power can be transmitted at high voltage and low cost to major load centers 1,000 km distant. Hence the entire national areas of the four lower basin riparian countries lie within the feasible market area.

A review of the many forecasts of power and energy requirements made since 1963 (Ref. 1, 3, 4, 10-28) shows the actual increases to be greater than predicted in the earlier studies. The total installation capacity of the four riparian countries in 1965 was 570.5 MW, of which 527.3 MW was in Thailand and 10.2, 33, and 300 MW in the Lao PDR, Democratic Kampuchea, and Viet-Nam respectively (Ref. 29). The annual energy consumption in 1965 the four countries was 1,087.4, 11.2, 61.2, and 433.3 MKWh for Thailand, Lao PDR, Democratic Kampuchea, and Viet-Nam respectively (Ref. 4). The installed capacities of Thailand and Viet-Nam in 1973 were 1,530 and 813 MW respectively, while Democratic Kampuchea and Lao PDR in 1972 had 66.5 and 77 MW installed capacity respectively (Ref. 30). The annual consumptions of energy in Thailand, Lao PDR, and Viet-Nam were 6,207, 62.2, and 1,150 MKWh respectively, while Democratic Kampuchea consumed 115.2 MKWh in 1972 (Ref. 4). The average annual increases in power and energy consumption, during 1965 and 1973 (during 1965 and 1972 for Democratic Kampuchea), were 21.4, 21.0, 9.2, and 11.5 per cent for Thailand, Lao PDR, Democratic Kampuchea, and Viet-Nam respectively.

It has been estimated (Ref. 3) that the market ability in Thailand alone can absorb the large blocks of power to be produced at Pa Mong. Figure 1 shows the comparison of the load forecast of the four riparian countries with and without the loads of central, northern, and southern Thailand. This figure clearly shows that Thailand, especially the Bangkok metropolitan area, will be the major consumer of the electricity that Pa Mong project will be able to produce. Figure 2 shows the regional distribution of power from Pa Mong project as a result of load flow studies (Ref. 22).

The Electricity Generating Authority of Thailand (EGAT) has prepared forecasts for the electricity load growth of Thailand (Ref. 22) which are somewhat lower than the latest load forecast made for the Mekong Committee by the Netherlands Economic Institute (NEI) (Ref. 4). Figure 3 shows

the comparison of the two electric load forecasts. The EGAT report anticipated the comissioning date of Pa Mong power generating unit numbers 1 and 2 would be in 1988, according to the installation schedule shown in Figure 4. Hence, if based on the latest electric load forecast (Ref. 4), unless EGAT is supplied with a source of generating power other than now planned, as shown in Figure 4, the Pa Mong project will be needed earlier than 1988 in order to meet the increasing power requirements.

## 3. Pa Mong project power features

### 3.1 Stage One

Pa Mong will be a multipurpose project with power generation, irrigation, and flood control, as the primary features. It will become the main source of electric power for the lower basin. The Pa Mong powerplant, to be constructed as part of the dam, would have generating units equally divided and located on each bank of the river. The Stage One report (Ref. 14) assumed eight units each having capacity of 600 MW would be required. This number of generating units was based on the space available at the Pa Mong damsite. Selection of the size of the generating unit is not yet definite, however, because the Pa Mong reservoir maximum pool level has not yet been decided. However, studies of power regulation of Pa Mong as an isolated system, with four different maximum pool elevations, 230, 240, 250 and 260 m MSL, each of which was associated with three different minimum pool elevations, have been completed (Ref. 15, 16, 17, and 18). These studies provide the inputs for assessing at site and downstream beneficial effects accredited to Pa Mong for each scale of development considered. The usable storage under consideration is between 21 to 104 x $10^9$ $m^3$. The installed capacity of the Pa Mong powerplant will vary from 3,200 MW to 5,600 MW while the firm power and energy will vary from 990 to 2,700 MW and 8,650 to 23,600 GWh/year respectively.

The Pa Mong Stage One transmission system will consist initially of two 500 kV alternating current circuits constructed on single circuit steel towers from the dam to Bangkok, one 115 kV AC circuit from the dam to Udorn Thani and one 115 kV AC circuit to Vientiane. It will be necessary to construct two additional 500 kV single circuit lines to the load centre in the vicinity of Bangkok under full Stage One development. A substation just northeast of Chaiyaphum will provide for the transmission of power over separate 230 kV lines to Khon Kaen and Nakhon Ratchasima (Ref. 14).

### 3.2 Phase II

The Pa Mong Phase II report looks beyond the Stage One development to achieve full power utilization after 1993 (Ref. 19). The following are the potential power projects considered in the Phase II report:

(a) Nam Ngum reservoir enlargement: Nam Ngum reservoir can be enlarged by adding 35 m to the maximum normal retention of 212 m. This would form a single reservoir out of Pa Mong, Nam Lik, Nam Mong, and Nam Ngum reservoirs. This would result in greater power production by the Pa Mong generators, amounting to 1,738 MkWh, which is about the same as would be obtained if another 600 MW generator were to be installed at Nam Ngum. This may be compared to the present installed capacity at Nam Ngum of 30 MW and the planned additional capacity of at least 105 MW to be included in the second phase of Nam Ngum construction.

(b) Pa Mong side channel powerplant: It would be possible to expand the power installation at Pa Mong by means of a forebay dam on the Thailand side of the channel. About 5,400 MW can be added to the Stage One power development. Hence, the generation pattern would be changed from base to peak generation.

(c) Huai Bong pumped storage development: The Huai Bong site is located adjacent to the existing Nam Pong reservoir. Nam Pong reservoir would be used as the afterbay. The development of the Huai Bong pumped storage project would help meet the peaking requirements within the project area over the next 26 year period, 1990-2016. The active reservoir capacity would be 155 million $m^3$ and the total power generating capacity for the year 2016 would be 15,000 MW, including 5,600 MW of reversible units and 9,400 MW of generating units. The weekly pumping energy is 346.5 MkWh and energy generated is 210 MkWh. The unit cost of the Huai Bong pumped storage development is 11.42 and 11.21 $/kW-year for the 50 and 100 year analysis respectively.

## 3.3 Transmission lines and distribution of power

Subsequent to the studies noted above, a report by SOFRELEC in 1971 (Ref. 20) describes various alternative development plans for an extra high voltage (EHV) transmission system interconnected between the four riparian countries in order to utilize the bulk of hydroelectric power along the mainstream of the Mekong river. The report stated that a 525 kV AC system would appear to be the most economic alternative for transmitting the bulk of hydroelectric power from future Mekong mainstream projects to the power market areas of the four riparian countries.

For geographical reasons, the Mekong Committee has recommended the power market of the Mekong countries be divided into two main areas, namely Thailand/Lao PDR and Democratic Kampuchea/Viet-Nam. The Mekong Committee

recommended another alternative, such as a 345 kV system, as more suitable for transmitting power in the range of 250-750 MW to be considered for the system in Democratic Kampuchea/ Viet-Nam as an alternative for early stage development (Ref. 21). In the same report the Mekong Committee noted the difference in the unit cost of the EHV transmission system as estimated by SOFRELEC and by EGAT in the Pa Mong Stage One feasibility report. The EGAT estimation is about 37 per cent higher than that by SOFRELEC. The Mekong Committee concluded it is essential to keep all factors, including equipment costs, under continuing review, and that is would be desirable to use a load flow programme to analyze various possible systems by computer.

The Mekong Committee and EGAT staff have also been engaged in a study of alternative Pa Mong transmission systems. The study consists of two parts, first a feasibility grade study of the development of a Pa Mong-Bangkok transmission system dealing with factors related to the economics of transmission systems, and second, a preliminary study of the initial development of a regional transmission grid between Bangkok and Saigon via Khon Kaen, including possible transmission systems for downstream projects (Ref. 14, 33).

The report on the study of the Pa Mong-Bangkok extra high voltage transmission system (Ref.22) was issued in 1975, prepared by EGAT in cooperation with the Mekong Committee. This report determined the best development scheme would comprise 500 kV transmission lines from Pa Mong to the Bangkok area, using alternating current transmission. The report recommended three 500 kV alternating current transmission lines to run from the Pa Mong switchyard to a 500 kV intermediate substation at Chaiyaphum and end at the Min Buri and Sai Noi 500/230 kV bulk power receiving stations in the greater Bangkok area. A double circuit 115 kV line will link Pa Mong and Vientiane. Also a double-circuit 230 kV line is recommended from the Chaiyaphum substation to the Nakorn Ratchasima 2 substation. The transmission cost per KWh is estimated to be 1.724 mills based on the 1974 price level (Ref. 22).

## 4. Electric power processing industries

The Mekong Committee has sponsored numerous studies designed to encourage development of major power using industries as a means for assisting in the financing of Pa Mong and other lower basin projects. These various studies, which are reviewed in the discussions on mineral development and agro-industries, include evaluations of the potentials in the four riparian countries of numerous industries including fertilizer, calcium carbide, pulp and paper, iron and steel, ferro alloy, aluminium, and various agro-industries. The estimated power needs for to these industries and others are summarized in the Table 4. An additional review of projected power needs of the power-oriented industries has been made by the Netherlands Economic Institute (Ref. 32).

The rates of growth in power needs for large electro-processing industries will be affected significantly by the levels of rates and tariffs. Such establishments probably would not purchase power at prices higher than certain levels depending on the competitive situations, because power is essentially a major raw material and a very substantial cost factor. If Pa Mong power can be supplied to electro-processing industries at prices significantly lower than those for power from other sources, the effect in increasing the rate of growth in the power market of the region should be substantial.

Most of the studies sponsored by the Mekong Committee for encouraging industrial use of power, including development of mineral resources and of agro-industries, concluded that power costs would have to be in the range of 3 to 5 mills (US) per KWh to be attractive. This range correspond to prices of 5 to 8 years ago, before the dramatic rise in oil prices, hence a comparable range for current conditions is believed to be from 6 to 10 mills.

For most situations, the key factors influencing decisions of industries which might locate in the lower basin, in addition to power cost, are proximity to raw materials and export markets. Aluminium, however, is an exception where the availability of inexpensive power is the predominant factor. This metal continues to be one of the most promising products for countries offering low-cost power but lacking in domestic markets and raw materials. Although most aluminium smelters are being built within industrialized countries, even using power above 5 mills per KWh, notable exceptions occur. These exceptions include Iceland, Angola, Sharain, and New Zealand where smelters serve the export market exclusively and are being developed only because of low-cost power. The basic material for aluminium is bauxite, which is found in countries not far from the Mekong basin including India, Malaysia, and Indonesia. Also, if detailed studies indicate that import of bauxite for conversion into alumina into the lower basin is not economical, alternatively alumina could be imported from large processing plants in Australia for conversion into aluminium in the lower basin. Such an arrangements would be in keeping with the practice prevailing in some other parts of the world.

5. Cost of thermal alternative

As previously noted the trend of increase in energy cost due to the current energy crisis all over the world has had a major impact on the cost of an alternative thermal powerplant. The Mekong Committee has reviewed and updated the energy cost of thermal plants, both oil-fired and nuclear, by taking the expected new fuel prices into consideration. The study included updating of the estimated energy costs for oil-fired thermal plants of various unit sizes from 100 MW to 900 MW. It was found, with the effects of increases in

both the investment and fuel costs, the present average energy cost is estimated to be almost double that obtained from previous studies (Ref. 6). For example, the average cost of power from a 200 MW oil-fired plant at 60 per cent plant factor was estimated at 7 mills per kWh in the Indicative Basin Plan study in 1969, compared with 15 mills per kWh as computed by the recent study. The power cost of nuclear plants of various sizes were also determined. The average nuclear energy cost for a 200 MW unit is 13.6 mills per kWh and 9.1 mills per kWh for a plant of 600 MW size (Ref. 6).

A comparison of energy costs between the oil-fired and nuclear plants is shown in Table 2. Also, a comparison between the energy cost of hydroelectric and thermal plants is presented in Table 3.

## 6. Reservoir operation studies

### 6.1 Stage One report

The Pa Mong Stage One report assumed an installed hydroelectric power capacity of 4,800 MW at the Pa Mong damsite. The average annual firm energy (based on 1930-68 hydrological conditions) would be about 19,125 MkWh with about 6,015 MkWh of secondary energy, assuming no sediment encroachment and channel degradation. The effects after 50 years of project development were also considered, including sediment encroachment and increased water requirements for irrigation, fishery, domestic, and industrial uses, and again assuming a 4,800 MW capacity hydroelectric powerplant. The average annual (1930-68) energy generated would be 14,800 and 4,065 MkWh of firm and secondary energy respectively (Ref. 25).

### 6.2 Phase II report

The Pa Mong Phase II report found, for the Stage One hydroelectric power development of 4,800 MW, that the average annual (1930-69) firm energy would be 19,500 MkWh with the secondary energy at 6,700 MkWh, assuming no sediment encroachment and channel degradation. The effects of sediment encroachment and channel degradation after 50 years from Pa Mong dam closure, plus increased water requirements for irrigation, fishery, domestic and industrial uses would change the average annual (1930-69) energy generation to 16,900 and 7,000 MkWh of firm and secondary energy respectively (Ref. 26).

The study also considered operation of Pa Mong reservoir with the additional reservoir storage of Nam Ngum (18,479 million $m^3$ active storage) added to that of Pa Mong (77,998 million $m^3$ active storage for the 50 year development). All hydroelectric energy was assumed to be generated at the Pa Mong 4,800 MW power plant. The average annual (1930-69) energy generated was 19,226 and 6,415 MkWh of firm and secondary energy respectively (Ref. 26).

## 6.3 Pa Mong optimization and downstream benefits

An important aspect of the Pa Mong optimization and downstream benefits study will be an analysis of Pa Mong reservoir operation alternative for various condition, i.e., for maximum pool elevations of 230, 240, 250 and 260 m MSL.

### 6.3.1 Minimum pool elevation

For each alternative full pool elevation, three levels of minimum pool elevation are assumed for reservoir regulation study. The study objective is to determine the optimum minimum pool elevation for each maximum pool alternative. Table 8 shows the minimum pool elevation selected for each full pool elevation.

### 6.3.2 System seasonal regulation study

The system seasonal regulation study includes all four alternative high pool elevations, each of which is associated with three minimum pool elevations, giving a total combination of 12 schemes. These schemes vary greatly in usable storage, from 21,000 to 104,000 million $m^3$. The Pa Mong project has been examined both as an isolated project and as a component of systems in which other projects such as Sambor and Stung Treng are included, including the following alternatives:

(a) The 12 schemes for the Pa Mong project in isolation.

(b) Six schemes for the system Pa Mong/Nam Ngum/Stung Treng.

(c) Six schemes for the system Pa Mong/Nam Ngum/Sambor.

(d) Eleven schemes for the system Pa Mong/Nam Ngum/Stung Treng/Sambor.

(e) Three schemes for the system Nam Ngum/Stung Treng/Sambor.

The results of the above studies are presented in Tables 9, 10, 11, 12 and 13. These results are an important input for assessment of at-site and downstream beneficial effects accredited to Pa Mong for each scale of development considered.

## 6.4 Reservoir surface fluctuation

In the case of Stage One development, i.e. for a high pool elevation of 250 m MSL, the maximum rate of reservoir drawdown during operation is about 2.5 metres per month and the maximum rate of reservoir filling is about 7 metres per month (See Fig. VIII-10, VIII-11, Ref. 14). The fluctuation rates of the reservoir surface are about 5 and 23 cm per day during reservoir drawdown and filling respectively. The rate of exposed ground area during reservoir drawdown and inundated ground area during reservoir fill up depend

upon the initial elevation of the reservoir prior to drawdown and fill up; however, the average values can be estimated. The rough estimate of rate of exposed ground area during reservoir drawdown would be about 220 $km^2$ per month or about 7 $km^2$ per day. The maximum rate of ground surface inundated during reservoir fill up, normally from the end of August to the end of September, would be about 520 $km^2$ per month or 17 $km^2$ per day. The total normal change in reservoir elevation during the operating year is from the high pool elevation to minimum elevation fixed by the operating rule curve (levels of elevations to be maintained in the reservoir at various time of the year). In the case of the Stage One development, the total normal reservoir drawdown would be from elevation 250 m MSL to 237 m MSL, 13 metres. The exposed ground area during the reservoir drawdown is about 1,060 $km^2$.

The reservoir drawdown process extends from December to June while the reservoir filling extends from July to September. Table 5 shows the reservoir drawdowns and exposed ground areas for four schemes of Pa Mong reservoir development. Drawdown from the high pool elevation, 280 m MSL, to the minimum pool elevation, 216 m MSL, would occur very rarely (once in the 40 years of record).

In Table 5 the drawdown is defined as the difference in the reservoir elevation between the average high pool elevation, at the end of October, and the average minimum reservoir elevation at the end of June. This table shows the results of the Pa Mong regulation study, as an isolated system, for high water levels of 260, 250, 240, and 230 m MSL, corresponding to minimum pool elevations of 230, 216, 210, and 205 m MSL respectively.

## 7. Fluctuation of river stage during peak generation

The river stage fluctuation during the peak load generation will cause problems in navigation and in river bank stability downstream of the powerplant. According to the Stage One development plan, the effect of the fluctuation is unlikely to be known until the Pa Mong project approaches the implementation stage. However, a report by the USBR in 1960 (Ref. 27) analyzed the typical daily system load, the Pa Mong plant output, and hourly water releases. In brief, from the assumed generation schedule in 1995, with the assumed installed capacity of 5,000 MW, the plant output will vary from a minimum of 300 MW to a maximum of 4,575 MW. In terms of water release from Pa Mong, this is equivalent to 1,456 $m^3$/sec at a minimum and 8,328 $m^3$/sec at a maximum.

On the basis of the available hydrologic data the flow release has been calculated for six locations below the dam, namely Vientiane, Nong Khai, Nam Ngum, Nam Thnon, Tha Khek, and Mukdaharn (Savannakhet). It appears that the

fluctuations in the flow are severe only at Vientiane and Nong Khai due to their proximity to the damsite. Below Nong Khai, the hourly increases or decreases are sufficient to be an obstacle to navigation. In the case of the fluctuations at Vientiane, the variation in the gage height level is 0.85 m/hr (Ref. 27). The fluctuation of river stage at the Pa Mong power plant, calculated corresponding to the release pattern of the Pa Mong regulation study, for a Pa Mong high water level 250 m MSL and minimum pool elevation 216 m MSL, is shown in Table 7. The maximum hourly fluctuations of tailwater elevation at the Pa Mong power plant, where generation is in accordance with the typical daily system load curve of 1983 and 1992 in which there will be 2 and 8 generating units (Figure VIII-8, VIII-9, Ref. 14) respectively, are 0.40 m in 1983 and 0.20 m in 1992.

## 8. Probable environmental effects of hydroelectric power generation

While Pa Mong will be a multipurpose reservoir, important for many uses of which power generation is only one, nevertheless it will be the power generating function which will generally control the rates and amounts of discharge from the reservoir. It is estimated that approximately 96 per cent of the total releases will be power oriented. Hence the effects of operation of the reservoir with respect to effects in the drawdown zone and in the river downstream may be said to be mostly induced by power generation.

### 8.1 Physical effects

(a) Reservoir bank erosion: The reservoir drawdown caused by the release of water, together with inflow to the reservoir during the rainy season, will cause water surface fluctuation in the reservoir. It is often difficult for vegetation to establish itself on the banks of reservoirs subject to large fluctuations in water surface elevation, and the shoreline may remain bare in places and exposed to erosion from either rainfall or wave action. In the case of Pa Mong reservoir, the exposed bare shorelines area would be about 1,200 km$^2$ during the reservoir drawdown period. In addition to the shoreline erosion, the exposed bare areas are unsightly and interfere with the quality of the recreational facilities that can be provided (See discussion on reservoir ecology for additional evaluation of this problem).

(b) Changes in reservoir level: The total drawdown of the reservoir will vary from 12 m to 18 m in accordance with the four development schemes of the reservoir (high pool level from 260 m MSL to 230 m MSL) as shown in Table 14. The drawdown process extends over a period of about eight months, from the end

of October to the end of June. The average change in water levels would be 1.5, 1.7, 2.1, and 2.25 metres per month, for high pool elevations of 260, 250, 240, and 230 m MSL respectively. However, the maximum monthly reservoir drawdowns are 1.95, 2.30, 3.70 and 3.07 metres for pool elevations 260, 250, 240 and 230 m MSL respectively.

The rate of reservoir drawdown is not great because Pa Mong is a large reservoir; however, the total drawdown will range from 12 to 18 metres depending on the scale of development.

The increase in water level in the reservoir during the filling period is maximum during September. The monthly increase in water level during September will be 4.44, 5.43, 5.48, and 5.04 metres for Pa Mong pool elevations of 260, 250, 240 and 230 m MSL respectively. Table 6 shows the average (1929-1969) Pa Mong reservoir elevation at the end of each month for the four schemes of development (high pool elevation 260, 250, 240, and 230 m MSL respectively).

The effects of fluctuation in the Pa Mong reservoir elevation as assessed above will not be severe as related to the human uses of the shoreline, provide the shoreline facilities are properly designed and areas subject to landslides are excluded from use. The rate of fluctuation will be rather slow in terms of change in water elevation during the day. However, the annual range of reservoir drawdown will be significant for navigation and the design of navigation facilities must accommodate this range of fluctuation (See discussion on navigation).

(c) Downstream river fluctuation: The schedule for release of water from the reservoir will depend on the operation of the reservoir to meet its many purposes. Hence the schedule for releases will be very complex and no doubt ultimately controlled by a "master model". However, as previously noted, the power needs can be expected to exercise primary influence on the operating regime.

The system seasonal regulation studies of the Pa Mong reservoir and power plant made by the Mekong Committee have used a monthly basis. For estimating downstream effects a tentative estimation was made of hourly fluctuation, based on the typical daily system load curve shown in Table 7. This shows that the maximum river fluctuation when the power plant is commissioned, with two 600 MW generating units, is about 0.40 m per hour at the Pa Mong power plant. Nine years later, after eight 600 MW generating units

have been installed, the river fluctuation at the power-plant would be 0.80 m per hour. The maximum change of r 'er stage in a day are 0.90 m and 3.40 m at time of commissioning and nine y ars later, respectively. The time interval from the minimum to maximum river stages is about 5 hours.

The effects of river fluctuations on the stability of the river bank downstream of Pa Mong, caused by the static head of water which induces seepage and saturation, are substantial. However, as compared to the effect of flood damage to the Mekong river without the Pa Mong project, the problems of river bank stability may tend to be better with project than for the without project conditions, as has been the experience reported at Nam Ngum (Ref. 31). The effects of fluctuation of the river stage on navigation along the river downstream will be substantial for navigation between Vientiane and Savannakhet (See discussion on navigation).

According to the Pa Mong Stage One report, hourly fluctuation of power releases will be nearly dissipated by the time the Nam Ngum confluence is reached (Ref. 14), based on use of 4,800 MW power plant. The effects of river stage fluctuation will be more severe should the additional Pa Mong side channel power plant, with a potential capacity of 5,400 MW, be later added to the Stage One development scheme, which would change the generation pattern from base to peak generation (Ref. 19). No details are available with respect to the Pa Mong side channel power plant except that the peaking power discharge would be not greater than 17,000 $m^3$/sec, which is the downstream bankful capacity limitation of the river channel. In this case the daily fluctuation at the power plant would be in the order of about 6 to 8 metres depending on the regulation criterion. However, at present, it is not definite that the development of the Pa Mong side channel will be included in the future development.

The estimates presented above differ somewhat from those included in the Stage One report's corollary studies (Ref. 27), which estimate the daily fluctuations of the Mekong river at various locations. These are at Vientiane, Mong Khai, Nam Ngum, Nam Theun, Thakhek, and Mukdahan. The maximum daily river fluctuation at Vientiane is estimated at 1.3 m at the beginning of the commissioning year, and at 5.9 m when the generating capacity is full utilized. This study is based on an installed capacity of 5,000 MW. However, the estimation of daily river fluctuation downstream of Pa Mong dam noted above, based on 4,800 MW installed

capacity, is considered more precise being based on the typical daily load curve in the Pa Mong Stage One report which differed from the earlier study which was made in 1966. It is found that the maximum daily fluctuations in the Mekong river just downstream of the power plant will be 0.9 m and 3.4 m at time of commissioning and nine years later respectively.

## 8.2 Effects on water quality and aquatic life

The effect of Pa Mong on water quality and on aquatic life are evaluated in the discussion on reservoir ecology. The main effect will be the high range of water level fluctuations during the day, which will make the stretch of river some 20 km below the dam a poor habitat for many aquatic species. In effect the Pa Mong project plan assumes most of the existing aquatic wildlife values in this zone will be lost. A new ecosystem, featuring a different distribution of species, will become established.

## 8.3 Effect of power on industries

The availability of hydroelectric power at a reasonable cost will help boost industrial development. The Mekong Committee visualizes many feasible electro-process industries to be developed once the Pa Mong project is in existance. These include the fertilizer industry, calcium carbide industry, medium scale pulp and paper industry, iron and steel industry, ferro alloy industry, and others. The development of these industries would improve the economic conditions of the four riparian countries in terms of increase in the gross domestic products. There will of course also be effects on the negative side such as pollution problems and socio-economic problems which follow transition from rural to industrially based communities. However, with proper planning and protection measures these problems can be solved and will not be detrimental to the public welfare.

## 8.4 Effect of power on socio-economic values

The public welfare of the people in the lower Mekong basin can be significantly improved by the benefits from Pa Mong power generation, not only in improving the regional economy but also in improving the quality of life in rural communities, both by development of rural electrification and by decentralization to the rural areas of industries generally concentrated in a few cities. The economic and social problems of the lower basin cannot be said to be solved unless the existing conditions of low rural income and severe underemployment are improved. The decentralization of light industries to rural areas to the extent economically feasible should be the object of deliberate policy. There are a number of industries, some agro-based, which are more dependent on availability of raw materials and power than on proximity to population centres. These industries should be encouraged by incentives which include extension of power distribution systems.

The rapid increase in power demand in undeveloped areas when power becomes available is demonstrated by experience in northeast Thailand where a supply of approximately 31,000 kW from tributary hydropower projects (Nam Pung and Nam Pong) had to be doubled by addition of gas turbine generating sets less than three years after the hydropower was made available. This rapid growth in demand can be attributed to the construction of the power transmission network and the hydroelectric facilities. Power market growth can be expected to accelerate with expansion of irrigated agriculture and the emergence of agro-based industries such as food processing and textile manufacture.

A more detailed description of the socio-economic impacts of the Pa Mong project is given in the discussion on socio-economics.

## 8.5 Effect of transmission lines

Transmission lines and substations will have significant effects on land uses and values along the right-of-way. Trees will have to be cut down so that they will not interfere with the safe and reliable operation of the line nor impede restoration of service when outages occur. The appearance of the transmission towers in the landscape may cause some adverse visual impacts. However, with careful design these effects can be reduced to tolerable or insignificant levels.

From the experiences of other projects elsewhere (Ref. 26), it is expected that there will minor noise effects in the immediate vicinity of the substations and 500 kV transmission lines, but this noise will be essentially limited to the right of way. In general no adverse environmental impact is expected to occur during normal operation of the 500 kV transmission lines.

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TABLE 1

SUMMARY OF RESULTS OF PA MONG REGULATION STUDY
(Period of Study November 1929 - October 1964)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Alternative Pa Mong Development Plan | | | | | | | | | | | | |
| 1.1 High water level - HWL (m) | 260 | | | 250 | | | 240 | | | 230 | | |
| 1.2 Low water level - LWL (m) | 235 | 230 | 225 | 220 | 216 | 210 | 216 | 210 | 205 | 210 | 205 | 200 |
| 1.3 Usable storage 1/ ($10^6$ $m^3$) | 87,698 | 97,016 | 104,351 | 69,065 | 72,563 | 76,763 | 39,643 | 43,843 | 46,587 | 21,987 | 23,831 | 26,017 |
| 1.4 Installed capacity (MW) | 5,600 | 5,600 | 5,600 | 4,800 | 4,800 | 4,800 | 4,000 | 4,000 | 4,000 | 3,200 | 3,200 | 3,200 |
| 2. Results | | | | | | | | | | | | |
| 2.1 Prime power | | | | | | | | | | | | |
| (a) in MW | 2,656 | 2,674 | 2,697 | 2,180 | 2,184 | 2,185 | 1,660 | 1,674 | 1,680 | 987 | 1,020 | 1,036 |
| (b) in GWH/year | 23,270 | 23,420 | 23,620 | 19,100 | 19,130 | 19,140 | 14,540 | 14,660 | 14,720 | 8,650 | 8,940 | 9,080 |
| 2.2 Average annual generation (GWH) | 29,820 | 29,760 | 29,470 | 25,790 | 25,750 | 25,740 | 21,500 | 21,460 | 21,460 | 16,180 | 16,150 | 16,100 |
| 2.3 Plant peaking capability (MW) at: | | | | | | | | | | | | |
| (a) 100% of time duration | 4,356 | 3,875 | 3,515 | 3,155 | 2,850 | 2,760 | 2,740 | 2,340 | 1,895 | 2,530 | 2,218 | 1,895 |
| (b) 99% of time duration | 5,132 | 4,676 | 4,020 | 4,407 | 4,378 | 4,362 | 3,406 | 3,406 | 3,406 | 2,696 | 2,696 | 2,644 |
| (c) 95% of time duration | 5,600 | 5,344 | 4,990 | 4,800 | 4,800 | 4,800 | 3,436 | 3,436 | 3,436 | 2,711 | 2,711 | 2,711 |
| 2.4 Increase of average monthly flow from Nov. - Jun. ($m^3$/sec) 2/ | | 2,170 | | | 1,910 | | | 1,500 | | | 970 | |

1/ The figures shown in table correspond to the storage at year 0 after project completion (without reservoir siltation).

2/ The period from Nov. to Jun. represents the normal drawdown period of the reservoir. During this period, for a given HWL, the variation of average monthly regulated flow due to the change in LWL is insignificant.

TABLE 2

ENERGY COST OF THERMAL ALTERNATIVE

AT VARIOUS UNIT SIZES

(Reference 3)

| Unit Size | Energy Cost in US Mills per kWh at 70% Plant Factor | |
|---|---|---|
| | Oil-Fired | Nuclear |
| 100 | 15.7 | 19.7 |
| 200 | 14.3 | 15.1 |
| 300 | 13.7 | 12.9 |
| 400 | 13.3 | 11.5 |
| 600 | 12.0 | 10.0 |

TABLE 3

ENERGY COST COMPARISON BETWEEN MAINSTREAM PROJECTS AND THERMAL ALTERNATIVE

(Reference 3)

| | Installed Capacity | Average Hydro Energy Cost Mills/kWh | Composite Energy Cost of Thermal Mills/kWh | Ratio of Thermal to Hydro |
|---|---|---|---|---|
| High Luang Prabang | 2,750 | 5.8 | 11.27 | 1.94:1 |
| Pa Mong | 4,800 | 6.5 | 11.27 | 1.73:1 |
| Upper Thakhek | 2,250 | 9.2 | 11.27 | 1.23:1 |
| Bankoum | 3,300 | 6.2 | 11.27 | 1.82:1 |
| Stung Treng | 7,200 | 8.2 | 11.27 | 1.37:1 |
| Sambor | 3,250 | 6.2 | 11.27 | 1.82:1 |
| Total | 23,550 | 7.0 | 11.27 | 1.61:1 |

## TABLE 4

## ESTIMATED POWER NEEDS FOR MAJOR INDUSTRIES

| | Name of Industries | Estimated Power Needs |
|---|---|---|
| 1. | Fertilizer and Calcium Carbide (Chemical complex producing fertilizers, etc., based on production of calcium carbide in electric furnace) | 320 MW |
| 2. | Pulp and Paper | 10 MW |
| 3. | Iron and Steel | 300 MW |
| 4. | Ferro Alloy | 50 MW |
| 5. | Aluminium Smelters | 420 MW |
| 6. | Furnace Phosphoric Acid | 200 MW |

TABLE 5

EXPOSED GROUND AREA DURING PA MONG RESERVOIR DRAWDOWN

ACCORDING TO FOUR DEVELOPMENT SCHEMES 1/

| High Water Level (HWL), m MSL | Ave. Water Level At the End of October, m MSL 2/ | Ave. Water Level At the End of June, m MSL 3/ | Drawdown m | Exposed Ground Area $km^2$ |
|---|---|---|---|---|
| 260 | 258.06 | 246.93 | 11.93 | 1,000 |
| 250 | 249.45 | 235.94 | 13.51 | 1,140 |
| 240 | 239.94 | 223.19 | 16.75 | 1,230 |
| 230 | 230.00 | 212.05 | 17.95 | 1,200 |

1/ The water level, for each scheme of development, varies little with respect to the minimum pool elevation.

2/ Average of the water level at the end of October during 1929-1969, (the highest level).

3/ Average of the water level at the end of June during 1929-1969, (the lowest level).

Power

TABLE 6

AVERAGE RESERVOIR SURFACE ELEVATION (FROM 1929-69) FOR PA MONG

HIGH POOL ELEVATION 260, 250, 240 AND 230 m MSL

| Scheme of Development Pa Mong HSL m MSL | Average Reservoir Surface Elevation (1929-69), End of Month m MSL | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
| 260 | 255.34 | 253.83 | 251.91 | 249.96 | 248.04 | 246.93 | 249.46 | 253.62 | 258.06 | 258.86 | 258.14 | 256.86 |
| 250 | 245.67 | 244.65 | 241.92 | 239.71 | 237.33 | 235.34 | 238.78 | 243.20 | 248.63 | 249.45 | 248.65 | 247.38 |
| 240 | 237.03 | 235.45 | 233.17 | 229.88 | 226.16 | 223.19 | 227.63 | 233.02 | 239.00 | 239.94 | 239.93 | 238.85 |
| 230 | 226.29 | 224.33 | 221.98 | 219.28 | 215.41 | 212.05 | 212.25 | 223.36 | 228.40 | 230.00 | 229.96 | 229.62 |

Power

TABLE 7

HOURLY WATER RELEASES, PLANT OUTPUT, AND DOWNSTREAM

GAGE ELEVATION AT PA MONG POWER PLANT

| Hours | Commissioning Year | | | Plus Nine Years | | |
|---|---|---|---|---|---|---|
| | MW | Release-1/ cms | Gage Height m | MW | Release-1/ cms | Gage Height m |
| 1.00 am | 1,000 | 1,820 | 2.20 | 2,900 | 5,280 | 5.50 |
| 2.00 am | 850 | 1,550 | 1.90 | 2,400 | 4,370 | 4.70 |
| 3.00 am | 700 | 1,270 | 1.50 | 2,200 | 4,000 | 4.40 |
| 4.00 am | 700 | 1,270 | 1.50 | 2,200 | 4,000 | 4.40 |
| 5.00 am | 850 | 1,550 | 1.90 | 2,550 | 4,640 | 5.00 |
| 6.00 am | 1,000 | 1,820 | 2.20 | 2,900 | 5,280 | 5.50 |
| 7.00 am | 1,100 | 2,000 | 2.40 | 3,400 | 6,190 | 6.20 |
| 8.00 am | 1,100 | 2,000 | 2.40 | 4,000 | 7,280 | 6.90 |
| 9.00 am | 1,100 | 2,000 | 2.40 | 4,350 | 7,920 | 7.30 |
| 10.00 am | 1,100 | 2,000 | 2.40 | 4,500 | 8,190 | 7.40 |
| 11.00 am | 1,100 | 2,000 | 2.40 | 4,400 | 8,010 | 7.30 |
| 12.00 noon | 1,100 | 2,000 | 2.40 | 4,300 | 7,830 | 7.20 |
| 1.00 pm | 1,100 | 2,000 | 2.40 | 4,100 | 7,460 | 7.00 |
| 2.00 pm | 1,100 | 2,000 | 2.40 | 4,750 | 8,650 | 7.70 |
| 3.00 pm | 1,100 | 2,000 | 2.40 | 4,800 | 8,740 | 7.80 |
| 4.00 pm | 1,100 | 2,000 | 2.40 | 4,600 | 8,370 | 7.50 |
| 5.00 pm | 1,100 | 2,000 | 2.40 | 4,200 | 7,650 | 7.10 |
| 6.00 pm | 1,100 | 2,000 | 2.40 | 4,600 | 8,370 | 7.50 |
| 7.00 pm | 1,100 | 2,000 | 2.40 | 4,800 | 8,740 | 7.80 |
| 7.30 pm | 1,100 | 2,000 | 2.40 | 4,800 | 8,740 | 7.80 |
| 8.00 pm | 1,100 | 2,000 | 2.40 | 4,800 | 8,740 | 7.80 |
| 9.00 pm | 1,100 | 2,000 | 2.40 | 4,800 | 8,740 | 7.80 |
| 10.00 pm | 1,100 | 2,000 | 2.40 | 4,800 | 8,740 | 7.80 |
| 11.00 pm | 1,100 | 2,000 | 2.40 | 4,100 | 7,460 | 7.00 |
| 12.00 pm | 1,100 | 2,000 | 2.40 | 3,400 | 6,190 | 6.20 |

1/ Based on net head 70.00 m, 0.80 efficiency, and 1972 rating curve.

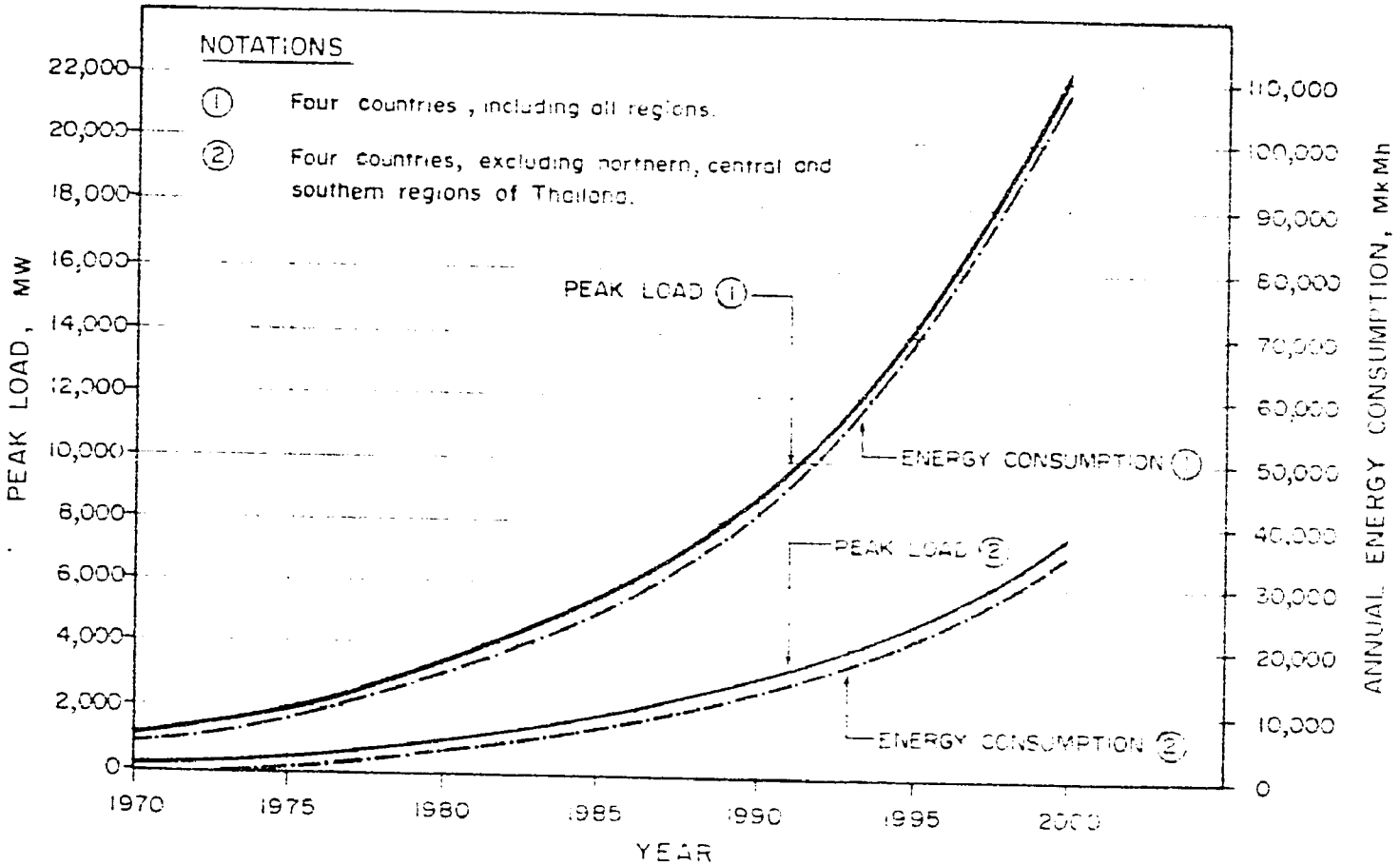
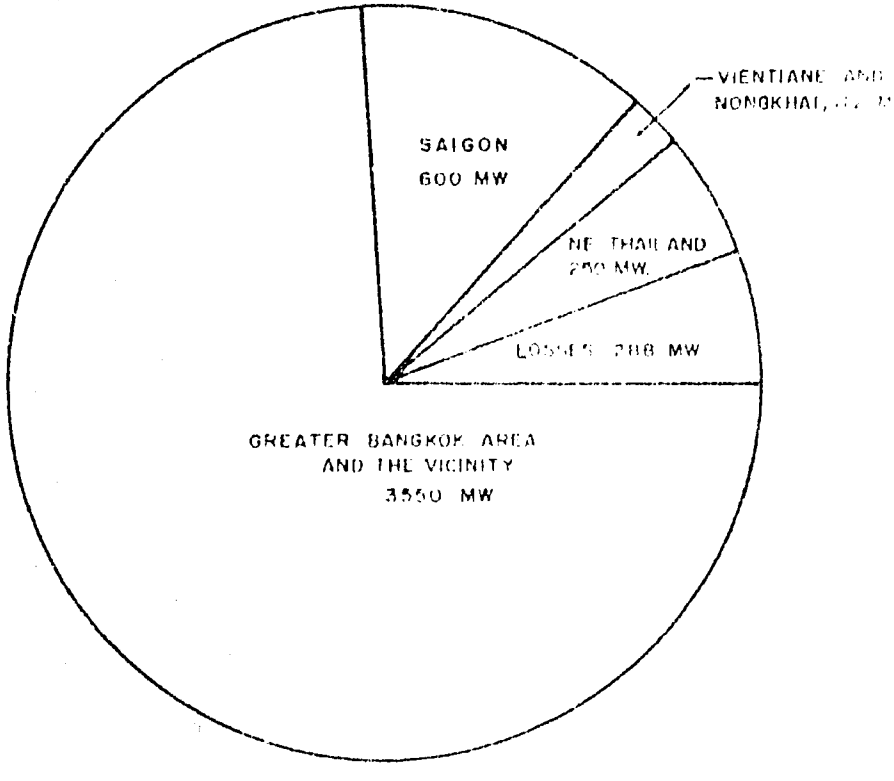



FIGURE 1

PROJECTED POWER AND ENERGY REQUIREMENTS OF THE FOUR RIPARIAN COUNTRIES




TOTAL POWER 4,800 MW

SOURCE . Power Flow Study by EGAT ( Ref 22 )

FIGURE 2

REGIONAL DISTRIBUTION OF POWER FROM PA MONG

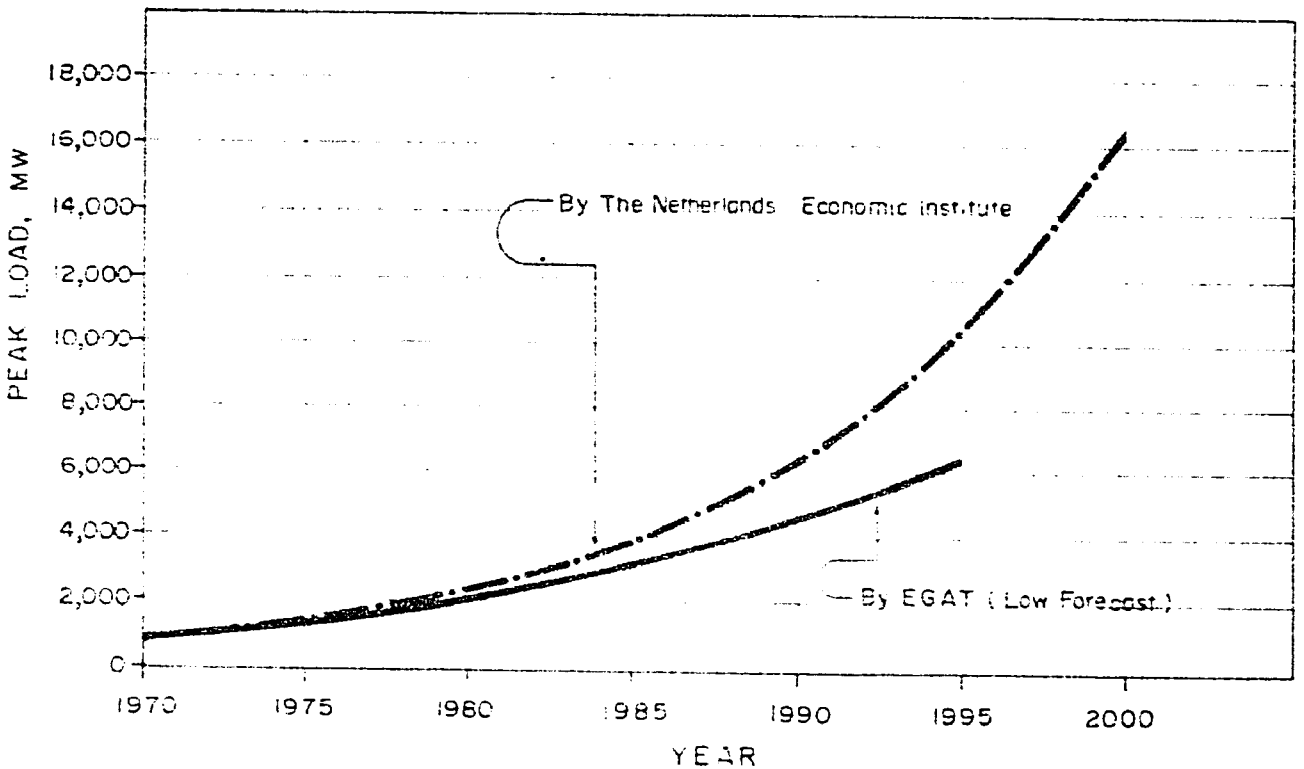



FIGURE 3

COMPARISON OF LOAD FORECAST FOR THAILAND BETWEEN NEI AND EGAT

Power

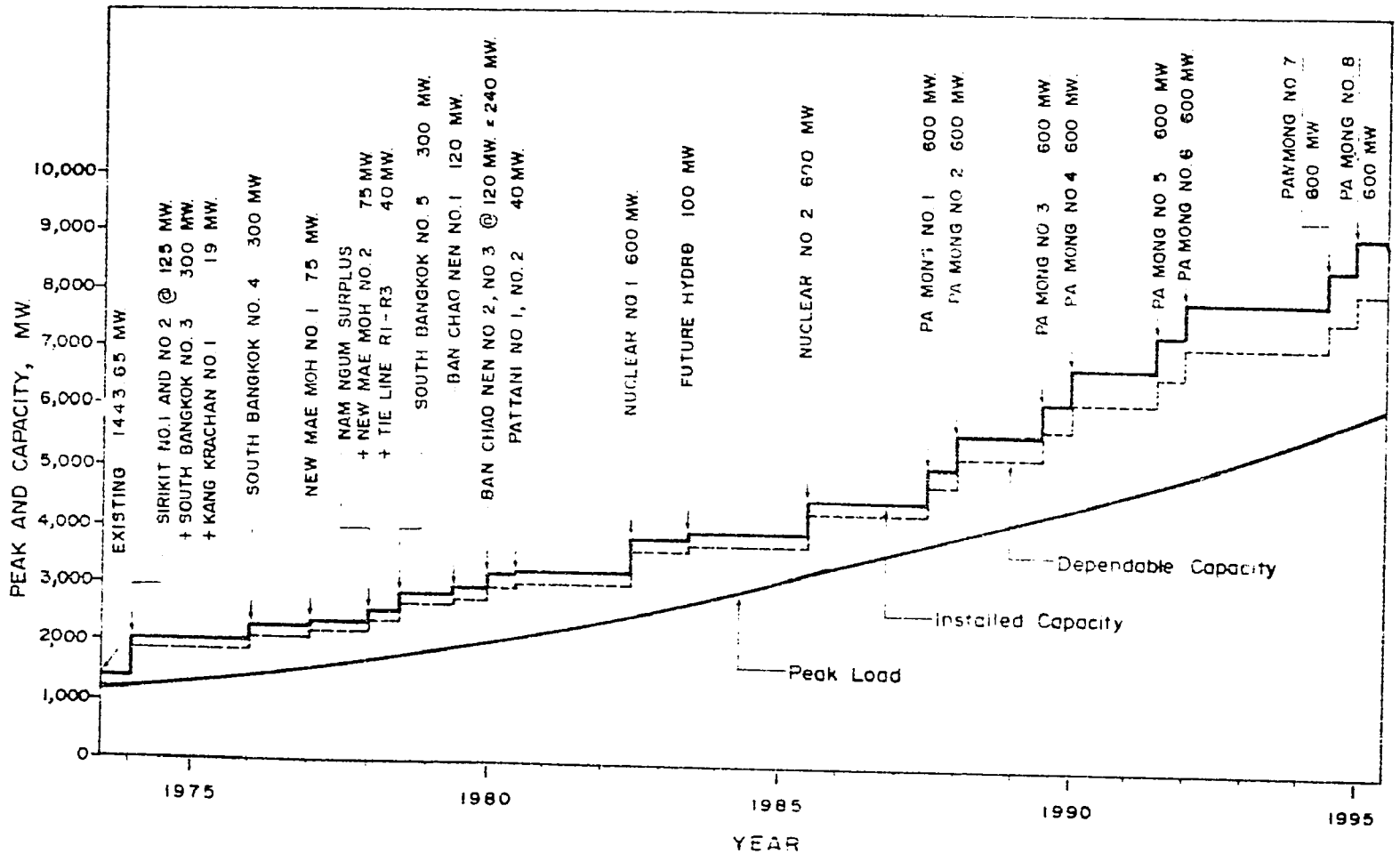



FIGURE 4

INSTALLATION SCHEDULE FOR EGAT (THAILAND)

SOURCE - REFERENCE 22

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## PUBLIC HEALTH

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Table 10: Entomological study at Nam Pong, November 1972 - April 1974 larval collections

Table 11: Malaria control measures at water development sites during and after construction

Figure

Figure 1: Map of malaria in lower Mekong basin 1970

# PA MONG ENVIRONMENTAL ASSESSMENT

## PUBLIC HEALTH

### 1. Introduction

Construction and operation of the Pa Mong project can affect public health in the lower basin in many ways, hence this subject has been an important component of the Mekong Committee's overall programme of study. The problem is compounded because present general health conditions in much of the lower basin area that would be affected by Pa Mong are below standards desired. This is due mainly to lack of good community water supplies and lack of sanitation facilities for disposal of wastes. A summarized description of the existing public health situation in Thailand and the Lao PDR in the Pa Mong project area is given in the Pa Mong Stage One report (Ref. 34) for the Stage One areas and in the Pa Mong Phase II report for the Phase II areas (Ref. 36).

With respect to the specific effects of Pa Mong, the Mekong Committee's programme has directed attention to three general problem areas as follows:

(a) Communicable diseases: To the extent that these may be influenced by the altered water regime (creation of the reservoir and distribution of irrigation water), or by construction activities, or by human resettlement, especially malaria (Ref. 1-14, 21, 28, 35) and schistosomiasis (Ref. 23, 24, 29).

(b) Environmental health: Provision of adequate water supply, sanitation, and health centres for servicing human resettlements and construction villages associated with the project and for servicing developing villages in the irrigation service zones (Ref. 22, 27).

(c) Ancillary activities: Contributions toward general health improvement in the lower basin through support for progressive strengthening of health programmes of the riparian governments, such as assistance in monitoring of nutrition (Ref. 16-19, 31).

All the activities of the Mekong Committee have been carried out in close association with WHO's continuing programme in the region, and in support of the riparian country governments having direct responsibilities for programme operations. The role of the Mekong Committee has been essentially one of providing technical support to the national governments including sponsoring of research, training, and of improved collaboration between the riparian countries though periodic conferences and meetings.

In all of its efforts, the Mekong Committee has approached the problem areas recognizing, while the immediate interest is with planning for public health hazards related to water resource development, the information obtained will have potentials for general application throughout the basin.

## 2. Malaria

### 2.1 Extent of malaria

Virtually the entire population of the lower Mekong basin is exposed to the risk of malaria transmission. The most hazardous areas, where the known malaria vectors are prevalent, are in the foothills and forest fringes including the vicinity of the proposed Pa Mong reservoir.

Malaria was previously a major public health problem in Thailand but control measures started in 1949 have progressively reduced the malaria death rate from 201.5/100,000 in 1949 to 30.2/100,000 in 1960, then, following activation of the national malaria eradication programme in 1965 (based on residual insecticide spraying and use of antimalaria drugs), further reduced to from 10 to 12/100,000 by the early 1970's. However, while malaria transmission is at a relatively low level in most of the country, active transmission still occurs in hilly and forested areas.

Four species of Anopheline mosquitoes transmit malaria in Thailand, namely A. minimus, A. balabacensis, A. maculatis, and A. sundaicus. The first breeds primarily in the streams in foothill areas. The second occurs exclusively in forests. The third occurs in open hilly land, and the fourth (not occurring in the Pa Mong watershed) is a coastal species breeding in brackish water. Also, A. aconitus in the plains area and flat high plateaus, A. campestris in paddy fields, and A. philippinensis in open reservoirs in the northeast are suspected to be secondary vectors.

With respect to the portion of northeast Thailand lying within the Mekong basin, the results from active case detection of malaria in 1971 and 1972 in the nine northeast provinces in the lower basin showed many positive cases in all provinces. The incidence was about 1.2-5.2 per cent, mostly in forest or foothill areas.

Malaria has been and still is a major problem in the Lao PDR. An estimated 85 per cent of the total population reside in hazardous areas, especially in the mountains and hills prevalent in the Pa Mong watershed. Only the Vientiane plain is considered non-hazardous. Anti-malaria measures were begun in 1956 but since 1960 this programme has been of limited effectiveness due to conditions of insecurity.

Figure 1 is a map showing the extent of malaria and malaria control programmes in the lower basin in 1970, and Tables 1 through 5 present summarized data on extent of malaria in each riparian country as of 1970 (Ref. 2). These are the latest such comprehensive tabulations available. However, data are available for Thailand which show the number of malaria cases for 1974 to be 286,753 as compared to 123,724 for 1970. It is likely that similar increases have occurred in the other three riparian countries.

## 2.2 Entomological aspects

The two principal malaria vectors of the basin, which are widely distributed in foothills and jungle-covered areas in all four countries, are *Anopheles balabacensis* and *A. minimus* (Ref. 2). The former will breed in shade streams, swamps, pools and seepages in jungle areas, and become abundant during the rainy season, breeding in hoof-prints and cart-tracks in the fringe of semi-dense forests. *A. minimus* is more in evidence during December to May and prefers slow-running streams and ditches with grassy edges. In addition to these, *A. sundaicus* is recognized as a vector in coastal and delta areas, *A. maculatus* and *A. aconitus* have been incriminated as vectors in parts of Thailand, and *A. jeyporiensis* in the central highlands of Viet-Nam.

Studies on other species which may be involved, to be undertaken in the future, are the following:

(a) Study of the role of *A. philippinensis*, a proven vector in some neighboring countries, which is found in most parts of the lower basin.

(b) Study of the behaviour response of *A. balabacensis* to DDT spraying.

(c) Study of vectorial status of *A. maculatus*.

(d) Survey of Vietnamese delta to determine if vectors other than *A. sundaicus* are transmitters.

In the plains areas where DDT spraying has been carried out, the tendency has been for *A. minimus*, in particular, to disappear and this is a reason for the lack of malaria transmission in formerly malarious regions in northeast Thailand. Evidence suggests that all the vectors still remain susceptible to DDT and other insecticides. The principal difficulty from the entomological point of view is the manner in which *A. balabacensis* will transmit malaria to persons engaged on jungle clearing or other activities in forested areas. This mosquito has a high vectorial capacity and is liable to attack groups of people who are irregular in their movements and who may go undetected by the anti-malaria services.

## 2.3 Parasitological aspects

The distribution of the different parasite species of malaria in the region in 1970 is shown in Table 5. It is noted that *Plasmodium falciparum* infections (also known as "malignant tertian malaria") account for about 80 per cent of the cases, with very similar figures for Thailand and Democratic Kampuchea. In the delta area of Viet-Nam, although only 42 per cent of the cases were due to *P. falciparum*, this proportion is increasing. Formerly nearly all cases detected in this area were *P. vivax* ("benign tertian") infections.

A serious problem is posed by the existence in all four countries of strains of *P. falciparum* which are resistant to chloroquine, the anti-malaria drug usually favoured. Research has been conducted in Democratic Kampuchea with sulfadoxine and pyrimethamine, in Thailand with sulfalene and trimethoprin, and in Viet-Nam with other combinations of drugs. It has not yet been possible to standardize either a radical treatment for proven cases of drug resistance, nor an efficient prophylactic treatment for areas where the malaria strain is suspected to be resistant.

## 2.4 National anti-malaria services

Each of the riparian countries maintains an anti-malaria service (Ref. 2). Conditions of insecurity in widespread areas of three of the four countries have meant that full region-wide coverage has not been possible, but in Thailand the National Malaria Eradication Project (NMEP) includes the entire country in its programme of activities. These services and the organizations dealing with malaria control in the four riparian countries are described in detail in reference 2, representing conditions as of 1970, the latest year for which these compilations have been made on a comprehensive basis for the lower basin.

## 2.5 Hazards from impoundments

To gain definitive information on malaria hazards which might result from impoundment, and how to control them, detailed entomological surveys were carried out by the Mekong Committee at two tributary reservoir sites in Thailand over a three-year period from 1971-74 (Ref. 3, 4, 6). These were at Nam Pong, an existing reservoir completed in 1966, used for both power production and irrigation, and at Nam Phrom, a power project then under construction. The Nam Pong site is in relatively open country, mainly rice paddy area, which had been previously freed from malaria transmission by the NMEP operations, hence was in the "consolidation" phase (last DDT spraying in 1968). The Nam Phrom project is located in hilly forested terrain where malaria was known to be endemic and which was in the "attack" phase (periodic DDT spraying of houses accompanied by malaria case findings). The Nam Pong study followed up an earlier Mekong Committee study made in 1970 (Ref. 1).

Three sites were selected in the vicinity of each reservoir project for monthly collection of adult and larval anophelines, representing a variety of environmented conditions. At Nam Phrom additional data were collected on malaria incidence, population changes and movement, and DDT spraying. Full-night collections (18:00 - 6:00)of adult anophelines were made two nights each month at each site, and searches for breeding areas and collection of larvae were carried out monthly.

At each of the three Nam Pong sites, the following studies were made on a routine basis each month:

(a) Human-bait night collections indoors and outdoors from 18:00 to 06:00 hours for two consecutive nights.

(b) Identification of all anopheline species collected.

(c) Dissection of those mosquitos recognized as malaria vectors or considered to be potential vectors.

(d) Collection of indoor-resting mosquitos.

(e) Larval searches.

The routine studies at Nam Phrom were the same except that no indoor daytime resting collections were made.

2.5.1 Nam Phrom study

(a) Study area and collection sites: The study area encompasses the local community known as "Village 8", which includes the dam site, power plant, and a series of hamlets along the main road to the dam site. Breeding areas were usually small slow-running streams, small pools in the forest, and the Nam Phrom river. The three collection sites, all in or close to the forest, were at the power plant (altitude 380 m), at the water treatment plant above the future lake (800 m), and at a temporary guesthouse downstream of the dam near the labor camp (720 m).

(b) Results of collections: Tabulations were made of the data for two periods, for June 1971 through May 1972 (Ref. 4) and for December 1972 through April 1974 (Ref. 6). The tabulations for the 1972-74 studies are included here as Tables 6 and 7.

For adult anophelines, of the known and suspected vectors *A. balabacensis* was the most abundant in 1971-72 (95 specimens) followed by *A. minimum* (39), *A. maculatus* (32), *A. philippinensis* (21), and *A. aconitus* (2). *A. vagus* was the most abundant anopheline (172 specimens) but this species is not involved in malaria transmission in Thailand. These

densities are relatively low. Approximately 90 per cent of all vectors were taken outdoors. Most of the specimens were nulliparous (indicating DDT effects) regardless of time or location of collection. The data for adults for 1972-74 indicate a continuing low density for the known and suspected vectors.

Regarding larvae collections, over the year collecting period 1971-72 only 31 specimens of known vectors were collected, representing 2.3 per cent of the total specimens. Of these 17 were A. balabacensis, 8 were A. minimus and 6 were A. maculatus. A. barbumbrosus was the most abundant anopheline taken. The average density of anopheline larvae was 3/10 dips, which is relatively low. The most abundant breeding habitat were isolated pools in dry stream beds. The larvae results for 1972-74 indicate a considerable increase in the number of both known vectors. A. minimus increased from 39 for the 12 month period in 1971-72 to 104 specimens for the 17 month period 1972-74, and A. balabacensis increased from 95 to 238. Also, the average density of anophelines increased from 3 to 4.8/10 dips.

(c) Evaluation of results: Analysis of the data on the known vectors at Nam Phrom is complicated by the presence of three vector species, but A. balabacensis appears to be the species most prominently involved in transmission. The area is ecologically well suited for this species and although numbers are low, A. balabacensis was taken when man-biting much more often than A. minimus and A. maculada. The data for the three-year period represent the immediate and in some respects temporary effects of initial development of a remote area, and the long term ecological changes from the new reservoir are yet to become manifest. However, the increase in larvae in known vectors from 1971-72 to 1972-74 may indicate an increased threat of malaria in the Nam Phrom vicinity, especially in view of the increasing number of people living in the area both in isolated dwellings in forest clearings and along the streams.

2.5.2 Nam Pong study

(a) Study area and collection sites: As contrasted to Nam Phrom, the Nam Pong vicinity lies within a "consolidated" phase area having no malaria transmission. Also, irrigation canals supply water to an area of 800 km$^2$. The population has been fairly stable except for creation of resettlement areas near the dam for people formerly living in the flooded areas. The three sites selected for entomological observations represented a variety of ecological

conditions, namely one site near the impounded water, the second at a resettlement area, and the third in the irrigated zone. Because there was no malaria transmission and no DDT spraying, no epidemiological data were obtained.

(b) Results of collections: Reference 4 includes tabulations of the collection data for 1971-72 and Reference 6 for 1972-74. The 1972-74 tables are included here as Tables 8, 9 and 10. These data indicate virtually total absence of the principal known vectors, A. minimus and A. balabacensis, and only a small number of adults of the two possible vectors, A. aconitus and A. philippinensis. Considerably more anophelines were taken outdoors than indoors. The percentages of nulliparous mosquitoes were low, at 15.3 and 36.6 respectively for A. aconitus and A. philippinensis, reflecting the absence of effects from DDT insecticide.

Only one larvae of a vector species was found during the study, this being an A. macuatus. This was the only vector specimen, larvae or adult, found during the study. However, the number of A. philippinensis larvae collected per month increased by 44 per cent from 1971-72 to 1972-74, these larvae being found mostly along the reservoir edges. The density of anopheline larvae was considerably less than at Nam Phrom (2.24/10 dips compared to 4.80/10 dips for the 1972-74 period).

(c) Evaluation of results: No entomological evidence was found that the new environmental situation at Nam Pong favors the breeding of Thailand's known malaria vectors, and the fact that malaria attack measures ended in the vicinity four years earlier further supports this conclusion. However the increase in larvae of a suspected vector from 1971-72 to 1972-74 indicates continuing surveillance is needed. No doubt the ecological changes in the vicinity have not fully expressed themselves, particularly in areas where irrigated agriculture has yet to become fully developed. The gradually changing environment may possibly furnish opportunities for vector species to become established or for assisting suspected vectors to evolve into primary vector status.

2.5.3 Conclusions

The Nam Phrom situation illustrates the need for positive malaria surveillance and control measures in new reservoir vicinities located in hilly forested areas where the disruption of forest habitat and population influx serve to create definite malaria hazards. Prior to development of such projects, mass blood surveys and anopheline collections

should be conducted to determine the degree of malaria incidence and presence of vectors. Where sites of development are localized and many people are directly employed in a project, as during dam construction, local posts for distributing anti-malaria drugs are particularly effective. These posts can be set up at the project clinic (as was done at Nam Phrom) or medicine can be distributed with pay checks. Because of the relatively low standard of housing often associated with developing areas, a higher level of DDT spraying is needed to be fully effective.

After construction has been completed and the situation stabilized as at Nam Pong, continuing surveillance is still needed for purposes of monitoring, especially in irrigation zones. Irrigated agriculture, although now not extensive, is expected to become widespread throughout the lower basin in the future.

## 2.6 Anti-malaria measures during construction

The Nam Phrom entomological survey noted above, as well as the 1969 malaria outbreak during construction of Nam Ngum in Lao PDR (Ref. 9), indicated the need for special measures for malaria surveillance and control in new dam site vicinities in upland areas during the construction phase, when an influx of population is exposed in clearings in a forest habitat where the ecology has been disturbed and is undergoing change. In 1973 following a recommendation of the Second Technical Malaria Meeting, the Mekong Committee together with WHO undertook a study to evaluate the costs of at-site anti-malaria measures as part of the cost of dam construction.

The results of the study (Ref. 28) were based both on the general and specific requirements at dam construction sites in the lower basin. General measures that apply to a wide range of projects in malaria areas comprise insecticide sprays (DDT) and prophylactic drugs. When drugs are taken, parasite resistance may be detected and more than one drug may be needed to get positive results. Also, the treatment of *P. falciparum* infections resistant to 4-Aminoquinolines should be stipulated.

The effectiveness of spraying depends on the standard of shelter provided in the camp and nearby squatter settlements. For instance the absence of walls or with wide openings, through which mosquitoes can fly without resting on sprayed areas, obviously reduces the effectiveness of spraying. Based on field experience in Thailand and Lao PDR, the cost of spraying at construction camps may be less than US$1 per person per year and that of anti-malaria drugs about US$2.

The steps to be followed in formulating control measures at any construction site are given in the outline guide shown in Table 11. This provides for (a) surveys and investigations before construction, (b) control measures, (c) planning and siting construction camps, and (d) related services after construction. Specific measures involve jungle clearance, reduction of mosquito breeding sites, clearance of vegetation along the edges of reservoirs or streams, and the use of larvicides. The adoption of such measures will depend on an assessment of local conditions and the extent to which any one measure will contribute to the control of malaria transmission. For cost estimating purposes an amount of $10 to $20 per person may be assumed.

## 2.7 Outlook for malaria in lower basin

The eradication of malaria from the entire Mekong basin area is not envisaged in the near future. Even when peace and security return to the region, many problems, both technical and administrative, will still have to be overcome, especially the required extensive financial commitment and the associated shortage of trained personnel. It is realistic therefore for the immediate future to think only in terms of "malaria control" as far as development of the water resources of the lower basin is concerned, while planning to lay the basis for eventual eradication as a long-term regional goal.

Whatever physical form the development project may involve, whether dam, irrigation system, bridge or dyke construction, a labour force will be required. In many cases, non-immune workers will be recruited from non-endemic areas or from areas cleared for some years from malaria. These persons will be particularly at risk, especially when the projects are situated in mountainous areas in the jungle, such as in the case with many of the planned tributary hydroelectric projects. To avoid delays in construction, as well as to prevent sickness, suffering and even loss of life, the government agencies responsible for the projects should inform the anti-malaria services at the time of the earliest site surveys, and should seek their advice and assistance in malaria control. This has not always been done and, in several past instances in the lower basin, malaria has interfered with the completion of initial surveys and has even caused potentially expensive delays during construction. Recommendations of the Second Technical Malaria Meeting of the riparian countries relating to protection of labour forces were:

(a) Malaria diagnostic and treatment services should be established.

(b) Residual insecticide should be sprayed twice a year in all housing structures in the camps and in the neighbouring villages.

(c) Screening of housing should be used where feasible.

(d) The jungle should be properly cleared for at least 100 metres from the edges of labour camps.

Where dams are constructed, ecological changes necessarily take place. From a flowing stream subject to differing levels, floods and possible dry periods, a lake is formed which has only gradual seasonal fluctuations of level. It is, perhaps, a fortunate natural phenomenon of the region that, as far as evidence to date indicates, still waters of reservoirs and lakes are not suitable breeding places for the two principal vectors of malaria in the basin, A. balabacensis and A. minimus. This has not, however, been the case in other parts of the world and it is too early to be sure there will continue to be no problem. The changed ecological situation may yet prove favourable for other mosquito vector species, and, in any case, with many of these dams being built or to be built in forest areas, the danger from A. balabacensis breeding in forest fringes is still present. With the development of fishing villages and marginal cropping on the lake shores, more persons in the area will be at direct risk and the anti-malaria services will need to exercise appropriate control measures. Since, for economic reasons, it is not possible to carry out complete clearing of vegetation from the fluctuation zone of most of the dams constructed or planned, the possibilities of mosquito larvae developing in the vegetation at the lake edges will be increased. Likewise, the anticipated growth of water weeds in many of the reservoirs may promote increased densities among certain anopheline species. For this reason routine entomological studies are needed in the vicinity of new reservoir projects to record any changes of species which may be related to the water resources development.

Attention must be given also to the people who have to be resettled from reservoir basin areas. Where they have been paddy farmers, they may have lived in relatively malaria-free conditions and lack immunity to the disease. If they are transferred to upland agricultural sites, there is danger that they may be moving to areas where the more virulent vectors are found (e.g., the Lam Dom Noi project in Thailand). If, on the other hand, they are being moved out of a malarious area, they may carry a dangerous reservoir of malaria parasites to an area in which malaria has not been highly endemic (e.g., Prek Thnot in Democratic Kampuchea). The anti-malaria services should be consulted regarding selection of new village sites and the malaria control measures necessary.

Irrigation projects in the Pa Mong irrigation service region will normally, though not always, be in areas of low malaria endemicity. Experience over many years, particularly in Thailand and Viet-Nam, has not shown any association

between development of irrigated agriculture and an increase in malaria transmission. However, it may happen that the changed ecology, with year-around water availability in areas previously subjected to severe periods of drought, may result in a new ecological balance where new vectors become important. Particular attention must be paid to the drainage side of the irrigation schemes, since in some parts of the world faulty drainage design creating water logged conditions some 10 or 15 years after the construction of the irrigation network, has given rise to extensive anopheline development and severe malaria epidemics.

## 2.8 Summary

The Mekong Committee, early in its history, recognized the importance of malaria as a possible impediment in basin development and together with WHO and the riparian country governments, and with the cooperation of other international agencies, has carried out a continuing programme for devoting proper attention to this hazard as part of the overall plan for basin development. All of this work has been in close cooperation with the anti-malaria service agencies of the riparian countries responsible for actual malaria control operations.

The main accomplishments of this effort to date may be summarized as follows:

(a) Sponsoring of periodic meetings of the anti-malaria service agencies of the riparian countries for technical assessment of their programmes, thus providing a basis of statistical facts describing the prevalence of malaria, the vectors involved, the control measures undertaken and the "gaps" to be solved, and thus stimulating and assisting these agencies to strengthen their programmes and moreover to work cooperatively to achieve an efficient regional programme.

(b) Sponsoring of detailed entomological surveys at two tributary reservoirs (Nam Pong and Nam Phrom), extending over a three-year period, to obtain specific information on the hazards which may be generated by impoundments especially breeding of vectors in new reservoirs or in the associated irrigation areas, for both the construction and post-construction phases of such projects.

(c) Development of recommendations for specific practicable control measures to be used during the construction phase of dam and reservoir projects, and endorsement of the concept that dam construction budgets include allowance for these measures.

(d) Recognition, while no firm evidence has been found, that proposed dam and irrigation projects such as Pa Mong may result in generation of malaria hazards, that continuing surveillance should be carried out by the anti-malaria service agencies, together with continuing assistance to these agencies from the Mekong Committee in technical aspects and in financial support.

The current programme of the Mekong Committee and WHO for continuing study of malaria in the lower basin and for continuing assistance to the anti-malaria services of the riparian countries, has been effective in preparing for construction of a major mainstream project such as Pa Mong. These same efforts are needed regardless of the Pa Mong pool level to be selected. It is necessary that this programme be continued, at its present level, with malaria experts continuing to serve with the Mekong Committee staff from time to time. This effort should include sponsoring or encouraging continuing entomological monitoring in tributary reservoir zones.

Should the decision be made to proceed with Pa Mong, a detailed work programme will need to be formulated (following the guidelines already developed by the Mekong Committee) and progressively implemented for malaria control and surveillance in the Pa Mong vicinity. This will provide for control of malaria during construction, including spraying and drug distribution and for continuing entomological monitoring of the reservoir and irrigation service areas. It is assumed these anti-malaria measures will be carried out by the national anti-malaria services of Thailand and Lao PDR with support from the Mekong Committee.

As a result of the Mekong Committee's efforts, basic information and guidelines have been produced such that, should the decision be made to proceed with Pa Mong, effective and practicable anti-malaria provisions can readily be incorporated into the project plans and budget both for construction and operation of the dam and associated irrigation works. It is expected no new malaria problems should be created by the advent of Pa Mong, and moreover, the planned anti-malaria measures should, by demonstration, materially assist the anti-malaria services of the riparian governments in the continuing development of their country-wide anti-malaria programmes.

## 3. Schistosomiasis

### 3.1 Mekong river study

Schistosomiasis, or human blood fluke infection, has been called, after malaria, the second most important infectious disease of the tropics. The discovery of human

schistosomiasis in Southeast Asia in recent years added a new element of concern to the health planning for major water resources development projects in the region. In recognition of this threat, the Mekong Committee approved in 1970 a programme of field research to be undertaken by the Smithsonian Institution with support from USAID and the riparian governments. The objective was to discover the unknown intermediate host or hosts of the Mekong schistosome and to study its biology, ecology, and geographic distribution with a view to formulating methods of control (Ref.23,24,29).

A major finding of the study, completed in 1974 (Ref. 29), was identification of an intermediate host for Mekong schistosomiasis, namely the aquatic snail, Lithoglyphopsis aperta. It was found in the Mekong river between Khemmarat and Khone Falls but its range may extend as far south as Kratie. A distinct race of this species has also been found in the Mun river near its confluence with the Mekong. The transmitting snails are abundant only in the months of late March, April, May, and early June. The infecting agent, whose life cycle has been studied in the laboratory of the Faculty of Tropical Medicine, Bangkok, and whose eggs were found in the faeces of sick individuals, has been termed "Schistosoma japonicum, Mekong strain".

As far as is known, human schistosomiasis is transmitted only at Khong Island and Kratie. Dogs at Khong Island are also infected, but apparently not buffaloes, cattle, pigs, or rats. Overall prevalence at Khong Island is believed to be 15 per cent but among children aged from 4 to 15 years the rate is about 30 to 40 per cent. Nevertheless, the total number of people at risk is comparatively small, in the order of 10,000.

L. aperta snails have not been found in the Mekong river between the Burma border and the Khemmarat rapids, and suitable habitats have not been located in that part of the river. Schistosomiasis has not been reported in this section of the lower basin and there appears no reason to anticipate its introduction into the Pa Mong area under present conditions.

### 3.2 Probable effects of impoundment

Because both snail populations and intensity of transmission of the disease are reported to be greater when the river is low than when it is high, increased flows in the low water season may have a significant effect on the incidence of the disease. Thus, water releases from the proposed Pa Mong reservoir upstream, which would double the low water flows in the Mekong below the reservoir, may check disease transmission. Other complementary factors in this relationship between schistosomasis transmission and water level in the river may include the tendency of

children to enter the river less often when the water level is high and a reduction in the concentration of both miracidia and cercariae with dilution and increased water velocities. If adequate observations, to be carried out in future studies, confirm these predictions, then it could be stated that the Pa Mong project would carry with it this additional public health benefit.

Fears have been expressed that the spread of schistosomiasis which has occurred in some African countries may also take place in the lower Mekong basin, but there are important differences between conditions in Africa and those in Southeast Asia. For example, in African endemic areas there are large numbers of infected people passing large numbers of schistosome eggs, which find their way into lakes and streams where the intermediate hosts abound. There are also large numbers of people who come into frequent contact with the infected water. Since, in the case of urinary schistosomiasis (a type more prevalent in many parts of Africa than the intestinal), the eggs are present in the urine, they gain access to the lakes and streams more readily than eggs of the intestinal type of schistosomiasis. It is the latter type that is present at Khong Island.

3.3 Pilot control project

The Mekong Committee plans to implement the recommendations of the December 1974 report with a new project, namely a pilot control activity at Khong Island with the goal of achieving a measurable reduction in the existing level of transmission. The pilot project, funded in the amount of $535,000 for a period of three years, will include two phases, namely preliminary training of both professional and supporting technicians of furnish personnel capable of monitoring the population a risk, followed by implementation of control measures which can be immediately applied and planning for additional measures which can be implemented pending completion of further research. The component tasks of the pilot project are summarized as follows:

(a) Snail control by engineering methods: These are measures for destroying the snail habitats. Observations at Khong Island have shown that infective cercariae are present during the low-water period in the Mekong river which extends from February to June, and are found mainly in pockets of relatively still and shallow water from April to June. Some of these sites may be eliminated by filling with concrete and others may be treated with molluscicides added by "slow release" methods. The increase in the Mekong minimum flow which will result from releases from the Pa Mong reservoir may check transmission by interfering with snail breeding, increasing flow velocities, reducing pockets of relatively still water, diluting concentrations of parasite stages, and discouraging human contact.

(b) Prevention of contamination: These are environmental sanitation measures, namely:

(1) Measures for preventing excreta from entering the river involve the provision of suitable latrines for the resident population and the clearing of sheltered areas along the bank of the river where bushes and other vegetation offer concealment for defecation. The type of latrine selected should be one which does not result in increased discharge of excreta to the river (hence an intensification of the schistosomiasis problem). Although there are reservoir animals on Khong Island (dogs), their role in the transmission of the disease is considered marginal as compared with that of the human host.

(2) Measures for reducing the need to rely on river water for washing or domestic purposes involve the provision of a simple but adequate community water supply system. Water could be pumped from a protected submerged intake upstream of the town, into an overhead tank and from there distributed to public taps. Several public laundries could be constructed at selected sites.

(c) Health education: Health education involving the grade schools and the intermediate school (college) levels could make a significant contribution to the protection of the residents from schistosomiasis and other diseases which prevail under conditions of poor sanitation. Demonstration of the role of each link in the chain of transmission of schistosomiasis could be an important factor in checking transmission.

Additional control measures which might be feasible are (1) development and use of safe molluscicides for destroying snails in their habitats and of prophylactic and therapeutic drugs for both man and animals (most existing drugs appear to be toxic and unsafe), and (2) further study of the ecology and life cycle of aperta and of other possible transmitter snails, of the possible existence of other forms of infection, and of the pathobiology of the parasite. While not included in the pilot project, these are concepts which may merit attention at later stages of the studies.

## 3.4 Summary

The Mekong Committee's programme for investigating schistosomiasis in the lower basin represents a valuable contribution to the public health of the region in (a) delineating the location and extent of the disease, (b) identifying the snail host, and (c) evaluating the life cycle of the snail in relation to environment as the basis for the next step, an actual control programme aimed at achieving significant reduction in this disease.

While apparently now limited to only a few places in the lower basin, schistosomiasis has been a major disease in other tropical areas, hence it is the objective of the programme not only to contain the disease to these areas but to achieve reductions leading to eventual control.

The studies to date are not sufficient to predict precisely how upstream impoundment at Pa Mong will affect the existing situation on schistosomiasis but the preliminary findings indicate upstream storage, by increasing dry season flows and hence decreasing the extent of shallow pools, will tend to alter the riverine environment to the detriment of the snail and thus help in reducing the prevalence of the snail and the disease. The effect of different pool levels for Pa Mong reservoir would be significant only if this were to affect the extent of the dry season flow releases.

4. Other tropical diseases

There are numerous other tropical diseases existing in the lower basin whose incidence might be altered by changes in water regimes resulting from Pa Mong. These include dengue hemorrhagic fever, liver fluke infections (opisthorchiasis), and other helminth diseases (Ref. 25, 26, 29). Because these diseases are of much lesser priority (as related to water resource development) than malaria and schistosomiasis, the Mekong Committee's public health programme has thus far been limited to review and compilation of information on these diseases in the lower basin. Should the decision be made to proceed with Pa Mong, its possible affect on these diseases is to be kept under review.

5. Environmental health

A significant problem area in planning for Pa Mong relates to the needs for environmental health and other community facilities in the new villages to result from resettlement and from introduction of irrigation. Traditionally villages in northeast Thailand and in Lao PDR in the Pa Mong project watershed and irrigation service areas have been simple villages not having public water supplies nor sewerage and drainage systems nor solid waste collection and disposal facilities, etc. It is recognized, if the villagers in the project area are to share in the benefits from the project, one appropriate benefit should be an improvement in the community facilities to be provided, especially environmental health facilities including public water supply and sanitation systems. It is also recognized that criteria for such systems, as practiced in the industrialized nations, represent levels of expenditures which will likely not be affordable in the foreseeable future for most communities in the lower basin. There is a real need for innovative engineering and pilot-scale experimentation to develop concepts for village environmental health facilities which represent a significant advance in the quality of village life and which can later be further improved by stages in proportion to economic growth.

To develop and demonstrate the feasibility of this approach the Mekong Committee has proposed a series of demonstration projects in a group of villages and small cities located within the pioneer agricultural projects (Ref. 22).

In addition, the Mekong Committee, recognizing the importance of safe water for drinking and other domestic uses, as a key element in community environmental health, has sponsored research for developing and testing a new approach to filtration of village water supplies. This novel concept of filtration involves the use of shredded coconut fiber and burnt rice husk (both locally available waste products) as the filtration media. Such filtration would be less costly than conventional slowsand or rapid sand filtration, might require less chemicals and would be simpler to operate (Ref. 27). The results of these tests were not conclusive. The Mekong Committee deferred the matter; however, further tests have been carried out with USAID sponsorship.

The Mekong Committee also arranged for expert service and practical demonstrations to be given to the authorities concerned in the manufacture and use of simple equipment for well-drilling by means of high-pressure water jetting. This system, which results in higher speed and lower costs, has been used with success in many locations.

6. Nutrition

The importance of the irrigation potentials to be made possible by Pa Mong can scarcely be exaggerated in that the most critical problem anticipated in the lower basin in the coming decades will be provision of enough food to support the expected population growth. The opportunities provided by irrigation will not be limited to total food quantity but will permit diversified cropping, hence can contribute very significantly to improved and more healthful diets.

The present role of the Mekong Committee in improving nutrition in the lower basin is essentially in cooperation with TROPMED/SEAMEO and other interested agencies in developing a programme for monitoring nutrition in the riparian countries to establish a fund of facts to serve as a basis for further planning (Ref. 16-19, 31).

7. Summarized assessment of public health programme

A cooperative programme for attention to public health problems associated with water resource development in the lower Mekong basin has been carried out over the past decade by the Mekong Committee in cooperation with WHO, working through the riparian countries, and with assistance from other international and private agencies. With respect

to the Pa Mong project, the public health studies to date have produced sufficient findings to indicate that construction and operation of Pa Mong dam and associated irrigation systems will result, not in deterioration of public health, but in positive improvement in public health throughout the region. The specific activities to be undertaken as part of the construction and operation of the Pa Mong project should (for all pool level alternatives) serve not only to maintain improved public health and sanitation in the project service areas but to demonstrate the feasibility for general application of these methods throughout the lower basin.

As previously noted, provision needs to be made in planning Pa Mong for proper attention (using the guidelines already developed by the Mekong Committee programme) to malaria control and for adequate community sanitation for the construction camps and their vicinities. Also, in planning resettlement communities and development of communities in irrigation service areas, provision needs to be made for assistance to the riparian countries in developing and demonstrating how minimum acceptable levels of community water supply and sanitation can be achieved.

The plans of the Mekong Committee for continuing attention to other public health problem areas, including schistosomiasis and other infectious diseases, and in ancillary areas including nutrition, appear to be valuable contributions to overall regional public health improvement.

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## TABLE 1

## MALARIA CASES IN DEMOCRATIC KAMPUCHEA IN 1970

(From Reference 2)

### (a) Slides examined and positive for malaria parasites by zone laboratory

| Zone[1] Laboratory | Popn.[3] x 1000 | Slides examined and found positive for malaria[4] | | | | | | | | SPR[5] % |
|---|---|---|---|---|---|---|---|---|---|---|
| | | PCD | | ACD | | Other | | Total | | |
| | | Ex. | + | Ex. | + | Ex. | + | Ex. | + | |
| Battambang | 668 | 13 390 | 6 283 | [illegible] | [illegible] | 1 059 | 361 | 19 713 | 7 374 | 37.4 |
| Pailin | | 2 659 | 1 274 | 4 695 | 1 257 | 58 | 38 | 7 412 | 2 569 | 34.7 |
| Siem-Reap | 284 | 347 | 113 | 560 | [illegible] | 2 935 | 446 | 3 822 | 647 | 16.9 |
| Oddar Meanchey | 148 | 304 | 138 | 1 [illegible] | 52 | 717 | 3 | 2 430 | 193 | 7.9 |
| Stung Treng | 42 | 289 | 67 | 2 106 | 251 | 350 | 130 | 2 745 | 448 | 16.3 |
| Ratanakiri | 60 | 295 | 125 | 1 079 | 292 | – | – | 1 365 | 417 | 30.5 |
| Mondulkiri | 18 | 82 | 27 | 448 | 177 | – | – | 530 | 204 | 38.5 |
| Kratié | 153 | 1 278 | 336 | 2 025 | 408 | 206 | 22 | 3 509 | 766 | 21.8 |
| Kompong Thom | 175 | 484 | 163 | 2 190 | 374 | 2 652 | 281 | 5 316 | 822 | 15.5 |
| Preah Vihear | 160 | 422 | 190 | 1 119 | 343 | 570 | 101 | 2 111 | 632 | 29.9 |
| Pursat | 218 | 1 384 | 693 | 2 179 | 756 | [illegible] | 320 | 4 557 | 1 769 | 38.8 |
| Kompong Chhnang | 332 | [illegible] | 265 | 2 187 | 417 | – | – | 2 941 | 682 | 24.0 |
| Kompong Cham | 994 | 4 148 | 583 | 2 931 | [illegible] | 596 | 206 | 7 675 | 1 123 | 14.6 |
| Kompong Speu | 372 | 947 | 435 | 704 | 71 | 897 | 96 | 2 548 | 602 | 23.6 |
| Kompong Seila[2] | 48 | 2 189 | 653 | 1 [illegible]61 | 266 | 373 | 56 | 4 223 | 1 190 | 28.2 |
| Kampot[2] | | 520 | 225 | 1 040 | 235 | 569 | 9 | 2 149 | 469 | 21.8 |
| Kompong Som[2] | 431 | 1 374 | 326 | 2 319 | 143 | 553 | 119 | 4 246 | 588 | 13.8 |
| Phnom Penh | – | 1 034 | 421 | – | – | 1 830 | 980 | 2 914 | 1 401 | 48.1 |
| Total | 4 103 | 31 850 | 12 452 | 32 677 | 6 276 | 15 579 | 3 167 | 80 106 | 21 895 | 27.3 |

### (b) Slides examined and found positive for malaria parasites by month

| Month | No. of labs. Reporting | Slides examined and found positive for malaria[4] | | | | | | | | SPR[5] % |
|---|---|---|---|---|---|---|---|---|---|---|
| | | PCD | | ACD | | Other | | Total | | |
| | | Ex. | + | Ex. | + | Ex. | + | Ex. | + | |
| January | 18 | 6 601 | 2 487 | 10 398 | 2 191 | 6 937 | 1 021 | 23 896 | 5 699 | 23.8 |
| February | 17 | 4 865 | 1 498 | 8 740 | 1 586 | 4 658 | 831 | 18 263 | 3 915 | 21.4 |
| March | 12 | 3 185 | 1 177 | 4 210 | 746 | 617 | 61 | 8 012 | 1 984 | 24.8 |
| April | 13 | 2 552 | 1 003 | 3 034 | 444 | 857 | 45 | 6 443 | 1 492 | 23.1 |
| May | 9 | 1 913 | 799 | 899 | 223 | 112 | 15 | 2 924 | 1 037 | 35.5 |
| June | 9 | 1 875 | 792 | 745 | 168 | 34 | 6 | 2 654 | 972 | 36.6 |
| July | 9 | 1 875 | 865 | 546 | 103 | 911 | 512 | 3 332 | 1 480 | 44.4 |
| August | 9 | 2 033 | 923 | 1 043 | 205 | 1 115 | 561 | 4 197 | 1 689 | 40.2 |
| September | 8 | 1 875 | 757 | 808 | 135 | 77 | 12 | 2 760 | 904 | 32.8 |
| October | 9 | 2 089 | 907 | 1 057 | 211 | 234 | 95 | 3 380 | 1 213 | 35.9 |
| November | 7 | 2 355 | 1 051 | 761 | 221 | 17 | 8 | 3 133 | 1 280 | 40.9 |
| December | 6 | 626 | 197 | 486 | 43 | – | – | 1 112 | 230 | 20.7 |
| Total | – | 31 850 | 12 452 | 32 677 | 6 276 | 15 579 | 3 167 | 80 106 | 21 895 | 27.3 |

Notes: 1/ Zones relate to provinces except that additional zones are established at Pailin (Battambang province) and Kompong Som (Kampot province). An additional laboratory is located at Phnom Penh for PCD activities.

2/ These zones are largely outside the Mekong catchment area.

3/ Population in malarious areas based on mid-1970 estimates.

4/ ACD = active case detection; PCD = passive case detection; Other = slides from contacts and epidemiological investigations.

5/ SPR % = slide positivity rate per cent.

TABLE 2

COMPARISON OF MALARIA INCIDENCE IN THAILAND IN 1969 AND 1970

(From Reference 2)

| Phase | Year | Population 1/ x 1000 | Total slides 2/ | | Parasite species 3/ | | | | Analysis 4/ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | examined | positive | f | v | m | Mix. | ABER % | API % | SPR % |
| Consolidation | 1969 | 15 544 | 2 113 924 | 15 872 | 13 397 | 2 388 | 15 | 162 | 13.6 | 1.0 | 0.7 |
| | 1970 | 16 954 | 2 014 051 | 26 249 | 21 993 | 3 947 | 30 | 279 | 11.8 | 1.6 | 1.3 |
| Attack | 1969 | 13 530 | 2 555 365 | 47 850 | 38 117 | 8 826 | 128 | 779 | 18.9 | 3.5 | 1.9 |
| | 1970 | 9 751 | 1 957 951 | 59 414 | 48 839 | 9 692 | 114 | 769 | 20.1 | 6.1 | 3.0 |
| Attack (difficult areas) 5/ | 1969 | 1 244 | 408 665 | 23 265 | 19 155 | 3 720 | 15 | 375 | 32.8 | 18.7 | 5.7 |
| | 1970 | 1 563 | 487 357 | 38 061 | 32 387 | 5 115 | 6 | 553 | 31.1 | 24.4 | 7.8 |
| TOTAL | 1969 | 30 318 | 5 077 954 | 86 987 | 70 579 | 14 934 | 158 | 1 316 | 16.8 | 2.9 | 1.7 |
| | 1970 | 28 268 | 4 558 359 | 123 724 | 103 219 | 18 754 | 150 | 1 601 | 16.0 | 4.4 | 2.7 |

Notes:

1/ Population 1969 estimated from national census 1960 + 3% per annum increase; 1970 population from NSLP census July 1969.

2/ From all sources; ACD, FCD, epidemiological investigations, mass blood surveys etc.

3/ Parasite species: f = Plasmodium falciparum; v = P. vivax; m = P. malariae; Mix. = mixed infections of more than one species.

4/ Analysis: ABER % = annual blood examination rate, taking all slides examined as a percentage of population; API % = annual parasite incidence, considering all positive slides per 1000 population; SPR % = slide positivity rate per cent.

5/ "Difficult areas" in the attack phase are those where special measures are adopted, including two rounds of DDT spraying annually and intensified follow-up of temporary shelters.

## TABLE 3

## MALARIA CASES DETECTED IN

## THAILAND PORTION OF LOWER MEKONG BASIN IN 1970

(From Reference 2)

(a) Areas in Consolidation Phase

| Province | Pop^n.^ 1/ at risk x 1000 | Slides examined and found positive:2/ PCD Ex. | PCD – | ACD Ex. | ACD – | Other Ex. | Other – | Total Ex. | Total – | Classification 3/ A | B | O | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N. Ratchasima | 923 | 6654 | 1861 | 80280 | 319 | 6404 | 52 | 93338 | 2232 | 0 | 1027 | 1 | 1028 |
| Chaiyaphum | 137 | 6297 | 616 | 12052 | 1[illegible] | 307 | 2 | 18656 | 632 | 0 | 98 | 0 | 98 |
| Surin | 472 | 1848 | 307 | 43106 | 928 | 7933 | 218 | 52887 | 1513 | 2 | 1277 | 0 | 1279 |
| Buriram | 412 | 2239 | 359 | 37768 | 278 | 4651 | 68 | 44658 | 705 | 15 | 586 | 5 | 606 |
| Srisaket | 410 | 1522 | 388 | 41830 | 171 | 456 | 10 | 43858 | 569 | 0 | 404 | 0 | 404 |
| Khon Kaen | 831 | 18461 | 724 | 80345 | 123 | 7186 | 36 | 106092 | 883 | 11 | 494 | 2 | 507 |
| Udorn | 499 | 2862 | 225 | 59702 | 84 | 2499 | 6 | 65063 | 315 | 4 | 168 | 0 | 172 |
| Nong Khai | 157 | 1762 | 77 | 21211 | 42 | 2409 | 2 | 25382 | 121 | 0 | 73 | 0 | 73 |
| Mahasarakham | 562 | 7691 | 124 | 69134 | 171 | 2415 | 12 | 79240 | 307 | 5 | 260 | 1 | 266 |
| Kalasin | 356 | 2061 | 81 | 40303 | 92 | 1979 | 13 | 44348 | 186 | 7 | 152 | 0 | 159 |
| Ubon Ratchat. | 798 | 7609 | 799 | 87405 | 403 | 11426 | 58 | 106440 | 1259 | 37 | 817 | 2 | 856 |
| Roi Et | 676 | 2175 | 429 | 87226 | 214 | 4145 | 54 | 93546 | 693 | 11 | 511 | 1 | 523 |
| Chiangrai | 479 | 6774 | 69 | 69158 | 120 | 13149 | 12 | 89081 | 201 | 12 | 159 | 1 | 172 |
| Total | 6712 | 68155 | 6154 | 729675 | 2919 | 64959 | 543 | 862789 | 9616 | 104 | 6026 | 13 | 6143 |

(b) Areas in Attack Phase

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N. Ratchasima | 167 | 1808 | 570 | 25105 | 756 | 5051 | 306 | 31964 | 1632 | 441 | 849 | 2 | 1292 |
| Chaiyaphum | 521 | 2898 | 515 | 75326 | 1163 | 4393 | 226 | 82607 | 1904 | 291 | 1211 | 9 | 1511 |
| Surin | 114 | 745 | 57 | 19044 | 128 | 2042 | 57 | 21831 | 242 | 37 | 179 | 0 | 216 |
| Buriram | 290 | 219 | 36 | 40046 | 642 | 2726 | 69 | 42991 | 747 | 138 | 607 | 0 | 745 |
| Srisaket | 283 | 532 | 128 | 39418 | 338 | 1641 | 91 | 41591 | 567 | 3 | 387 | 0 | 390 |
| Khon Kaen | 127 | 796 | 54 | 21717 | 335 | 1183 | 35 | 23696 | 424 | 78 | 408 | 0 | 486 |
| Loei | 308 | 5619 | 647 | 68115 | 2072 | 7518 | 391 | 81252 | 3110 | 781 | 1789 | 0 | 2570 |
| Udorn | 441 | 2293 | 148 | 70694 | 765 | 7777 | 144 | 80764 | 1057 | 147 | 797 | 0 | 944 |
| Nong Khai | 247 | 3519 | 405 | 56608 | 3189 | 4049 | 215 | 64176 | 3809 | 250 | 773 | 0 | 1023 |
| Sakon Nakhon | 532 | 2394 | 217 | 73797 | 1060 | 3649 | 155 | 79840 | 1432 | 158 | 1023 | 1 | 1182 |
| Nakhon Phanom | 476 | 1746 | 292 | 63140 | 1736 | 2279 | 149 | 67165 | 2177 | 401 | 1205 | 1 | 1607 |
| Kalasin | 162 | 1424 | 60 | 27738 | 368 | 2426 | 35 | 31588 | 463 | 8 | 455 | 0 | 463 |
| Ubon Ratchat. | 493 | 3717 | 511 | 71293 | 918 | 6405 | 185 | 81415 | 1614 | 244 | 1196 | 1 | 1441 |
| Roi Et | 53 | 466 | 27 | 12115 | 53 | 989 | 21 | 13570 | 101 | 1 | 80 | 0 | 81 |
| Chiangrai | 661 | 13546 | 623 | 141844 | 2158 | 22682 | 357 | 178072 | 3138 | 991 | 1301 | 0 | 2292 |
| Total | 4885 | 41712 | 4290 | 906000 | 15691 | 74810 | 2436 | 922522 | 22417 | 3969 | 12260 | 14 | 16243 |

Notes: 1/ Population based on MMEP figures from July 1969.

2/ PCD = passive case detection; ACD = active case detection; Other = slides from epidemiological investigations, mass blood surveys etc..

3/ Case classification: A = indigenous; B = imported; O = other = relapsed, induced, introduced, unclassified; Total = total number of cases investigated.

TABLE 4

MALARIA CASES DETECTED IN VIETNAMESE DELTA IN 1970

(From Reference 2)

| Province | Population x 1000 1/ | Slides examined | Slides positive | SPR% 1970 |
|---|---|---|---|---|
| An Giang | 654 | 6811 | 10 | 0.1 |
| An Xuyen | 201 | 5477 | 5 | 0.1 |
| Ba Xuyen | 449 | 6383 | 9 | 0.1 |
| Bac Lieu | 335 | 2919 | 4 | 0.1 |
| Go Cong | 218 | 5304 | 215 | 4.1 |
| Dinh Tuong | 623 | 10850 | 229 | 2.1 |
| Kien Hoa | 608 | 10018 | 419 | 4.2 |
| Kien Phong | 408 | 4688 | 11 | 0.2 |
| Kien Tuong | 52 | 1524 | 42 | 2.8 |
| Kien Giang | 483 | 5915 | 84 | 1.4 |
| Vinh Binh | 458 | 4571 | 62 | 1.4 |
| Vinh Long | 600 | 11024 | 102 | 0.9 |
| Chuong Thien | 240 | 1218 | 18 | 1.5 |
| Sa Dec | 337 | 2588 | 14 | 0.5 |
| Chau Doc | 521 | 8570 | 152 | 1.8 |
| Phong Dinh | 527 | 8119 | 23 | 0.3 |
| Total | 6714 | 95979 | 1399 | 1.5 |

Note: 1/ Population is mid-1970 estimate.

TABLE 5

MALARIA PARASITE SPECIES FORMULAE, LOWER MEKONG BASIN, 1970

(From Reference 2)

| Country | Total slides examined | Slides positive for malaria | SPR 1/ % | Parasite species 2/ | | | | Parasite formula 3/ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | f | v | m | Mixed | f : | v : % | m |
| Democratic Kampuchea | 80 106 | 21 895 | 27.3 | (17 626) | (4 160) | (109) | (v) | 80.5 : | 19.0: | 0.5 4/ |
| Lao PDR | 23 942 | 778 | 3.2 | 436 | 287 | 37 | 18 | 56.4 : | 38.0: | 5.6 |
| Thailand (Mekong basin) | 1 785 311 | 32 033 | 1.8 | 25 865 | 5 756 | 70 | 342 | 80.9 : | 18.8: | 0.3 |
| Viet-Nam (Delta region) | 95 979 | 1 399 | 1.5 | 583 | 801 | 0 | 15 | 42.3 : | 57.7: | 0.0 |
| Total | 1 985 338 | 56 105 | 2.8 | 44 510 | 11 004 | 216 | 375 | 79.3 : | 20.1: | 0.6 |

Notes: 1/ SPR % = slide positivity rate per cent.

2/ f = Plasmodium falciparum; v = P. vivax; m = P. malariae; Mixed = mixed infection (mostly f plus v).

3/ Parasite formula is calculated after distributing mixed infections to various species.

4/ Parasite formula for Democratic Kampuchea relates to 1969 figures as the parasite distribution for 1970 was not available. Approximate extensions have been made from this formula to supply figures of positive slides for 1970.

TABLE 6

ENTOMOLOGICAL STUDY AT NAM PHROM, DECEMBER 1972 - APRIL 1974

HUMAN-BAIT NIGHT COLLECTIONS

(From Reference 6)

| Month | Site | Confirmed vectors | | | | Possible vectors | | | | | | Other anophelines | | Site totals | | Monthly totals | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A.minimus | | A.balaba | | A.macula | | A.aconit | | A.philip | | | | | | | |
| | | I | O | I | O | I | O | I | O | I | O | I | O | I | O | I | O |
| 1972 | | | | | | | | | | | | | | | | | |
| | 1 | | | 1 | 1 | | | | | | | 2 | | 3 | 1 | | |
| Dec. | 2 | | | | | | | | | | | 2 | 4 | 2 | 4 | 5 | 6 |
| | 3 | | | | | | 1 | | | | | | | | 1 | | |
| Total | | | | 1 | 1 | | 1 | | | | | 4 | 4 | 5 | 6 | 5 | 6 |
| 1973 | | | | | | | | | | | | | | | | | |
| | 1 | | 1 | 2 | 3 | | | | | | | | | 2 | 4 | | |
| Jan. | 2 | | | 1 | | | | | | | | | 1 | 1 | 1 | 4 | 5 |
| | 3 | | | | | | | | | | | | | 1 | | | |
| 1/ | 1 | | | 2 | 4 | | | | | | | | | 2 | 4 | | |
| Mar. | 2 | | | | 2 | | | | | | | | 2 | | 4 | 2 | 21 |
| | 3 | | 2 | | 8 | | | | | | | | 3 | | 13 | | |
| | 1 | | | | 2 | | | | | | | | | | 2 | | |
| Apr. | 2 | | | 1 | 14 | | | | | | | | 6 | 1 | 20 | 1 | 22 |
| | 3 | | | | | | | | | | | | | 0 | 0 | | |
| | 1 | | | 1 | 3 | | | | | | | | | 1 | 3 | | |
| May | 2 | | | 1 | 38 | | | | | | | | | 1 | 38 | 2 | 42 |
| | 3 | | | | | | | | | | | | 1 | | 1 | | |
| | 1 | | 1 | 7 | 13 | | | | | | | | 4 | 7 | 18 | | |
| June | 2 | | | | 3 | | | | | | | | 5 | | 8 | 7 | 35 |
| | 3 | | 1 | | 6 | | | | | | | | 2 | | 9 | | |
| | 1 | | | 4 | 11 | | 1 | | | | | | | 4 | 12 | | |
| July | 2 | | | | 28 | | | | | | | | 2 | | 30 | 4 | 42 |
| | 3 | | | | | | | | | | | | | | | | |
| | 1 | | | | 1 | | | | | | | | | | 1 | | |
| Aug. | 2 | | | | 2 | | | | | | | | 4 | | 6 | 0 | 9 |
| | 3 | | | | 2 | | | | | | | | | | 2 | | |

TABLE 6 (Cont'd)

ENTOMOLOGICAL STUDY AT NAM PHROM, DECEMBER 1972 - APRIL 1974

HUMAN-BAIT NIGHT COLLECTIONS

(From Reference 6)

| Month | Site | Confirmed vectors | | | | Possible vectors | | | | | | Other anopholines | | Site totals | | Monthly totals | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A.minimus | | A.balaba | | A.macula | | A.aconit | | A.philip | | | | | | | |
| | | I | O | I | O | I | O | I | O | I | O | I | O | I | O | I | O |
| 2/ Nov. | 1 | 5 | 5 | 3 | 1 | | | | | | | | | 8 | 6 | | |
| | 2 | | 14 | | 2 | | 2 | | | | | 1 | 18 | 1 | 36 | 11 | 92 |
| | 3 | 2 | 39 | | 5 | | 3 | | | | 2 | | 1 | 2 | 50 | | |
| Dec. | 1 | 7 | 10 | 1 | | | | 1 | | 1 | | | 2 | 10 | 12 | | |
| | 2 | | | | | | 1 | | | | 1 | 1 | 6 | 1 | 8 | 11 | 40 |
| | 3 | 1 | 5 | | 2 | | | | 4 | | 5 | | 4 | | 20 | | |
| Total | | 15 | 78 | 23 | 147 | | 7 | 1 | 4 | 1 | 8 | 3 | 61 | 42 | 305 | 42 | 308 |
| 1974 | | | | | | | | | | | | | | | | | |
| Jan. | 1 | 2 | 1 | 1 | | | | | 9 | | | | 1 | 3 | 2 | | |
| | 2 | | 1 | | | | | | | | | 1 | 5 | 1 | 6 | 4 | 44 |
| | 3 | | 4 | | 8 | | | | | | 3 | | 21 | | 36 | | |
| Feb. | 1 | | | | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | 1 | 5 | 1 | 5 | 2 | 14 |
| | 3 | | 1 | | | | | | | | | 1 | 8 | 1 | 9 | | |
| Mar. | 1 | | | 2 | | | | | | | | | 3 | 2 | 3 | | |
| | 2 | 1 | 1 | 9 | 22 | | | | | | | | 52 | 10 | 75 | 13 | 97 |
| | 3 | | 1 | 1 | 7 | | | | | | | | 11 | 1 | 19 | | |
| Apr. | 1 | | | 1 | 4 | | | | | | | | | 1 | 4 | | |
| | 2 | | | 1 | 5 | | | | | | | | 1 | 1 | 6 | 2 | 13 |
| | 3 | | | | | | | | | | | | 3 | | 3 | | |
| Total | | 3 | 9 | 15 | 46 | | | | | | 3 | 3 | 110 | 21 | 168 | 21 | 168 |

1/ No observations for February

2/ No observations for September, October

I - Indoor collections

O - Outdoor collections

TABLE 7

ENTOMOLOGICAL STUDY AT NAM PHROM, DECEMBER 1972 - APRIL 1974

LARVAL COLLECTIONS

(From Reference 6)

| Month | Anopheline larvae collected | Number of dips | Larvae per 10 dips | Notes on anopheline species |
|---|---|---|---|---|
| 1972 | | | | |
| Dec. | 77 | 963 | | 6 A.balabacensis at site 3 |
| 1973 | | | | |
| Jan. | 561 | 1515 | 3.66 | No balabacensis |
| Mar. | 578 | 1005 | 10.50 | No balabacensis |
| Apr. | 368 | 1250 | 2.83 | 2 A.balabacensis at site 1 |
| May | 192 | 1005 | 1.92 | 1 A.balabacensis at site 1 |
| June | 490 | 1370 | 3.55 | 5 A.balabacensis at site 3 |
| July | 333 | 980 | 3.36 | 2 A.balabacensis at site 3, 11 A.philippinensis |
| Aug. | 292 | 820 | 3.54 | No vectors |
| Nov. | 460 | 1485 | 3.27 | 1 A.philippinensis at site 2 |
| Dec. | 535 | 1020 | 5.25 | 4 A.minimus at site 1 |
| 1974 | | | | |
| Jan. | 713 | 1430 | 3.80 | No vectors |
| Feb. | 875 | 1150 | 7.00 | No vectors |
| Mar. | 1559 | 1190 | 13.10 | No vectors |
| Apr. | 672 | 1250 | 5.37 | No vectors |
| Total | 7905 | 16479 | 4.80 | 16 A.balabacensis, 1 A.minimus, 1 A.philippinensis |

TABLE 8

ENTOMOLOGICAL STUDY AT NAM PONG, NOVEMBER 1972 – APRIL 1974

HUMAN-BAIT NIGHT COLLECTIONS

(From Reference 6)

| Month | Site | Confirmed vectors | | | | Possible vectors | | | | | | Other anopholines | | Site Totals | | Monthly totals | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A.minimus | | A.balaba | | A.maculn | | A.aconit | | A.philip | | | | | | | |
| | | I | O | I | O | I | O | I | O | I | O | I | O | I | O | I | O |
| 1972 | 1 | | | | | | | | | | 3 | 2 | 2 | 2 | 5 | | |
| Nov. | 2 | | | | | | | | 3 | | 25 | | 2 | 2 | 30 | 11 | 54 |
| | 3 | | | | | | | 7 | 14 | 1 | | 1 | 5 | 9 | 19 | | |
| | 1 | | | | | | | | | | 1 | 1 | 2 | 1 | 3 | | |
| Dec. | 2 | | | | | | | | | | | | 4 | | 4 | 3 | 12 |
| | 3 | | | | | | | 1 | 4 | | | 1 | 1 | 2 | 5 | | |
| Total | | | | | | | | 8 | 21 | 1 | 29 | 5 | 40 | 14 | 66 | 14 | 66 |
| 1973 | 1 | | | | | | | | | | 2 | | 2 | | 4 | | |
| Jan. | 2 | | | | | | | | | | | | 7 | | 7 | 2 | 16 |
| | 3 | | | | | | | 2 | 2 | | | | 3 | 2 | 5 | | 16 |
| | 1 | | | | | | | | | | | | | 0 | 0 | | |
| Feb. | 2 | | | | | | | | 1 | | | | 3 | | 4 | | 6 |
| | 3 | | | | | | | | | | 1 | | 1 | | 2 | | |
| | 1 | | | | | | | | | | | | | 0 | 0 | | |
| Mar. | 2 | | | | | | | | | | | | | 0 | 0 | 0 | 0 |
| | 3 | | | | | | | | | | | | | 0 | 0 | | |
| | 1 | | | | | | | | | | | | | 0 | 0 | | |
| Apr. | 2 | | | | | | | | | 1 | | 2 | | 3 | | 3 | 1 |
| | 3 | | | | | | | | | | | | 1 | | 1 | | |
| | 1 | | | | | | | | | | | | 1 | | 1 | | |
| May | 2 | | | | | | | | | | | 2 | 9 | 2 | 9 | 2 | 10 |
| | 3 | | | | | | | | | | | | | 0 | 0 | | |
| | 1 | | | | | | | | | | | | | 0 | 0 | | |
| June | 2 | | | | | | | | | | | | 2 | | 2 | 0 | 4 |
| | 3 | | | | | | | | | | | | 2 | | 2 | | |
| | 1 | | | | | | | | | | | | | 0 | 0 | | |
| July | 2 | | | | | | | | | | | 4 | 2 | 4 | 2 | 4 | 2 |
| | 3 | | | | | | | | | | | | 0 | | 0 | | |

TABLE 8 (Cont'd)

ENTOMOLOGICAL STUDY AT NAM PONG, NOVEMBER 1972 – APRIL 1974

HUMAN-BAIT NIGHT COLLECTIONS

(From Reference 6)

| Month | Site | Confirmed vectors | | | | Possible vectors | | | | | | Other anophelines | | Site Totals | | Monthly totals | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A.minimus | | A.balaba | | A.macula | | A.aconit | | A.philip | | | | | | | |
| | | I | O | I | O | I | O | I | O | I | O | I | O | I | O | I | O |
| 1972 | 1 | | | | | | | | | | 1 | | | | 1 | | |
| Aug. | 2 | | | | | | | | | | | 4 | 1 | 4 | 1 | 4 | 4 |
| | 3 | | | | | | | | | | | | 2 | | 2 | | |
| 1973 | 1 | | | | | | | | 2 | | 6 | | 7 | | 15 | | |
| Nov. | 2 | | | | | | | 1 | | | 2 | 1 | 6 | 2 | 8 | 4 | 39 |
| | 3 | | | | | | | 1 | 9 | | | 1 | 7 | 2 | 16 | | |
| | 1 | | | | | | | | | | | | 1 | | 1 | | |
| Dec. | 2 | | | | | | | | 13 | | | 2 | 93 | 2 | 106 | 2 | 114 |
| | 3 | | | | | | | | 7 | | | | | | 7 | | |
| Total | | | | | | | | 3 | 33 | 1 | 11 | 16 | 148 | 21 | 191 | 25 | 191 |
| 1974 | 1 | | | | | | | | | | 1 | | | | 1 | | |
| Jan. | 2 | | | | | | | | | | 2 | | 53 | | 55 | 4 | 61 |
| | 3 | | | | | | | 2 | 2 | | 1 | 2 | 2 | 4 | 5 | | |
| | 1 | | | | | | | | | | | | | 0 | 0 | | |
| Feb. | 2 | | | | | | | | 1 | | 1 | 5 | 5 | 5 | 7 | 5 | 7 |
| | 3 | | | | | | | | | | | | | 0 | 0 | | |
| | 1 | | | | | | | | | 1 | | | 8 | 1 | 8 | | |
| Mar. | 2 | | | | | | | | | | | | 2 | | 2 | 3 | 17 |
| | 3 | | | | | | | | 2 | | 2 | 2 | 3 | 2 | 7 | | |
| | 1 | | | | | | | | | | | | | 0 | 0 | | |
| Apr. | 2 | | | | | | | | | | | 2 | 5 | 2 | 5 | 3 | 5 |
| | 3 | | | | | | | | | | | 1 | | 1 | | | |
| Total | | | | | | | | 2 | 5 | 1 | 7 | 12 | 78 | 15 | 90 | 15 | 90 |

Note: I = Indoor collections

O = Outdoor collections

TABLE 9

ENTOMOLOGICAL STUDY AT NAM POUG, NOVEMBER 1972 – APRIL 1974

INDOOR DAYTIME RESTING, COLLECTIONS

(From Reference 6)

| Month | Anopheline females collected | Hours of search | House searched | Mosquitoes per house | Notes on anopheline species |
|---|---|---|---|---|---|
| 1972 | | | | | |
| Nov. | 0 | 6 | 18 | 0 | |
| Dec. | 6 | 7 | 21 | 0.286 | 5 A.vatus, 1 A. aconitus |
| 1973 | | | | | |
| Jan. | 3 | 6 | 18 | 0.167 | 3 A.vagus |
| Feb. | 103 | 6-1/3 | 19 | 5.40 | 102 A.vagus, 1 A.ramsayi |
| Mar. | 82 | 6-3/4 | 20 | 4.10 | 80 A.vagus, 2 A.sinensis |
| Apr. | 31 | 6 | 18 | 1.72 | 31 A.vagus |
| May | 146 | 6 | 18 | 8.10 | 146 A.vagus |
| June | 95 | 6 | 18 | 5.27 | 95 A.vagus |
| July | 56 | 6 | 18 | 3.12 | 55 A.vagus, 1 A.barbirostris |
| Aug. | 4 | 6 | 18 | 0.223 | 1 A.vagus |
| Nov. | 2 | 6 | 18 | 0.111 | 4 A.philippinensis, 1 A.pursati |
| Dec. | 0 | 6 | 18 | 0 | |
| 1974 | | | | | |
| Jan. | 6 | 6 | 18 | 0.334 | 6 A.vagus |
| Feb. | 16 | 6 | 18 | 0.89 | 14 A.vagus, 2 A.sinensis |
| Mar. | 37 | 6 | 18 | 2.05 | 34 A.vagus, 3 A.sinensis |
| Apr. | 30 | 6 | 18 | 1.67 | 28 A.vagus, 2 A.ramsayi |
| Total | 617 | 98 | 294 | 2.09 | 604 A. vagus, 13 others |

TABLE 10

ENTOMOLOGICAL STUDY AT NAM PONG, NOVEMBER 1972 – APRIL 1974

LARVAL COLLECTIONS

(From Reference 6)

| Month | Anopheline larvae collected | Number of dips | Larvae per 10 dips | Notes on anopheline species |
|---|---|---|---|---|
| 1972 | | | | |
| Nov. | 278 | 720 | 3.86 | 139 A.philippinensis (91 at site 1, 45 at 2,3 at 3) |
| Dec. | 234 | 842 | 2.34 | 21 A.philippinensis at site 2 |
| 1973 | | | | |
| Jan. | 170 | 810 | 2.10 | 84 A.philippinensis (26 at site 1, 58 at 2) |
| Feb. | 198 | 975 | 2.04 | 21 A.philippinensis at site 2 |
| Mar. | 202 | 1130 | 1.79 | 31 A.philippinensis (5 at site 1, 26 at 2) |
| Apr. | 180 | 1005 | 1.79 | 34 A.philippinensis (28 at site 2, 6 at 3) |
| May | 171 | 890 | 1.91 | 87 A.philippinensis (60 at site 1, 16 at 2,11 at 3) |
| June | 206 | 810 | 2.55 | 18 A.philippinensis (13 at site 2, 5 at 3) |
| July | 130 | 940 | 1.38 | 10 A.philippinensis (3 at site 2, 7 at 3) |
| Aug. | 182 | 1083 | 1.68 | 15 A.philippinensis (15 at site 2, 4 at 3) |
| Nov. | 148 | 950 | 1.56 | 55 A.philippinensis (23 at site 1, 32 at 2) |
| Dec. | 224 | 910 | 2.45 | 84 A.philippinensis (22 at site 1, 41 at 2,21 at 3) |
| 1974 | | | | |
| Jan. | 605 | 1040 | 5.82 | 66 A.philippinensis (15 at site 1, 51 at 2) |
| Feb. | 187 | 1020 | 1.81 | 73 A.philippinensis (23 at site 1, 50 at 2) |
| Mar. | 183 | 1075 | 1.71 | 74 A.philippinensis (26 at site 1, 26 at 2,22 at 3) |
| Apr. | 134 | 1085 | 1.24 | 17 A.philippinensis (16 at site 2, 1 at 3) |
| Total | 3432 | 15285 | 2.24 | 833 A.philippinensis |

TABLE 11

MALARIA CONTROL MEASURES

AT WATER DEVELOPMENT SITES DURING AND AFTER CONSTRUCTION

(From Reference 28)

1. Surveys and investigations before construction

Geographical reconnaissance
Parasitological examination
Entomological investigation
Physical and hydrographic surveys
Land cover, vegetation, forest
Climate, rainfall, temperature
Current malaria control operations

2. Control measures

Intensification of current control operations
Source reduction, application of larvicides
More frequent spraying
Vegetation and jungle clearing
Prophylactic treatment
Establishment of health post
Extension of spraying operations 5 to 10 km
Reservoir site clearing and shore-line shortening

(Source reduction and larvicide application are justified particularly in view of the practice of night work in the open and the presence of outdoor biting mosquitoes)

3. Planning and siting constructing camp

Control of shanty construction near the camp
Entomological and parasitological surveillance
Screening of labourers
Prophylactic treatment
Frequent spraying of hutments as they are completed
Routine monthly or bi-monthly spraying

4. After construction services

Observations and protection of work area residents
Continuation of spraying as required in work area and for a radius of perhaps 5 to 10 km

5. Cost items

Earthworks for source reduction and drainage
Clearance
Larvicide application
Surveillance
Health post
Spraying
Diagnostic and treatment

These should be ascertained for each project. In general they constitute a very small amount compared with the project construction costs, estimated at approximately .2% .

FIGURE 1

MAP OF MALARIA

IN LOWER MEKONG BASIN - 1970

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## RECREATION AND AESTHETICS

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# PA MONG ENVIRONMENTAL ASSESSMENT

## RECREATION AND AESTHETICS

### 1. Introduction

The huge new lake to be created at Pa Mong should be an aesthetic "gem" and, because lakes are not plentiful in the region, this will certainly add to its overall aesthetic and recreational values. In areas where lakes are scarce, for example in Southern California, the creation of sizeable reservoirs has usually led, sooner or later, to their massive use by the public for recreational purposes including aesthetic enjoyment, boating fishing, swimming, skin-diving, and other water contact sports.

While it is recognised that the aesthetic values of waterways have not generally enjoyed any significant priorities nor much public attention in the lower Mekong basin in the past (except to a limited extent in Thailand), it is also true that there is growing recognition of outdoor environmental values. By the time Pa Mong has been completed it should be a recreational attraction for many residents in the lower basin as well as visitors from outside. Traditionally the Thai and Lao peoples in the Pa Mong region, when visiting the outdoors for recreation, have been mostly interested in picnicking and camping. The new lake will create inumerable choice sites for such activities as weel as for various types of water contact sports likely to become popular in the future.

### 2. Pa Mong recreational study

The Pa Mong Stage One report (Ref. 1), as one its support studies, includes an evaluation of the economic potentials of recreation in the project areas made by the National Energy Administration of Thailand. The study estimated the approximate numbers of tourists expected to visit the area each year from both Thailand and the Lao PDR, the per capita expenditures during visits, and the projected gross income versus costs. It was assumed that the primary recreational interest of the visiting public will be initially limited to sight-seeing, picnicking, and camping, with interest in water contact sports to be developed in later years. Important zones from which visitors will come include both Bangkok (despite the distance) and Vientiane. It is also assumed public interest in outdoor recreation will progressively increase due to increased population, increased income, shorter working hours, better roads, and improvement in transportation. The study includes estimates of costs for constructing and operating facilities for public use (picnicking and camping units, sanitary facilities, shelters, boat launching and swimming areas, etc., together with land clearing and access roads), for the initial construction stage and for continuing staged development. The study concluded that annual

visitation is expected to increase from approximately 81,000 persons/year initially to about 369,000/year in 50 years. The annual equivalent net earnings were estimated at about $ 90,000.

3. National parks

As noted in the discussion on wildlife, a number of national parts together with scientific reserves must be established in the lower basin, especially in the hilly areas, if representative samples of the terrestial biota are to be preserved. One key aspect of a national park is its tourist potential which, although only one aspect, can furnish the financial basis for the entire park plan. As noted by Talbot (Ref. 5), in Eastern Africa and India this type of venture has already been successfully demonstrated. The rich and varied wildlife of the Pa Mong reservoir vicinity and its scenic beauty offer the same potentials for Thailand.

Ultimately each country will require a park system ranging from urban recreation areas to traditional national parks used mainly for camping to totally protected scientific reserves. The need for recreational areas already exists in Thailand, where Khao Yai is an impressive beginning for such a national park system. With increasing urban concentrations of population, there will be increasing need for recreational areas away from cities.

4. Design considerations

Assuming Pa Mong is to be constructed, the design and operational phases of the project should include attention to numerous aspects involved in recreation use (Ref. 3, 4). These include (a) protection of special beauty areas (like waterfalls) from deterioration by over-visiting and/or carelessness by tourists, (b) selection and management of borrow/fill areas and open pit mining areas so that these will not mar the environmental aesthetics, including reforesting of areas not to be inundated, (c) design of roads, transmission towers, etc., to blend in with and not to mar the environmental aesthetics, (d) provision for construction and operation of essential tourist facilities, to be furnished progressively as needed, including facilities for sightseeing, camping, picnicking, boating, fishing, water-contact sports, housing, access, and sanitation.

5. Summary

The preliminary studies sponsored by the Mekong Committee have established the desirability and feasibility of recreational use of the Pa Mong reservoir area, as a means for accommodating the recreational needs of urban populations, while at the same time providing for protection and preservation of environmental beauty. Following the patterns established in other tropical areas, with proper management the economic revenues from tourism can finance the measures needed

for protection of aesthetic values including beauty spots and wildlife.

It would be the intention to proceed with development of detailed plans for construction and operation of recreational facilities and aesthetic protection measures at Pa Mong assuming the project proceeds to the design stage. In addition to these measures to be implemented in the Pa Mong reservoir area, the Mekong Committee's objectives include encouraging the establishment of national parks for use for tourism as well as preservation of terrestial biota. An initial step will be selection of suitable park sites.

References

(1) "Pa Mong Stage One Feasibility Report". Prepared by USBR for Mekong Committee, 1970.

(2) "Pa Mong Phase II" (Main Report plus 6 appendices). Prepared by USBR for Mekong Committee, 1972.

(3) "Selected Ecological Surveys of the Quae Yai Hydroelectric Scheme". Prepared by AIT for EGAT, 20 January 1974.

(4) "Design of Small Dams". U.S. Bureau of Reclamation, 1973, Chapter II, "Ecological and Environmental Considerations".

(5) "Some Environmental Considerations for the Mekong Basin". SEADAG, April 1973". Effects of Mekong Development on wildlife, Parks and Reserves", L.M. Talbot.

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## RESERVOIR ECOLOGY

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Figure 2: Components of a man-made lake ecosystem

Figure 3: Schematic illustration of reservoir fish production and harvest

# PA MONG ENVIRONMENTAL ASSESSMENT

## RESERVOIR ECOLOGY

### 1. Introduction

Construction and operation of the Pa Mong project will have far-reaching effects on environment and ecology throughout the lower basin, and particularly in the area of the reservoir itself and the immediate vicinity. Because these effects will be closely related to the physical features of the reservoir, such as maximum water height and surface area of the impounded water, these data are summarized in Table 1 for the four reservoir high pool elevations under study, namely, 230 m, 240 m, 250 m, and 260 m MSL. Figure 1 is a map showing the proposed Pa Mong reservoir (for elevation 250 m).

Considerable information on reservoir ecology is available for numerous reservoirs throughout the world, mostly in temperate climatic zones but with some information for tropical reservoirs. Based on these past studies schematic representations have been prepared to illustrate reservoir ecology including a chart showing the various components of a man-made lake ecosystem (Figure 2) and a chart showing the interlinked processes involved in fish production in the aquatic ecosystem (Figure 3).

This discussion is aimed at assessing the probable changes to be induced by impoundment at Pa Mong, based on the available information related to the Pa Mong project and on experience elsewhere especially for tropical reservoirs including Mekong tributary reservoirs in northeast Thailand and the Lao PDR. The discussion is limited to the area of the reservoir itself, the river reach immediately downstream and the reservoir fringe areas including the drawdown zone, as follows:

(a) Reservoir area: Impoundment in the reservoir will result in changes in water quality (Ref. 3-7, 28-29, 35), eutrophication (Ref. 4, 6-8), fisheries (Ref. 4, 5, 8-22, 25, 33, 35, 48-50), water weeds (Ref. 21, 23, 24, 45), wildlife (Ref. 29, 33-37, 51), forest reserves (Ref. 37-39), and diseases vectors (Ref. 4, 28, 40-43).

(b) River immediately downstream: There will be significant effects on water quality (Ref. 1, 3, 26-30, 44) and on downstream fisheries (Ref. 8, 14, 16, 20, 28, 31, 32, 49, 50).

(c) Fringe areas and drawdown zones: These effects mainly relate to the tendency of the Thai/Lao people to live close to the waters edge, hence to encroach into the drawdown zone.

The extent of the anticipated ecological effects has been projected for the four different Pa Mong maximum pool levels, namely 230 m, 240 m, 250 m, and 260 m MSL. In assessing ecological effects, where data for different elevations are not available and prediction without such baseline information may be subjected to serious errors, the evaluation in made only for the 250 m elevation.

## 2. Effects in Pa Mong reservoir area

### 2.1 Water quality

Creation of Pa Mong reservoir will result in changes in water quality from that in the Mekong river, especially changes in temperatures and dissolved oxygen concentration. Other water characteristics subject to alteration include turbidity, dissolved solids, and organic content.

A summary of the expected water quality characteristics at Pa Mong reservoir, based on river water analyses near Pa Mong, is given in Table 2 (see discussion on water quality).

#### 2.1.1 Temperature

It is expected that Pa Mong reservoir will be thermally stratified. This expectation is based on experience at Nam Ngum which is in the vicinity of the Pa Mong project, and experience at other tropical reservoirs such as Lake Kariba in Africa, and on the fact that Pa Mong reservoir will be rather deep (maximum depth is 74.6 m at elevation 230 m) compared with Nam Ngum (maximum dpeth about 40 m). A stable thermocline will probably occur at depths between 6 to 15 meters, depending on seasonal temperature.

During the hottest period of the year, the temperature at the upper thermocline will be as much as 5° - 8°C lower than the surface temperature. The thermocline will be relatively weak during the coldest month (January - February) and during rainy seasons, and perhaps broken down in a brief period due to wind-induced circulation expected to take place reaching depths of 20-25 meters. As a result some turnover will take place in the upper layers, but this is not anticipated to reach the deeper layers, particularly if inundated standing trees are present in considerable numbers.

Below the thermocline, the water temperature will fall gradually until becoming stable at depths of about 35-40 meters. The lowest temperature, according to experience at Nam Ngum, will be close to that of the river water temperature during the coldest month, i.e., about 20° - 22°C. Assuming that, as planned, the reservoir releases are drawn from these lower depths, their temperatures would be close to 20° - 22°C.

The surface temperatures are anticipated to vary with ambient air temperatures. Due to surface heating by sunlight,

the surface temperature can be $5^{o}$ - $10^{o}C$ higher than the inflowing water. Temperature at various water depths will tend to vary with surface water temperatures. The lower water temperature in the deepest layers will provide unfavorable habitats for several aquatic species.

The pattern of temperature is expected to be essentially the same at Pa Mong regardless of the selected pool level. The pattern for any pool level will change seasonally with lowering of the surface. The annual minimum level is expected to be at least 12 m lower than the maximum.

### 2.1.2 Dissolved oxygen

For a short period after the dam's closure, the dissolved oxygen content of the impounded water will drop below the level of dissolved oxygen in the inflow. Oxygen is expected to be exhausted in the deeper water layers and will be present only in the upper layers (epilimnion) where wind-induced circulation exists. After a period the dissolved oxygen concentration at the surface will stabilize at or near saturation. The oxygen content will decrease with increasing depth until it is totally depleted below the thermocline. This means that little or no oxygen will usually be present below the 6 - 15 m level except in the shallow exposed areas along the shoreline. The absence of dissolved oxygen at lower depths will be caused by decaying organic matter, mainly inundated vegetation. Lack of sufficient vertical mixing, due to the presence of a stable thermocline and drowned standing trees, will keep the bottom layers (hypolimnion) permanently devoid of oxygen. This zone, characteristic of most deep reservoirs, will not support aerobic life.

### 2.1.3 Other characteristics

The reservoir is expected to trap 99 per cent of the total sediment load, thus most of the impounded water will be relatively free of turbidity and suspended solids. However, the middle and lower layers may become turbid after the onset of the rainy season due to seimentation of silt through the thermocline.

It is expected that the upper cirulating layer will be lower in dissolved solids than the intermediate layers, and the intermediate layers lower than the bottom layer. The deeper water will accumulate these solids because it does not mix with other layers and because of releases of solids from the bottom soil. The hypolimnion will therefore be considerably richer in nutrients (such as nitrogen and phosphorus) than the upper layers.

The organic content of the lower layers is also expected to be higher than the layers above, due to decomposition of inundated organic matter. Anaerobic conditions will lead to a buildup of gaseous hydrogen sulfide and will result in dissolution of iron and manganese from the reservoir bottom, as the soils in the reservoir area contain high levels of iron and

manganese. As a result, precipitation of phosphates and reduction of sulfur ions will take place.

## 2.2 Eutrophication

Phosphorus and nitrogen are nutrients essential for the growth of plankton. Upon filling of Pa Mong, the nutrient levels are expected to increase markedly as the result of decaying vegetation and releases from the inundated soils. Abundance and species diversity of phytoplankton will increase, with probable change in species of dominance from those currently present in the Mekong river. Algal blooms or eutrophication is expected to occur at least to moderate degrees as in most tropical lakes. The blooms will be limited to the upper, lighted zones above the thermocline and to the shallow areas near the shoreline, probably with blue green algae being the predominant species. In the latter case, the algal blooms will be attributable primarily to leaching of nutrients from the flooded soils during rainy seasons and to availability of nutrients in the inflowing water.

Algae are expected to promote considerable growth of zooplankton, and both algae and zooplankton will contribute substantially to increased yields of fisheries in the reservoir. However, the presence of algae can degrade water quality and dead algae can help deplete oxygen in the hypolimnion. Eutrophication is not expected to create any aesthetic problems in the reservoir.

## 2.3 Fisheries

With the formation of Pa Mong reservoir, new food sources will be available which are not significantly present in the Mekong river, including plankton, water plants, and benthic invertebrates. Although these conditions will favor relative increases in most fish species, there will be some species readjustment due to changes from riverine to lacrustrine conditions. These changes are expected to induce a reduction in species diversity of fish from that occurently present in the river. Experience at Nam Pong reservoir has indicated that about 60 - 70 per cent of the approximately 139 fish species in the Mekong river will survive and be colonized in Pa Mong reservoir. Carps and murrals are expected to be among the most abundant groups, while catfish may also be a significant contribution to the reservoir fisheries.

The morphometric index (reservoir area to depth ratio) and morpho-edephic index (ratio of total watershed area to reservoir volume), though useful in helping predict res rvoir fish yields in temperate zones, are found to have no significant relationship with the fish yields in tropical reservoirs. For projecting fish yields in Pa Mong reservoir, an approximate relationship between yields and average depths based on experience with reservoirs in Thailand (Bhumipol and Nam Pong) and in the Lao PDR (Nam Ngum) is used as the basis. In these three reservoirs the yields decrease with increasing water depth. Without

special management measures, the natural fish yields in Pa Mong reservoir during the nutrient-rich period (5 - 10 years after initial filling), expressed as kg/ha/year, are expected to be 45, 40, 35, and 30 for maximum pool levels of 230 m, 240 m, 250 m, and 260 m, respectively. The natural yield after the fishery has stabilized is anticipated to be about 20 kg/ha/year, the same for all maximum water levels. However, if the reservoir is properly managed, including stocking with suitable fish species, the fish yield can be expected to be maintained in the neighbourhood of 40 to 60 kg/ha/year.

The total annual fish yields for different maximum pool levels were calculated as shown in Table 3. Although fish yield per hectare decreases with increasing depth, the total annual yield will increase with increasing pool level. At elevation 250 m MSL, the annual yields for several years will be 13,030 tons and 37,250 tons for the non-stocked and stocked reservoir, respectively. After stabilization, the annual benefit of the stocked reservoir will be about five times that of the non-stocked reservoir.

The fish population is expected to be more abundant in the shallow, nearshore zones and in the upper layer of the open water than in the deeper parts of the reservoir. There will be some effects of drawdowns on fish production, which will be beneficial in some areas and adverse in others. These effects are very complex and difficult to be quantitatively predicted.

Sound management is essential for achieving and maintaining maximum yields of desirable fish species at Pa Mong. Clearing of vegetation, especially along the shoreline and also to provide cleared channels away from the shore to facilitate navigation and setting of nets and traps, should be beneficial to fishing and fish production. It can also help reduce the extent of thermal stratification, which helps create unfavorable fish habitats. The management programme should include control of water weeds from the early stages of fisheries development. Reservoir releases should be controlled such that drawdown is gradual and harmless to eggs and fry. Fish stocking should be considered, and the species to be stocked should be carefully selected. As noted in the discussion on fisheries, it may be advantageous to introduce new fish species.

## 2.4 Water weeds

The water hyacinth, Echhornia crassipes, can be expected to infest Pa Mong reservoir, and water lettuce, Pistia stratiotes, and water fern, Salvinia, can also present problems. Such infestations can induce such problems as (a) excessive loss of water by transpiration, (b) impairment of navigation, flood control efforts, and access to the shoreline, (c) creation of habitats for certain vectors of diseases; (d) deterioration of water quality and aesthetic values, (e) hazards to reservoir fisheries, and (f) interference with power generation.

Little information is available by which predictions can be made on the probable extent of water weeds at Pa Mong. As at most tropical reservoirs, these species come and go for reasons not well understood. Research to develop feasible methods of control, applicable to tropical reservoirs in the lower Mekong basin, is planned by the Mekong Committee.

## 2.5 Wildlife

As noted in the discussion on wildlife, the existing wildlife in the reservoir area and immediate vicinity will be mostly lost, but will be replaced by an extensive waterfowl population of considerable value.

## 2.6 Forests

As noted in the discussion on watershed management, the local forests in the inundated area, except for the trees logged before inundation, will be lost. Table 4 presents summarized information on the types of trees present and their amounts and value. However, this inundated vegetation will be a main source of increased nutrients for many decades, which will support not only a rich reservoir fishery but also will increase the nutrients available to downstream fisheries.

## 2.7 Disease vectors

As noted in the discussion on public health, the advent of the reservoir at Pa Mong and the associated irrigation system is not expected to create, per se, any new public health hazards in the reservoir vicinity (nor throughout the lower basin).

Some specific findings on communicable disease hazards at Nam Ngum reservoir, in the same vicinity (Ref. 4), which would have similar applicability at Pa Mong, are the following:

(a) Pulmonate snails such as Radix and Indoplanorbis are abundant, but there is little molluscan diversity in the reservoir. The Nam Ngum river below the dam was essentially devoid of molluscs probably because of the hydrogen sulfide contained in the discharged water.

(b) The reservoir environment is unsuited for snails of the family Hydrobiidae, one species of which transmits human schistosomiasis near the Democratic Kampuchea border, hence schistosomiasis should not be a problem. Two snails which transmit non-human schistosomes, which cause "swimmer's itch", are abundant in the reservoir.

(c) Paragonimiasis, the human lung fluke disease, is a problem in the Nam Ngum area, but this apparently is not derived from hosts in the reservoir.

(d) Bithynia snails, which transmit the human liver fluke, were not found in the reservoir, although the habitat

is suitable. Apparently the fish are not infected.

(e) Malaria is the most serious vector-borne disease of the Nam Ngum region. Falciparum malaria is epidemic. Despite fears that the Nam Ngum impoundment would result in an increase in malaria vectors, no such increase has been observed. The steep shore-lines are not favorable for formation of pools of stagnant water.

## 3. Effect immediately downstream

### 3.1 Turbulence and stage variations

Turbulence is expected to be very vigorous in the river stretch extending some 20 km below the dam, together with extreme variations in water depth. This factor alone will, for practical purposes, make this river stretch unfavorable for many fish and other wildlife and unfavorable for most other uses.

As noted in the discussion on power, the expected maximum river fluctuation in the proposed commissioning year, under the Stage One plan assuming two 600 MW generating units, is about 0.4 m/hour at the power plant, and some nine years later, with a total of eight generating units, would be about 0.8 m/hour. The maximum change in river stage in a day would be 0.9 m and 3.4 m respectively, with the time interval from minimum to maximum being about five hours. These fluctuations will pose problems to river bank stability and to navigation, but at some times of the year these effects may actually by less than without project conditions because of the flood control achieved by Pa Mong.

### 3.2 Water quality

#### 3.2.1 Temperature

According to the Stage One plans for operation of Pa Mong reservoir, water will be released from the reservoir at elevation 183 m MSL, hence will be drawn from the hypolimnion (for all pool levels). The temperatures of the releases will be close to those of the hypolimnion, i.e. 20° - 25°C, which differ only slightly from those of the inflows (21° - 29°C). No significant adverse effects are expected due to temperature.

#### 3.2.2 Dissolved oxygen

The reservoir releases are expected to be devoid of or very low in dissolved oxygen, but the high turbulence in the river stretch below the dam will tend to achieve rapid reoxygenation over the first 20 km. It is estimated it will take about 50 km for the dissolved oxygen to return to normal saturation levels. The depressed oxygen content will induce changes, usually adverse, to such aquatic communities as zooplankton, benthos, and fish, but the higher nutrient levels will be beneficial to aquatic

communities. Increases in levels of iron and manganese could have adverse effects but these are not expected to be significant.

Nitrogen supersaturation, which can cause gas bubble diseases in fish, is not anticipated to be a problem because the reservoir releases will be primarily through turbines, not over the spillway. Also, as already noted, vigorous turbulence is expected in the first 20 km below the reservoir.

### 3.3 Fisheries

Fisheries immediately downstream from the dam will be affected by the altered flow regime and quality of the reservoir releases. Fish production in the 20 km stretch below the dam will be drastically reduced, primarily because of turbulence, with some species being exterminated. Nevertheless, substantial numbers of fish will tend to accumulate immediately below the dam, and to protect these, especially for purposes of reproduction, this area should be closed to fishing.

After some 20 km distance, the river will gradually change to normal conditions. Beneficial conditions of the water include low turbidity which can increase photosynthetic activities, more uniform temperature and flow, and increased nutrient levels. However, the depressed oxygen content may induce shifts of species of fish towards those having lower dissolved oxygen thresholds.

## 4. Effects in fringe areas including drawdown zone

As has been experienced at tributary reservoirs like Nam Pong, communities will tend to become established not only near the damsite but elsewhere around the reservoir, and without strict enforcement there will be encroachment of communities into the drawdown zone by people interested in either fishing or in growing crops in this zone. While there is nothing new in this concept - the Thai/Lao peoples traditionally have lived along bodies of water - and no new types of problems will be created, nevertheless these will be new communities. These will pose management problems assuming it is desired to utilize the Pa Mong project for improving traditional deficiencies in community facilities in terms of modern concepts of minimum desirable standards.

### 4.1 Physical effects

#### 4.1.1 Change in reservoir water level

The total drawdown of the reservoir is expected to vary from 12 m to 18 m, depending on the selected maximum pool level, and to extend over a period of about eight months, from the end of October to the end of June (see discussion on power). The maximum monthly change would be 1.95, 2.36, 3.70, and 3.87 m for pool levels of 260, 250, 240, and 230 m MSL respectively, and the corresponding maximum monthly change during filling would be 4.44, 5.43, 5.48, and 5.04 m respectively. This range of

fluctuations is sufficient to cause some bank landslides and will require that navigation facilities be designed to accomodate these changes in levels.

4.1.2 Reservoir banks

The drawdown noted above, augmented by surface inflow during the rainy season, may make it difficult for vegetation to become established along the reservoir banks, leaving the banks bare and exposed to erosion from either rainfall or wave section. The exposed shoreline area at Pa Mong would be about 1,200 $km^2$ at maximum drawdown (for the reservoir with 250 m MSL level). Such exposed areas will also be unisightly and would impair the quality of recreational facilities.

4.2 Socio-economic problems

(a) Socio-economic competitions: The availability of an attractive new reservoir fishery will induce in-migration. If not controlled the numbers of fishermen will become excessive and per capita income levels from fishing can become inadequate. Also, local conflicts may result between natives and in-migrants.

(b) Temporary housing: Without strict controls and planning for alternatives, slum housing conditions will be created along the reservoir edge and drawdown zone, particularly for housing fishermen and their families.

(c) Sanitation and water pollution: Without proper planning and financing of community facilities (e.g. water supply, sewage disposal, solid waste management), severe public health hazards will result in the new communities due to poor sanitation. Aslo, the near-shore waters will become heavily polluted with serious adverse effects on fisheries, water supplies, and potentials for recreation, tourism, and aesthetics.

To prevent these problems from developing to serious levels, careful planning will be needed. Feasible technology for solving these problems already exists, hence no new research is necessary. It is necessary, however, to develop realistic concepts on desirable levels for sanitation, housing, etc., so that an improved type of community environment can be achieved within reasonable cost levels.

5. Summary

Building of Pa Mong dam will create a vast new reservoir or lake of great value for numerous beneficial uses including power, irrigation, fisheries, industrial development, public health, recreation, tourism, and other benefits. The new lacustrine ecosystem will eliminate the previous riverine ecosystem, and also drastically alter another 20 km of riverine ecology downstream, but with a great increase in net benefits.

Releases from the reservoir, primarily to meet power needs, will result in a drawdown zone ranging from 12 to 18 m (vertical depth) depending on the selected pool level, which will result in extensive exposed fringe areas. These will probably be mostly bare of vegetation and hence pose landslide hazards, impair aesthetic values important to recreation, and hamper navigation.

With respect to water quality, storage at Pa Mong should have no adverse effects, and the released water will be of about the same temperature as the river water and be considerably richer in nutrients. While the dissolved oxygen content will be low in the river stretch immediately below the dam, this stretch of some 20 km will be an unfavorable environment for most purposes due to extreme turbulence and rapid fluctuations in the river stage. Farther downstream the river conditions including water quality should be excellent for support of aquatic life, with the transition to a normal flow regime and dissolved oxygen saturation being achieved within the 50 km stretch below the dam.

Eutrophication is not expected to pose any significant problem either in the reservoir nor downstream. However, water weeds will likely be an intermittent and unpredictable problem in the reservoir. The ultimate solution is in development of control measures which are both effective and financially feasible.

With respect to fisheries, the reservoir will become a valuable source of fish, even without controlled management. With controlled management including stocking, the sustained yields can be very substantially increased. Downstream fish productivity, except in the immediate zone below the dam, should be enhanced by the discharge of nutrients from the hypolimnion.

While the existing wildlife in the reservoir area and immediate vicinity will be mostly lost, this represents only a small percentage of the total watershed area. Also, a new prolific wildlife will be generated, especially waterfowl, with greater value than for without project conditions.

Similarly, the forest reserves in the reservoir area will be lost, except for those trees logged before inundation; however these inundated trees will be a continuing source of nutrients for supporting fishlife both in the reservoir and downstream.

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TABLE 1

IMPORTANT FEATURES OF PA MONG RESERVOIR AT DIFFERENT POOL LEVELS

(After Reference 1)

| Feature | Pool Elevation above MSL (m) | | | |
|---|---|---|---|---|
| | 230 | 240 | 250 | 260 |
| Maximum depth of water, m | 74.6 | 84.6 | 94.6 | 104.6 |
| Surface area, $km^2$ | 1,620 | 2,800 | 3,722 | 4,600 |
| Storage volume, million $m^3$ | 32,400 | 66,000 | 98,300 | 140,000 |
| Estimated mean depth, m | 20.0 | 22.8 | 26.4 | 30.4 |
| Estimate annual drawdown, m | – | – | 14.0 | – |
| Area of drawdown zone, $km^2$ | – | – | 1,220 | – |
| Elev. of penstock outlet, m MSL | 183 | 183 | 183 | 183 |
| Water height above penstock, m | 47 | 57 | 67 | 77 |
| Mean annual inflow, million $m^3$ | 151,800 | 151,800 | 151,800 | 151,800 |
| Drainage area above dam, $km^2$ | 305,422 | 305,422 | 305,422 | 305,422 |
| Annual precipitation in drainage area, mm | 1,796 | 1,796 | 1,796 | 1,796 |

Note: Annual drawdowns and the drawdown zone areas for elevations other than 250 m MSL not estimated.

TABLE 2

PROJECTED WATER QUALITY FOR PA MONG RESERVOIR
(see Discussion on Water Quality)

| Constituent | Range | Average |
|---|---|---|
| Temperature, °C | 20.0 - 30.0 | 27.0 |
| pH | 7.40 - 8.2 | 7.55 |
| Conductivity, micromho | 120. -360. | 240. |
| Total Dissolved Solids, mg/l | 88. -210. | 140. |
| Hardness (Ca + Mg) | - | - |
| me/l | 0.90 - 3.40 | 1.50 |
| mg/l (as $CaCO_3$) | - | 75. |
| Calcium | - | - |
| me/l | - | 0.85 |
| mg/l | - | 17. |
| Magnesium | - | - |
| me/l | - | 0.65 |
| mg/l | - | 8.0 |
| Sodium (Na) | - | - |
| me/l | 0.03 - 0.80 | 0.60 |
| mg/l | - | 14.0 |
| Potasium (K) | - | - |
| me/l | 0.03 - 0.65 | 0.15 |
| mg/l | - | 6.0 |
| Bicarbonate ($HCO_3$) | - | - |
| me/l | 1.35 - 2.15 | 1.8 |
| mg/l | - | 110. |
| Chloride (Cl) | - | - |
| me/l | 0.12 - 0.80 | 0.25 |
| mg/l | - | 9.0 |
| Sulfate ($SO_4$) (by difference) | - | - |
| me/l | - | 0.2 |
| mg/l | - | 5.0 |
| Saturation Index (Langelier) | - | + 1.15 |

Notes: me/l = milliequivalents per liter

mg/l = milligrams per liter

TABLE 3

ESTIMATED ANNUAL FISH YIELDS AT PA MONG
FOR DIFFERENT POOL LEVELS

| Maximum Pool Level m MSL | Without Management | | | With Management |
|---|---|---|---|---|
| | High-Yield Period | | Stabilization Period | |
| | Fish Yield | | Fish Yield 1/ | Fish Yield 2/ tons/yr |
| | kg/ha/yr | tons/yr 3/ | tons/yr | |
| 230 | 45 | 7,290 | 3,240 | 8,100 |
| 240 | 40 | 11,560 | 5,780 | 14,450 |
| 250 | 35 | 13,030 | 7,450 | 18,630 |
| 260 | 30 | 13,800 | 9,200 | 23,000 |

Notes:

1/ On the basis of yield of 20 kg/ha/yr.

2/ On the basis of yield of 50 kg/ha/yr.

3/ Metric tons.

TABLE 4

FORESTRY SURVEY OF PA MONG RESERVOIR (1969)

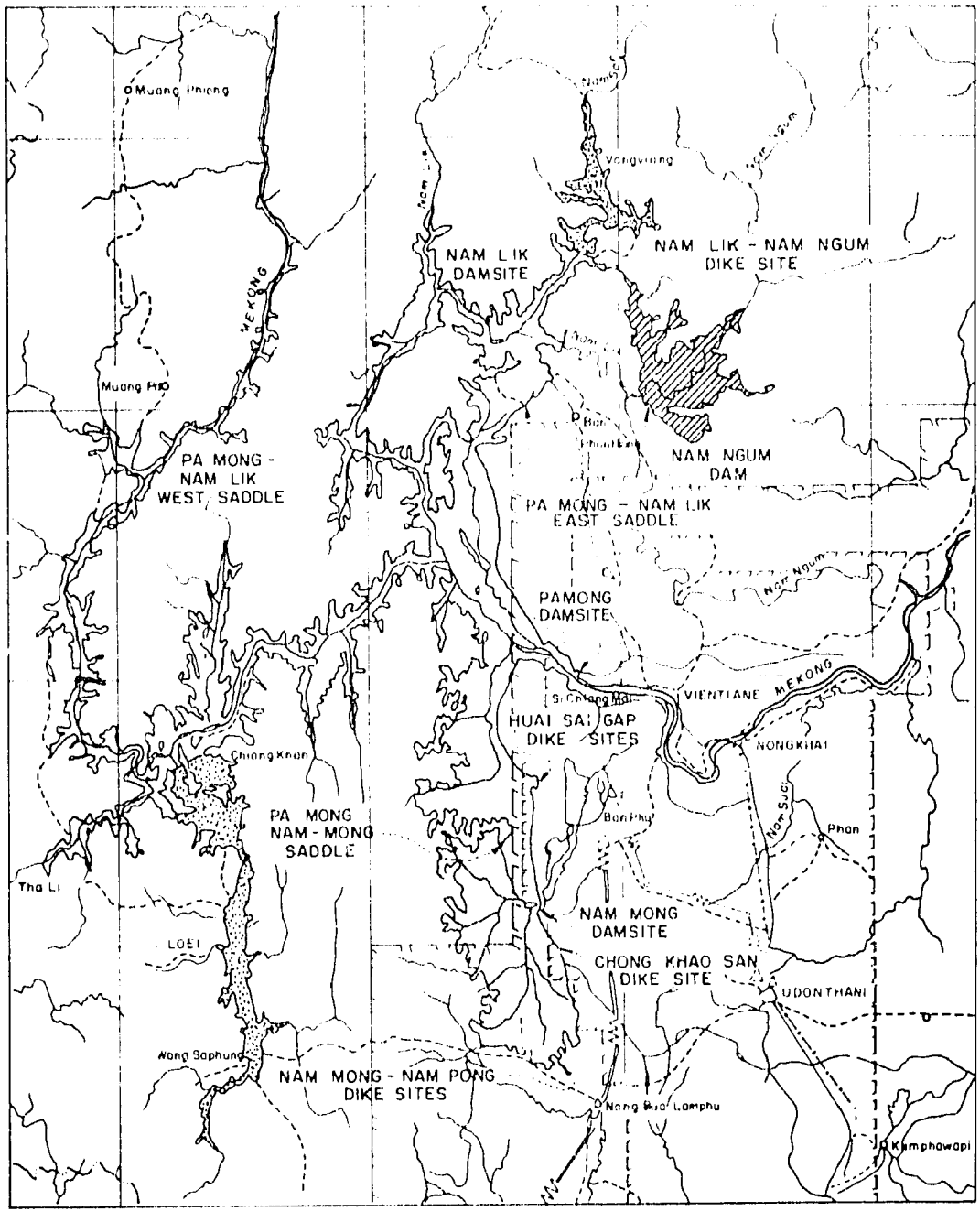
(From Reference 36)

(a) Type and Area of Inundated Forest

| Pool Elevation, m MSL | 250 | 240 | 210 |
|---|---|---|---|
| Type of Forest | Area, $km^2$ | Area, $km^2$ | Area, $km^2$ |
| Tropical evergreen | 286,645 | 199,096 | 33,999 |
| Mixed deciduous | 322,541 | 172,645 | 87,419 |
| Dry dipterocarps | 602,772 | 426,257 | 170,332 |
| Cultivated and old clearing area | 613,348 | 63,032 | 123,223 |
| Total | 1,823,276 | 861,030 | 414,973 |

(b) Amount and Estimated Value of Inundated Timber

| Pool Elevation, m MSL | 250 | | 240 | | 210 | |
|---|---|---|---|---|---|---|
| Type of Vegetation | Volume, $m^3$ | Value, $ | Volume, $m^3$ | Value, $ | Volume, $m^3$ | Value, $ |
| Growing stock diam. 30 cm | 7,303,545 | - | 4,799.735 | - | 1,520,069 | - |
| Over cut limit | 6,236,905 | - | 4,420,030 | - | 1,386,119 | - |
| Suitable for logging | 3,962,200 | 15,094,000 | 1.598,793 | 6,090,000 | 359,664 | 1,370,000 |
| For other purposes | 3,341,345 | 3,190,000 | 900,942 | 3,047,000 | 1,160,405 | 1,100,000 |




NOTE

PA MONG RESERVOIR AREA

AREAS WHICH MAY BE EXCLUDED BY PROTECTION SCHEMES

NAM NGUM RESERVOIR

FIGURE I

PA MONG RESERVOIR

( For 250 m. MSL High Pool Level )

SCALE 0 10 20 30 40 50 KM

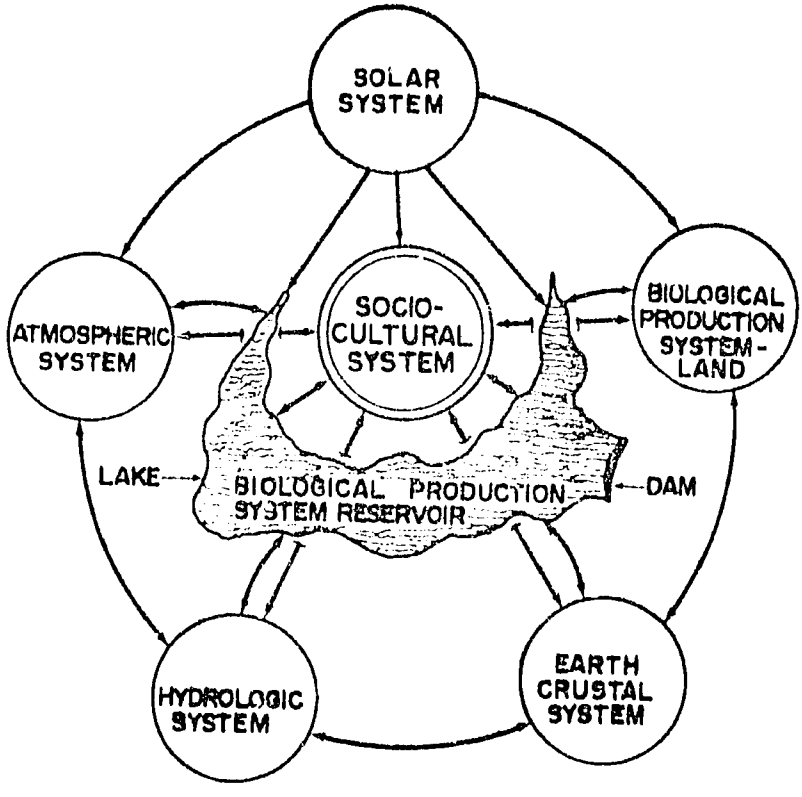



FIGURE 2

COMPONENTS OF A MAN-MADE LAKE ECOSYSTEM

( From Scope, Reference 2 )

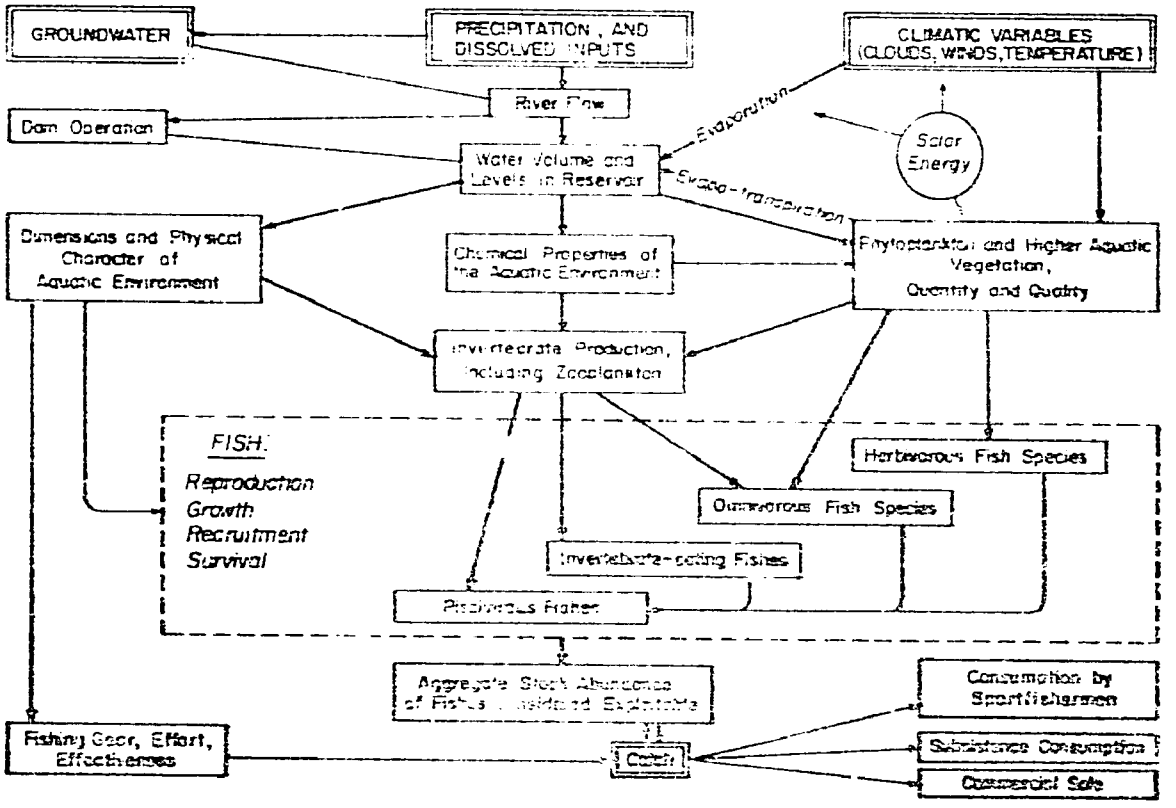



**FIGURE 3**

**SCHEMATIC ILLUSTRATION OF RESERVOIR FISH PRODUCTION AND HARVEST**

(Adapted from Ryder et al. 2)

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## RESETTLEMENT

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# PA MONG ENVIRONMENTAL ASSESSMENT

## RESETTLEMENT

### 1. Introduction

Because construction of Pa Mong will necessitate resettlement of several hundreds of thousands of people, and because the history of management of resettlement problems of a much smaller scale at existing tributary projects in northeast Thailand and Lao PDR has hardly been satisfactory, the resettlement issue is probably the most sensitive environmental impact issue involved in the entire project.

Major dam construction projects in the past in virtually all developing countries have provided only partial compensation to evacuees and almost invariably have resulted in much social injustice (Ref. 18, 19, 20, 21, 22, 25). Review of these situations indicates the primary reason for this injustice is the complexity of the problem and lack of attention to it, stemming largely from the practice of not including in the project budget provision for reestablishing the evacuees as well as for compensating them for their flooded properties. The cost of reestablishment is every bit as real as compensating for flooded properties but responsibility for reestablishment has often been left to the governmental public welfare agencies who, without any special budget for the purpose, can hardly be expected to do an effective job.

The Mekong Committee, in a statement of principles and policies for resettlement formulated in 1968 (Ref.1), concluded the only fair approach to resettlement is to include reestablishment as well as property compensation as an integral part of the project cost, and that recognition of this basic concept is essential for proceeding with any of the major projects envisioned by the Committee and especially for the proposed first major international mainstream project at Pa Mong.

### 2. Approach and methodology

To produce the necessary information on the existing status of the population to be resettled and to produce guidelines on how to plan the major resettlement program for Pa Mong, so that virtually all the resettled population will in fact be "at least as well off as before" and most of them significantly better off, the Mekong Committee since 1968 has sponsored a progressive series of studies. These have been concerned first with evaluating resettlement experiences at existing tributary projects in northeast Thailand and in the Lao PDR (Ref. 2-7). One of these, for

the Lam Dom Noi dam and reservoir project in northeast Thailand, where construction was completed in 1970, and which involved resettlement of 1,365 families, represented an excellent opportunity for study because it was possible to assess the socio-economic conditions both before impoundment and after resettlement (Ref. 6, 7). A summary of these various preliminary studies from 1968-73 and of related studies is given in Table 1.

Based on the accumulated experience noted above, in 1973 the Mekong Committee assessed its needs for further resettlement planning which led to establishment of the current program which includes two major study projects initiated in 1974. These are (a) the Pa Mong resettlement costing project (PMRCP), dealing specifically with ascertaining the proper costs associated with resettlement for Pa Mong (Ref. 8 and 9), and (b) a major pilot project effort, termed the "Resettlement study and planning project" (RSPP), with the object of developing guidelines for basinwide application including Pa Mong (Ref. 13, 14). Also, to assist both the projects noted above, a review was made of the methodology for estimating resettlement costs as a part of basinwide economic analyses made for the Mekong Committee by the Netherlands Economic Institute (Ref. 33). Most recently, as a part of the RSPP project, a reevaluation was made of the resettlement problems at Nam Ngum in the Lao PDR (Ref. 17). This lead to formulation in early 1975 of a new Nam Ngum project (Ref. 18), with the objective of developing definite plans for resolving the remaining problems of the Nam Ngum resettlers and thus demonstrating the interest and ability of the riparian governments, working with the assistance of the Mekong Committee, in the management of resettlement problems.

A brief review of the Lam Dom Noi study and of the current projects, for the purpose of illustrating the approach, methodology, and results, is presented in the following discussion.

## 2.1 Lam Dom Noi (1970-72)

Data for both pre-impoundment and post-impoundment conditions were collected by mean of household surveys using structured questionnaires. The post-impoundment survey was limited to households residing in the first resettlement area which had been occupied by most resettled households for about 1.5 years (the second resettlement area had only a few families at the time of the study). The sample included 25 per cent of all households, i.e., 174 of 706 households, using local school teachers as the enumerators. The subjects covered in the questionnaire included demographic characteristics, reservoir area background information, resettlement costs including relocation and compensation, land uses including farm innovations, crop production, livestock, fishery, other agricultural activities, non-farming activities, wage and labour factors, marketing debt situation, living standards, geographical mobility, and attitudes and opinions of the population.

The main conclusions of the post-impoundment study are summarized as follows:

(a) The households that moved to the resettlement were predominantly the least affuent ones; also smaller households showed a greater tendency to move to the resettlement than large households. Moreover, larger families showed a high tendency to break down into smaller units. Many households, through lack of funds or lack of manpower, were unable to clear their land to the extent warranted.

(b) Technical know-how to grow upland crops on the local soils was generally lacking. Very few of the resettled households could claim sufficient income from farming on the allocated 15 rai/family, hence most families believed the 15 rai allocation to be inadequate, and most were dependent on other sources of income. Households that could afford it have tended to acquire paddy land outside the resettlement area. Per capita income in the resettlement area was found to be low compared to that for northeast Thailand as a whole, or to that for the reservoir population prior to their evacuation.

(c) At least one-third and perhaps as many as one-half of all household heads felt dissatisfied with the resettlement. No relationship was found between opinion on compensation and amount actually received, which may indicate that opinion on compensation as such is subordinate to opinion on the overall issue of relocation and resettlement. Small households tend to be more positive in their evaluation of the resettlement than large households, while "have-nots" seem to be the ones least compelled to evaluate the resettlement negatively.

The main recommendations developed by the Lam Dom Noi studies were:

(a) Assistance should be given where needed in achieving clearing of the allocated land, either by pre-clearing on by provision of soft loans restricted to this purpose. Also, agricultural extension is most important, including the use of demonstration plots to be in operation when the resettlers arrive, together with credit and marketing facilities. Also, assistance should be available for helping families earn extra income from non-farming activities like charcoal production and local fisheries.

(b) Socio-economic surveys are needed prior to impoundment to separate families likely to succeed and not succeed when moved to resettlement areas featuring upland farming. In relation to this, an information campaign is needed to inform all household heads, well before impoundment starts, about the resettlement scheme and other alternatives.

(c) Alternatives to upland resettlement, including migration to urban areas, establishment of reservoir fisheries, and resettlement in paddy land elsewhere, need to be included in the overall resettlement plan.

(d) The overwhelming majority of the families preferred the "line system" rather than the "village system" for the physical layout of the resettlement. Proximity to farmlot was almost invariably felt to be more important than closeness to neighbours. If physical conditions allow, the location of all resettled families along the reservoir margin, which makes the reservoir accessible to all, should be considered.

## 2.2 Resettlement study and planning project (RSPP) (1974-76)

This project has attempted to analyze the entire spectrum of resettlement problems and how to plan and implement effective solutions for projects throughout the lower basin, with the focus on the traditional pattern of resettlement, i.e., moving to new agricultural lands in the uplands, as near as possible to the inundated area. Particular attention is being given to assisting the resettler to invest his compensation money to enhance his chosen new occupational situation and to furnishing essential services (infra-structure and socio-economic) so that the resettler can realistically be expected to solve his adjustment problems.

The two main objectives of the RSPP are (a) to establish sound methodology for planning resettlement based on analysis of physical and socio-economic opportunities and constraints, and development of an actual plan for one settlement project to illustrate the use of applicable criteria and methods, and (b) to plan and implement a pilot project within an existing resettlement scheme, to demonstrate how to increase farm productivity and thus the standard of living of the resettlers. The Huey Luang resettlement in northeast Thailand, scheduled to receive its first resettlers in 1976, was selected for the first objective, representing a site where a dam was in process of completion and preparation of a resettlement scheme already underway. The Nam Pong resettlement in northeast Thailand, activated in 1965, was chosen for the second objective, representing a resettlement situation with enough elapsed time to indicate the problem areas difficult to solve.

### 2.2.1 Huey Luang resettlement

The report of this study first reviews (a) the processes which have been involved in upland resettlement in Thailand, including compensation and notification, relocation and rehabilitation (site selection, site planning and preparation, and administration and development), with highlighting of the major constraints which have confronted the planners, (b) an alternative policy for resettlement, aimed at overcoming the obstacles noted above, including recommended communication between planners and evacuees, handling of compensations and organization of the resettlement, (c) the basic data requirements for resettlement planning, including number of reservoir evacuees to be resettled, their demographic and socio-economic characteristics, and the characteristics of the resettlement area (including suitability of the soil for farming, availability of water, and present habitation in the area), and (d) steps involved in planning the needed socio-economic infrastructure. This review includes illustration of a typical layout of a resettlement scheme in Thailand (at Lam Dom Noi) (Figure 1 of Reference 32-I), illustration of a typical layout of a resettlement village (Figure 2 of Reference 32-I), and illustration of the various activities that need to be carried out in the planning of a resettlement scheme, arranged in the form of a critical path or PERT chart (Figure 1).

Following the above preliminary steps plans were then developed for a pilot resettlement scheme for the Huey Luang situation as a practical test case. The Huey Luang reservoir capacity is approximately 113 million $m^3$, with a surface area of 31 $km^2$, with facilities for irrigation of 60,000 rai. The cultivated inundated area is approximately 19,000 rai, with some 600 households (average of 5.5 persons/family) being resettled. The Thai Department of Public Welfare has developed plans for a resettlement project in the Huey Luang area (about 30 km west of Udorn Thani) for handling some 1,800 households including the 600 noted above, 400 squatter households already in the area, and 800 additional households from elsewhere. The Department agreed that a part of the overall resettlement plan, for handling the 600 families inundated at Huey Luang, could be the pilot demonstration project sponsored by the Mekong Committee (Figure 2). The size of the pilot area is approximately 25 $km^2$ (15,625 rai), of which some 28 per cent was already under cultivation (20 per cent with upland crops and 8 per cent paddy).

The planning of the pilot project involved (a) basic data collection (topography, soils and vegetation, climate hydrology, irrigation potentials, present habitation), (b) development of the agricultural farm plan, with provision for irrigation (from 1.75 to 4 rai) out of a total land allotment between 15.5 and 18.5 rai, in order to reach a target income between 10,000 and 15,000 baht/year from crop production only, including three alternative farm plans

(See Tables 1-12 of Reference 32-I), (c) preparation of the physical plan, based on the "gathered settlement" concept with a group of five villages served by a common service center (Figure 3), including detailed layouts for each of the five villages (See Figure 4 for a typical layout, for Village 1), for the irrigation systems (See Figure 5 for layout for Village 1), for the service center (Figure 6) (including administrative offices, store, health facilities, workshop, agricultural input storage, demonstration farm building, community centre, educational facilities, and staff residences), and for the road network, and (d) a tentative budget for the pilot project.

The use of three alternative farm plans was decided upon to suit the variety of conditions encountered particularly soil fertility and types of crops which can be grown. The land areas and expected incomes for the three alternative farm plans are as follows:

| Farm Plan | Land Area (Rai) | | | | Net Income (Baht) | Income per Man-Day (Baht) |
|---|---|---|---|---|---|---|
| | Total | Home | Irrigated | Rainfed | | |
| I | 15.5 | 0.75 | 1.75 | 13 | 14,000 | 34 |
| II | 17.5 | 0.50 | 4.00 | 13 | 12,440 | 27 |
| III | 18.5 | 0.75 | 1.75 | 16 | 11,000 | 23 |

Farm plan I includes cultivation of mulberry (a relatively profitable crop, when applicable) in its rainfed area, but the others are assumed not suited for mulberry. For all farm plans all labour can be furnished by the farm family itself. The net income levels shown in the table represent agriculture crops only, hence would be increased by contributions from other sources of revenue including livestock.

The proposed service centre would accommodate all five villages (600 homes) plus 90 homes located at the centre plus another 400 homes from existing villages now lacking in community health and other services, and would be implemented in stages to match increasing income levels.

The proposed budget includes approximately ฿ 4.84 million for the village layout (roads, bush clearing, buildings at village centre), ฿ 5.75 million for the group service centre, and ฿ 18.24 million for the water supply system. The proposed initial first stage investment would be ฿ 15 million, with ฿ 3.32 million for the second stage. The investment per household is approximately 30,400 baht. Assuming a 20-year

project life, with two years for start-up, the internal rate of return would be between 22 and 26 per cent (for a higher water supply cost alternative the rate of return would be between 9 and 12 per cent). By comparison for the Nam Pong resettlement (for which comparable data were available), the household investment costs averaged 33,000 baht, with income from crop production alone of only 3,275 baht. This comparison indicates that resettlement schemes can be successful, not only in avoiding having the resettlers become worse off, but in bettering their situation.

2.2.2 Nam Pong project

The planning of the RSPP project was based on the assumption that resettlement is to be accomplished by moving the families from the lower rice-growing areas to be flooded to upland areas, usually in the vicinity of the reservoir, where the lands are usually characterized by poor soils and inadequate water resources and are suitable only for cultivation of upland crops. The Nam Pong resettlement area selected for this study is shown in Figure 7. At this project each resettled family received 15 rai (2.4 ha) of land, divided into a 2 rai homelot and a 13 rai farmlot. The total area of the Nam Pong resettlement project is more than 400,000 rai, planned to accommodate 4,000 families in two sites, the main Nam Pong site (3,165 families, in 58 villages) plus the Non Song subsite (835 families). The main site includes a pump irrigation system with capacity for year-around irrigation of about 1,000 rai, i.e., the homelots of some 500 farm households in some 14 villages.

Because it was felt it would not be possible to attain an adequate farm income from rainfed agriculture from 15 rai only, the villages with access to irrigation water were selected for the RSPP pilot project, with major emphasis on promotion of irrigated agriculture to increase farm income. During the first project year the activities were limited to 7 villages (195 households), then extended to 14 villages (477 households) in the second year. The overall project included two socio-economic bench mark surveys of the target population conducted in June 1974 and November 1975, not only to help plan the course of action of the project but to permit a preliminary estimate of the project impact.

The study included several distinct tasks, namely, development of the agricultural farm plan, activities for improving the irrigation system, description of the agricultural cooperative established during the first year of the project and its relationship to the service centre, a presentation of the major findings of the bench mark surveys, and a discussion of the major achievements and problems of the project and need for continuation of activities. A summary of the major findings and conclusions is as follows:

(a) Agricultural planning: Agricultural planning was one of the first steps in the project, beginning with a review of the existing situation. The most important crop is kenaf, which is grown on almost 90 per cent of the cultivated rainfed area. Only 18 per cent of the irrigable area had been utilized mainly due to lack of reliability in water supply. The average net income from crop production was very low, about 2,700 baht/year due mainly to poor soils and insufficient knowledge of how to grow upland crops including use of modern farm inputs (chemical fertilizers and insecticides). The agricultural plan which was adopted was based on four main objectives, namely maximum utilization of irrigated area, diversification in rainfed crops, utilization of farm inputs, and soil conservation. For purposes of illustration, details of the selected farm plan are given in Table 2.

(b) Irrigation system improvements: The existing irrigation system included pumps delivering water from the Nam Pong river to reservoirs from which water flows by gravity to the homelots in the 14 villages (Figure 8). The activities of the project included replacing one of the river pumps which had broken down, provision of standby diesel engines in event of additional breakdowns, appointment of a pump supervisor to provide continuing operation and maintenance, and improvement of irrigation of the homelots (use of distribution piping and hoses to eliminate use of buckets).

(c) Multi-purpose service centre and agricultural cooperative: The project activities included strengthening of institutional support including agricultural extension services for training in farming technology, assistance in obtaining farm inputs and in selling of surplus crops, and assistance in obtaining credit for farm capital improvements. These services and related services in education, health, recreation, and cultural activities, were made available through a multi-purpose service centre suited to serving 500 households completed in June 1974 (Figure 4 of Reference 32-II shows a drawing of the centre). The agricultural extension services utilized the concept of the "demonstration farmer", one selected from each village, so that the new practices introduced on his farmlot could be copied by other villagers. The centre included a cooperative store stocking a variety of seeds, fertilizers, insecticides and pesticides, and tools, together with commonly needed household items (to encourage use of the store).

(d) Agricultural cooperative: The Ubolratana dam settlement agricultural cooperative was formally established in December 1974. The membership by the end of 1975 included 181 farm households from the 14 villages of the PSPF project. The main functions of the cooperative are to supply credit, supply farm inputs, and to arrange for collective marketing of farm produce. Following establishment of the cooperative, responsibility for farm inputs and agricultural credit was transferred to the cooperative from the service centre.

(e) Summary and conclusions: The two-year period of the project limited the project's role to initiation of the desired new pattern of agricultural practices, as only the first step, with continuation of the project to be carried out by the Thai Department of Public Welfare. Hence it is not possible yet to make more than a preliminary assessment of the meaningfulness of the project. For example, cooperative schemes in Thailand have generally met with the little success, and the future of the cooperative agency at Nam Pong will depend on its success in being of real service to the farmers.

The data thus far available indicate encouraging results in promotion of irrigated agriculture. During the first year of the project the average cultivated area of irrigated crops doubled (from 0.35 to 0.7 rai), the number of cultivators increased from 50 to more than 80 per cent of all farmers, the yields of irrigated crops substantially increased, and the average gross value of irrigated crops almost tripled. For the households in the 7 villages included from the beginning of the project, the bench mark surveys indicated an increase in average gross total income of 4,500 baht in a period of one year (from 10,000 to 14,500 baht), including an increase in average gross income from crop production of 3,000 baht (from 4,200 to 7,200 baht). Further improvements (not yet measured) were observed during the second year.

The increases noted above were due both to expansion of the cultivated area and increase in farm productivity, primarily due to better farm management (better cropping techniques and improvement of irrigation methods), all improvements achievable by the farmer through increase in labour input. There was little improvement in farm inputs nor in soil conservation, probably because of financing requirements, but both are expected to be realized in time with the availability of short-term credit using the crops as collateral. The loans taken out by the farmers

have tended to be used for capital improvement (land and livestock), indicating the high value the Thai farmer attaches to land ownership and self-sufficiency, with preference to expansion of land area as the means for increasing production rather than more intensive cultivation of the land.

2.3 Economic planning/estimation of resettlement costs (1975)

As a complementary study, to help guide both the PMRCP and the RSPP projects, a review was made on methodology for estimating resettlement and other non-construction costs involved in reservoir projects, as part of basinwide economic studies completed in 1975 for the Mekong Committee by the Netherlands Economic Institute (Ref. 33). This study differs from the PMRCP and RSPP studies in being purely methodological in nature, and it does not restrict itself to resettlement only but tries to take into account all non-construction costs in water resource control projects.

The results of the study may be summarized as follows:

(a) Financial costs: The conventional approach to estimating non-construction costs is a financial one, based essentially on use of the "right-of-way" concept, i.e., the project must buy the needed land at fair market prices, with the selling price presumably including both the value of the land and the cost of moving and reestablishing in the new property. While this method has been useful in advanced market economics, it is difficult to apply even in developed countries, mainly because of the difference in market interest rates and the discount rate which should properly be used for appraising public sector projects, the differences between market prices and opportunity costs, the fact that the capitalized value of the inundated land involves a labour component, and the problem of flooding certain infrastructure such as highways serving not only for local transport but for regional linkages. Application of the right-of-way approach is even more difficult to apply in the developing countries because of the greater price distortions making it more difficult to use financial costs as proxies for economic costs, because the real estate markets are usually very fragmented, especially for farming land, and because real estate prices in developing countries are not based only on the capitalized income stream to be derived from use of the land.

(b) Economic costs: A preferable approach is based on identification of potential economic cost items, namely (a) the capitalised value of production lost as a result of impoundment, including both permanent

losses in the inundated area and temporary losses while starting up in the new area, (b) replacement value of immovable wealth other than the land and other production means, (c) replacement value of transport routes through the flooded area which will need to be relocated, (d) costs for moving people and movable objects to the place of new settlement, (e) cost of organizing and administrating the evacuation including costs for surveys, and (f) the psychological costs stemming from being uprooted and moved. Methods for measuring these costs are described including methods applicable to agricultural production, to manufacturing, and to services including crafts and trades, and including methods for estimating the replacement value of immovable wealth, roads/infrastructure, moving of people and their belongings, overhead on administrative costs, and psychological costs (e.g., a "bonus" to overcome apprehensions about moving).

(c) Social costs: If the resettlers are to be at least as well off as before, allowances must also be made, in overall project analysis, for such items as living costs to make up for the difference in actual income and target income until the latter is achieved. Resettlement in vacant rural areas will also involve costs for the capitalised value of the present income from the forest (forest products, game, erosion control , etc., including both present value and potential increased future value for a reasonable period of years), and the cost for management of squatters already living on the "vacant" land. For resettlement on the reservoir edges, social costs will include investment costs for adjusting to the new types of occupations (fishing and drawdown agriculture). Social costs for resettlement in urban areas will be the costs involved in creating the necessary number of additional jobs in the urban environment.

(d) The project analysis should include consideration of all of the three categories of costs noted above, financial, economic, and social. However, social cost considerations involve policies on income distribution and value judgements on the relative values of increased income for different income classes. Hence to the extent that social costs exceed economic costs, these should not be treated, in the economic appraisal, as part of the project costs.

(e) In summary, the obligation to a resettled family is to enable the household to maintain, after inundation, the same level of living it had before. Hence, apart from a transitory period, no compensation needs to be given to households which are resettled in a resettlement area where they will have the same

income and level of amenities as before. For those buying privately owned land, the compensation price will be that needed to achieve an equivalent situation. Examples are given also for methods for estimating reasonable compensation payments for families to be relocated in the urban sector.

## 2.4 Nam Ngum resettlement project (1974-76)

As an additional opportunity for "proving out" the new resettlement concepts being developed, in preparation for undertaking a massive resettlement program such as will be required for Pa Mong, the Mekong Committee early in 1975 initiated an additional project, the Nam Ngum resettlement project (Ref. 17). This is intended to serve not only as a meaningful demonstration in an existing resettlement area, but also to assist the Government of the Lao PDR to correct a bad resettlement situation which by its existence has tended to cast doubts on the resettlement capabilities in the lower basin.

The construction of the Nam Ngum dam and reservoir, completed in 1971, necessitated the evacuation of 579 households, and although some resettlement measures were implemented, most of these families have not since been able to make an adequate living. A socio-economic survey conducted in 1974, and a preliminary land survey completed in January 1975, furnished the necessary basic information for formulating a competent resettlement plan (Ref. 17). The resettlement plan includes provisions for reclaiming forest areas for creation of new agricultural lands, to be used both for paddy and other crops, for small scale water control projects, for land distribution, and provision of physical and socio-economic infrastructure to bring the existing facilities up to the desired minimum levels. The total project would cost $1.17 million and require two years. In March 1975 a detailed preliminary plan was prepared (Ref. 27) which describes the engineering and agricultural aspects of the project including (a) description of the area involved (about 1,300 ha) and its existing villages and infrastructure, (b) description of the soils and agronomic aspects, and (c) plans for implementing cadastral surveys on land ownership, for land clearing and levelling, for needed new infrastructure, and for irrigation and drainage.

## 2.5 Pa Mong resettlement costing project

The Pa Mong resettlement costing project (PMRCP) is designed to set a true and fair value for the amount to include in the Pa Mong project budget for both property compensation and reestablishment costs. This includes a variety of feasible reestablishment alternatives, so the evacuees will have a reasonable number of choices in selecting their new home locations and occupations. These choices include a variety of alternatives, in addition to moving to

resettlement in vacant rural uplands, such as use of the reservoir fringe areas, reservoir fisheries, purchase of privately owned land, cattle raising, and urban employment.

At the time of preparation of this discussion (July 1976), the final PMRCP report was not yet available. Thus, the detailed data reported below, taken from the latest available report (Ref. 34), are subject to modification; but any changes are not expected to alter the relativeness or order of magnitude of numbers.

### 2.5.1 Magnitude of problem

The above referenced report assumes a timetable such that Pa Mong would be closed by 1990, and for a high pool level of 250 m MSL with no protection scheme, estimates the population to be inundated/resettled at the time to be 462,150, comprised as follows:

| Sector | Thailand | Lao PDR | Total |
|---|---|---|---|
| Rural | 289,856 (63%) | 88,237 (19%) | 378,093 (82%) |
| Urban | 61,789 (13%) | 22,270 ( 5%) | 84,059 (18%) |
| Total | 351,645 (76%) | 110,507 (24%) | 462,152 (100%) |

The land areas to be flooded, and the present uses of these lands, are as follows:

| Use | Thailand (Rai) | Lao PDR (Rai) | Total (Rai) |
|---|---|---|---|
| Paddy | 357,652 (32%) | 109,280 (10%) | 466,932 (42%) |
| Upland | 525,868 (46%) | 68,846 ( 6%) | 594,714 (52%) |
| Residences | 59,345 ( 5%) | 12,471 ( 1%) | 71,816 ( 6%) |
| Total | 942,865 (83%) | 190,597 (17%) | 1,133,462 (100%) |

In making the land use projections it was assumed land use ratios will continue as shown above, with the total land use increasing at the expense of the remaining forest up to a limit where only 20 per cent of the area is forested. Hence clearing of forests would cease about 1985 on the Thai side but would continue beyond 2000 in the Lao PDR.

### 2.5.2 Estimates of property damage

Assuming the above conditions, for the 250 m/no protection alternative, the value of the private property to be flooded is estimated to total $113,047,362 and of the public property to be flooded at $25,852,797. These values would be modified if the dam closure were to occur before or after 1990, as follows:

| Year of Closure | Population | Used Land Area (Rai) | Private Property, $ | Public Property, $ |
|---|---|---|---|---|
| 1985 | 330,093 | 1,106,528 | 93,829,308 | 25,852,797 |
| 1990 | 462,152 | 1,133,462 | 113,047,362 | 25,852,797 |
| 1995 | 544,204 | 1,164,977 | 134,526,350 | 25,852,797 |
| 2000 | 637,344 | 1,201,869 | 158,266,300 | 25,852,797 |

### 2.5.3 Protection alternatives

The total population and used land areas to be inundated would, of course, depend both on the selected high pool level and degree of protective works used. Eight alternative schemes were considered, as follows:

| Alternative No. | Description | Total Population | Total Used Land Areas, Rai |
|---|---|---|---|
| (1) | 260 m, no protection | 530,713 | 1,367,611 |
| (2) | 250 m, no protection (the "base alternative" scheme) | 452,152 | 1,133,462 |
| (3) | 250 m, with Loei valley and Vang Vieng valley protection | 405,037 | 1,077,592 |
| (4) | 250 m, with Loei valley, Nam Lik valley, and Nam Mong protection (minimum 250 m) | 264,437 | 592,316 |
| (5) | 240 m, no protection | 379,541 | 890,313 |
| (6) | 240 m, with Loei city, Nam Lik valley, and Nam Mong protection (minimum 240 m) | 222,543 | 501,175 |
| (7) | 230 m, no protection | 263,711 | 693,244 |
| (8) | 230 m, with Nam Lik and Nam Mong protection | 163,983 | 403,294 |

Table 5 of the PHRCP report shows the estimated values of the private and public property inundated for each of the above alternatives, including the 250 m/no protection "base alternative" scheme.

### 2.5.4 Resettlement alternatives

The resettlement programme assumes that evacuees will be able to select from among several resettlement alternatives, including relocation on or close to the reservoir margin, relocation on a planned land settlement, relocation in urban areas, or self managed settlement in the private land market. The study concludes that self managed resettlement in the private land market is both the most preferred, most successful, and least expensive form of resettlement.

Table 3 indicates the probable distribution of population among these major resettlement alternatives for a 1990 dam closure. This is considered to be not only the least cost programme but to represent the most probable distribution of population. The estimate of the number of evacuees who can be resettled on the reservoir margin assumes no expensive development programmes. The number of evacuees to be located or planned land settlements is sharply limited in Thailand by the absence of suitable land, but in the Lao PDR a large portion of evacuees may select this alternative. Most evacuees from urban areas within the reservoir will wish to locate in other urban areas.

### 2.5.5 Total resettlement costs

The various types of all cost components included in resettlement costs, including and in addition to flooded properly values, are delineated as follows:

(a) Compensation costs: Costs for land and other lost factors of production.

(b) Communications/placement costs: Costs for a programme to provide information on resettlement alternatives to evacuees, respond to their preferences, and facilitate their successful placement in the selected alternatives.

(c) Dislocation allowance: Compensation for material pecuniary and psychological losses which cannot be covered in compensation costs.

(d) Moving allowance: Actual cost of moving evacuees to resettlement destinations.

(e) Early moving programme: Cost of moving people out of the reservoir at a regular or optimal rate, spaced over the eight years allowed for dam construction.

(f) Land development costs: Costs involved in establishing land settlement areas in the Lao PDR, plus an allowance for costs for minimal land development along the reservoir margin, namely basic access roads and other limited development (It is assumed that evacuee compensation will be used to meet most new land development expenses).

(g) Social overhead: Capital costs of reestablishing vats, schools, health care facilities, police protection facilities, and other essential government service facilities.

(h) Title verification: Costs for programme of measures for protecting evacuees from fraud or damaging improvidence in the process of resettlement.

(i) Downtime allowance: Support of the evacuees in their new locations until they can reestablish their former income level.

(j) Administration: Actual cost of administrative services for implementing the programme, exclusive of personnel costs included in the categories noted above.

(k) Replacement roads and towns: Costs for reconnecting minor roads providing access to new communities, and for establishing replacement towns for those flooded by the reservoir.

A summary of the above components of resettlement costs and of total resettlement costs, for the eight alternative schemes considered, is shown in Table 4. A breakdown of the compensation costs, between farmland, urban land, perrenial tree crops, private property, and public property, is given in Table 5.

The total resettlement costs for the base alternative scheme (250 m/no protection), assuming closure at various times, are summarized as follows:

| Year of Closure | Compensation Costs, $ | Other Costs, $ | Total Resettlement Costs, $ |
|---|---|---|---|
| 1985 | 368,535,000 | 189,373,000 | 557,908,000 |
| 1990 | 400,582,000 | 225,444,000 | 626,026,000 |
| 1995 | 436,634,000 | 266,023,000 | 702,657,000 |
| 2000 | 472,686,000 | 311,112,000 | 783,798,000 |

2.5.6 Summary and conclusions

Costs of resettlement are estimated for a variety of alternative schemes, assuming dam closure at 1985, 1990, 1995, and 2000. The "base alternative" scheme is taken to be 250 m high pool level with dam closure in 1990.

Assuming 250 m/no protection and a 1990 closure, the total resettlement costs, including both compensation and rehabilitation costs, will be $626,026,000 corresponding to a flooded land use area of 1,133,462 rai and a population to be resettled of 462,152. This is equivalent to a unit total resettlement cost of $1,355 (1975 dollar values) per person.

It is assumed, of the total population to be resettled, that (a) planned upland settlements can accommodate only 51,714 (11 per cent) and the reservoir margin only 56,523 (12 per cent), (b) the bulk of the population, or 273,094 (59 per cent) will seek self settlement by purchasing agricultural lands in other parts of the country, and (c) the portion of the population to be resettled as urbanities, or 80,821 (say 18 per cent), would be essentially limited to those already living in the urban sector in the inundated area. This is stated to be not only the most economical plan but that most likely to be preferred by the resettlers.

3. Anticipated problems

The statement of principles and policies for resettlement formulated by the Mekong Committee in 1968 (Ref.1) sets an ideal, and the argument can be made that it is not within the powers of the Mekong Committee to implement these concepts because authority to do rests with the riparian governments. However, these principles and policies certainly represent the

**desirable** goal, and the continuing program of work spon-sored by the Committee is aimed at bringing about a gradual lution to these many problems including improvement of the administrative mechanics of the local governmental agencies who must carry out the schemes. It is believed that several key steps will in effect make it possible to develop a com-petent resettlement plan for Pa Mong, namely (1) recognition by the Committee that the costs of reestablishment as well as compensation for flooded properties is an integral part of the project budget, (2) determining the amount of a fair allowance to cover these costs, and (3) making available to the resettler a variety of alternative choices for his new career including urban employment. The very key factor is the decision to furnish a reasonably adequate amount of money, at the outset, to cover all real components of resettle-ment costs. It is realistic to expect it is possible to solve all other problems if the money is there.

Assuming the proper amount of money is to be available, it can be argued that much of this will be wasted unless the mechanics for managing resettlement can be developed to the extent they may be applied with confidence. In this sense the resettlement planning studies sponsored by the Committee are admittedly in their early evolving stages, as is the case in the development of any new approach to solving diffi-cult socio-economic problems. The current programs should lead to continuing and more advanced programs (as has been evidenced since the statement on principles and policies was formulated in 1[illegible]). Step by step, the new concepts which appear feasible can be tested and proven through demonstra-tion in tributary project resettlements as is now being done in the first trials at Huey Luang, Nam Pong, and Nam Ngum.

4. SCOPE review criteria

The Scientific Committee on Problems of Environment (SCOPE), established by the International Council of Scientific Unions in 1[illegible], includes recommendations for guiding the planning of resettlement in its report, "Man-Made Lakes As Modified Ecosystems" (Ref. 22). The SCOPE Committee notes that, while no amount of preparation can completely solve the problems of shock and trauma of being uprooted and moved, the relocation authority can do a number of things to ease the stress and to minimize the period of transition. These include:

(1) Carry out suitable social surveys which will, among other purposes, identify those who wish to move as communities and those who prefer to move as families or individuals. Because of the complexity, costs, and risks associated with planned resettlement, it will probably be advan-tageous to the government to accommodate these differing desires.

(2) Continuing two-way communication with the resettlers (and to some extent also with the host population receiving them) to educate and prepare them for relocation, including seeking the advice of the lake basin population (through selected representatives) in the planning, execution, and evaluation of resettlement.

(3) Early initiation of educational and training programs so that resettlers can realize the potentials of their new opportunities. Where people wish to move as a group, consideration should be given, prior to relocation, to establishing pilot communities to pave the way.

(4) Provision of essential services from the beginning in the resettlement communities including housing, adequate community facilities, and adequate equipment and/or stock for their agricultural pursuits.

(5) Restoration of community self-sufficiency at the earliest possible date, i.e., establishment of a self-sustaining economic productive system. Because relocation planning and preparations are time consuming, they must be scheduled to take place before closing the dam, otherwise the relocation may require extra government subsidies (as happened in Africa at Kariba, Volta, Aswan, and Kossou) which are not only costly but may create a "dependency syndrome".

(6) Plan for reasonable participation of the hosts in new developmental opportunities (e.g., lake fisheries) to promote community stability.

Comparison of the criteria listed above with the program of the Mekong Committee shows that all of these needs are being recognized in the Committee's present resettlement studies program.

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TABLE 1

SUMMARY OF SELECTED STUDIES ON RESETTLEMENT

| No. | Short Name of Study | Authors | Ref. No. | Year Completed | Sponsor | Subject of Study |
|---|---|---|---|---|---|---|
| 1 | Land Settlement in Northeast Thailand | Thomas and Block | 2 | 1970 | USAID | Constraints in applying resettlement principles to lower Mekong basin. |
| 2 | Tributary Resettlement Projects in Northeast Thailand | R. Ben-Nun | 4 | 1971 | MC | Problems experienced in tributary resettlement projects. |
| 3 | Costs of Resettlement in Ghana and Northeast Thailand | B. Ross | 19,24 | 1972 | USAID | Review of resettlement costing practices in Ghana and northeast Thailand |
| 4 | Aerial Photography for Resettlement Planning | Mekong Committee | 5 | Aug. 1972 | USAID | Aerial photography as alternative to ground surveys for assessing village development. |
| 5 | Quae Yai Resettlement Review | AIT | 19,21 | 1972 | EGAT | Preliminary evaluation of anticipated problems for project in western Thailand. |
| 6 | Lam Dom Noi Resettlement Study | C. Tohtong Mekong Committee | 6,7 | 1970-72 | MC | Review of situation at Lam Dom Noi before and after resettlement. |
| 7 | Pa Mong Resettlement Costing Project | Mekong Committee | 8,9,10,11, 12, 29, 34 | 1976 | MC | Detailed evaluation of costs involved in resettlement including consideration of all feasible resettlement alternatives. |
| 8 | Resettlement Study and Planning Project | Mekong Committee | 13,14,15, 16,31,32 | 1976 | MC | Development of methodology for resettlement planning and implementing pilot demonstration within existing resettlement scheme. |
| 9 | Nam Ngum Resettlement Project | Mekong Committee | 17,18,26 | Started 1975 | MC | Assistance in solving resettlement problems at tributary project. |
| 10 | Estimation of Resettlement Costs | Netherlands Economics Institute | 33 | 1975 | MC | Methodology for estimation financial, economic, and social costs of resettlement. |

## TABLE 2

## DETAILS OF FARM PLAN FOR NAM PONG RESETTLEMENT, RESETTLEMENT STUDY AND PLANNING PROJECT

### PART I: FARM PLAN, LAND USE, AND CROPPING PATTERN

| | | | |
|---|---|---|---|
| **Land Use** | | | |
| Homelot: | House and yard | 0.25 rai | |
| | Irrigation area | 1.75 rai | |
| Rainfed area: | | 13.00 rai | |
| | Total area | | 15.00 rai |
| **Livestock:** | Draft animals: | 2 water buffalo | |
| | Other animals: | pigs, poultry, etc. | |
| **Crops** | | | |
| A. Irrigated area: | Mulberry | 1.00 rai | |
| | Banana | 0.50 rai | |
| | Vegetables (2 crops) | 0.50 rai | 2.00 rai |
| B. Rainfed area: | Kenaf | 7.00 rai | |
| | Peanuts | 4.00 rai | |
| | Mungbeans | 1.00 rai | |
| | Soyabeans | 1.00 rai | 13.00 rai |
| | | | 15.00 rai |

## TABLE 2 (Part II)

## FARM PLAN, GROSS PRODUCTION VALUE, AND NET FARM INCOME

| | | Production Value (Baht) | |
|---|---|---|---|
| Irrigated: | Mulberry | 2,000 | |
| | Banana | 1,125 | |
| | Vegetables | 2,550 | 5,675 |
| Rainfed: | Kenaf | 4,725 | |
| | Peanuts | 4,000 | |
| | Mungbeans | 640 | |
| | Soyabeans | 520 | 9,885 |
| | Gross production value | | 15,560 |
| | | Farm Inputs (Baht) | |
| Irrigated: | Mulberry | 230 | |
| | Banana | 270 | |
| | Vegetables | 475 | 975 |
| Rainfed: | Kenaf | 1,918 | |
| | Peanuts | 2,040 | |
| | Mungbeans | 420 | |
| | Soyabeans | 390 | 4,768 |
| Total input cost | | | 5,743 |
| Net farm income (cost of family labor has not been substracted) | | | 9,817 |

TABLE 2

PART III: FARM PLAN, FARM INPUTS, AND FARM OUTPUTS FOR IRRIGATION AREA

Inputs

| Crop | Area (rai) | Seedlings Seeds (Baht) | Insecticides (Baht) | Fertilizers (Baht) | Total (Baht) |
|---|---|---|---|---|---|
| Mulberry | 1.00 | 30 | - | 200 | 230 |
| Banana | 0.50 | 45 | 25 | 200 | 270 |
| Vegetables | 0.50 | 200 | 100 | 175 | 475 |
| Total | 2.00 | 275 | 125 | 575 | 975 |

Outputs

| Crop | Area (rai) | Yield (kg) | | Return (Baht) | | Total Input (Baht) | Net Income (Baht) |
|---|---|---|---|---|---|---|---|
| | | per rai | total | per unit | total | | |
| Mulberry | 1.00 | 1,000 | 1,000 | 200.0* | 2,000 | 230 | 1,770 |
| Banana | 0.50 | 1,500(h) | 750 | 1.50 | 1,125 | 270 | 855 |
| Vegetables | 0.50 | | | | 2,550 | 475 | 2,075 |
| Total | | | | | 5,675 | 975 | 4,700 |

(h) hands

* 1,000 kg leaves = 10 kg silk

1 kg silk = 200 Baht

TABLE 2

PART IV: FARM PLAN, FARM INPUTS, AND FARM OUTPUTS FOR RAINFED AREA

Inputs

| Crop | Area (rai) | Seed | | | Insecticides | | | Fertilizers | | | Total per crop (Baht) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | kg per rai | Price per kg | Total (Baht) | kg per rai | Price per kg | Total (Baht) | kg per rai | Price per kg | Total (Baht) | |
| Kenaf | 7 | 3 | 3 | 9 | 2 | 20 | 40 | 50 | 4.50 | 225 | 274 x 7 = 1,918 |
| Peanuts | 4 | 30 | 5 | 150 | 3 | 20 | 60 | 60 | 5 | 300 | 510 x 4 = 2,040 |
| Mungbeans | 1 | 10 | 6 | 60 | 3 | 20 | 60 | 60 | 5 | 300 | 420 x 1 = 420 |
| Soyabeans | 1 | 5 | 6 | 30 | 3 | 20 | 60 | 60 | 5 | 300 | 390 x 1 = 390 |
| Total | | | | | | | | | | | 4,768 |

Outputs

| Crop | Area (rai) | Yield (kg) | | Return (Baht) | | Total Input (Baht) | Net Income (Baht) |
|---|---|---|---|---|---|---|---|
| | | per rai | total | per unit | total | | |
| Kenaf | 7 | 225 | 1,575 | 3 | 4,725 | 1,918 | 2,807 |
| Peanuts | 4 | 200 | 800 | 5 | 4,000 | 2,040 | 1,960 |
| Mungbeans | 1 | 160 | 160 | 4 | 640 | 420 | 220 |
| Soyabeans | 1 | 130 | 130 | 4 | 520 | 390 | 130 |
| Total | | | | | 9,885 | 4,768 | 5,117 |

Resettlement

TABLE 2

PART V : FARM PLAN, LABOUR REQUIREMENTS

| Crop | Area (rai) | Total Labour Requirement | | Monthly Labour Requirement (Mandays) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (per rai) | (per crop) | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. |
| Irrigated: | | | | | | | | | | | | | | | |
| Mulberry | 1.0 | 34.0 | 34.0 | 2.0 | 2.0 | 2.0 | 3.0 | 3.5 | 3.5 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Banana | 0.5 | 16.0 | 8.0 | 0.5 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.6 |
| Vegetables | 0.5 | 60.0 | 30.0 | 2.0 | 3.0 | 3.5 | 2.5 | 2.0 | 2.0 | | 1.5 | 4.5 | 4.0 | 3.5 | 1.5 |
| Rainfed: | | | | | | | | | | | | | | | |
| Kenaf | 7.0 | 30.0 | 210.0 | 35.0 | 38.0 | 24.0 | 6.0 | 2.0 | 2.0 | 26.0 | 30.0 | 28.0 | 17.0 | | |
| Peanuts | 4.0 | 15.6 | 62.4 | | | | 3.0 | 13.4 | 3.2 | 15.2 | 21.6 | | | | |
| Mungbeans | 1.0 | 9.4 | 9.4 | | | | 0.5 | 1.5 | 3.5 | 3.5 | 0.4 | | | | |
| Soybeans | 1.0 | 9.7 | | | | | 3.5 | 4.0 | | 1.6 | 0.6 | | | | |
| Total | | | 363.5 | 39.5 | 43.6 | 30.2 | 25.2 | 27.1 | 14.9 | 42.0 | 57.8 | 36.2 | 24.7 | 7.2 | 5.1 |

Roastlument

TABLE 3

DISTRIBUTION OF POPULATION FOR PA MONG RESETTLEMENT ALTERNATIVES (1990)

(From Pa Mong Resettlement Costing Project, Reference 34)

| RESERVOIR ALTERNATIVE | | | ESTIMATED DISTRIBUTION OF POPULATION | | | | |
|---|---|---|---|---|---|---|---|
| No. | High Pool Level | Protection Scheme | Reservoir Margin | Planning Settlement | Self Settlement | Urban | Total |
| 1 | 260 m | None | 48,626 | 60,505 | 329,801 | 99,781 | 538,713 |
| 2 | 250 m | None | 36,523 | 51,714 | 273,894 | 80,821 | 462,152 |
| 3 | 250 m | Loei Valley Vang Viang | 40,365 | 45,508 | 267,675 | 52,489 | 406,037 |
| 4 | 250 m | Loei Valley Nam Lik Nam Mong | 22,497 | 29,477 | 165,785 | 46,678 | 264,437 |
| 5 | 240 m | None | 53,970 | 42,405 | 216,700 | 66,446 | 379,541 |
| 6 | 240 m | Loei City Nam Lik Nam Mong | 26,352 | 24,822 | 126,871 | 44,498 | 222,543 |
| 7 | 230 m | None | 60,897 | 29,994 | 136,882 | 40,938 | 268,711 |
| 8 | 230 m | Nam Lik Nam Mong | 23,356 | 18,099 | 86,119 | 36,409 | 163,983 |

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TABLE 4

VARIATIONS IN PA MONG RESETTLEMENT COSTS FOR ALTERNATIVE RESERVOIRS (1990)

(From Pa Mong Resettlement Costing Project, Reference 34)

Resettlement

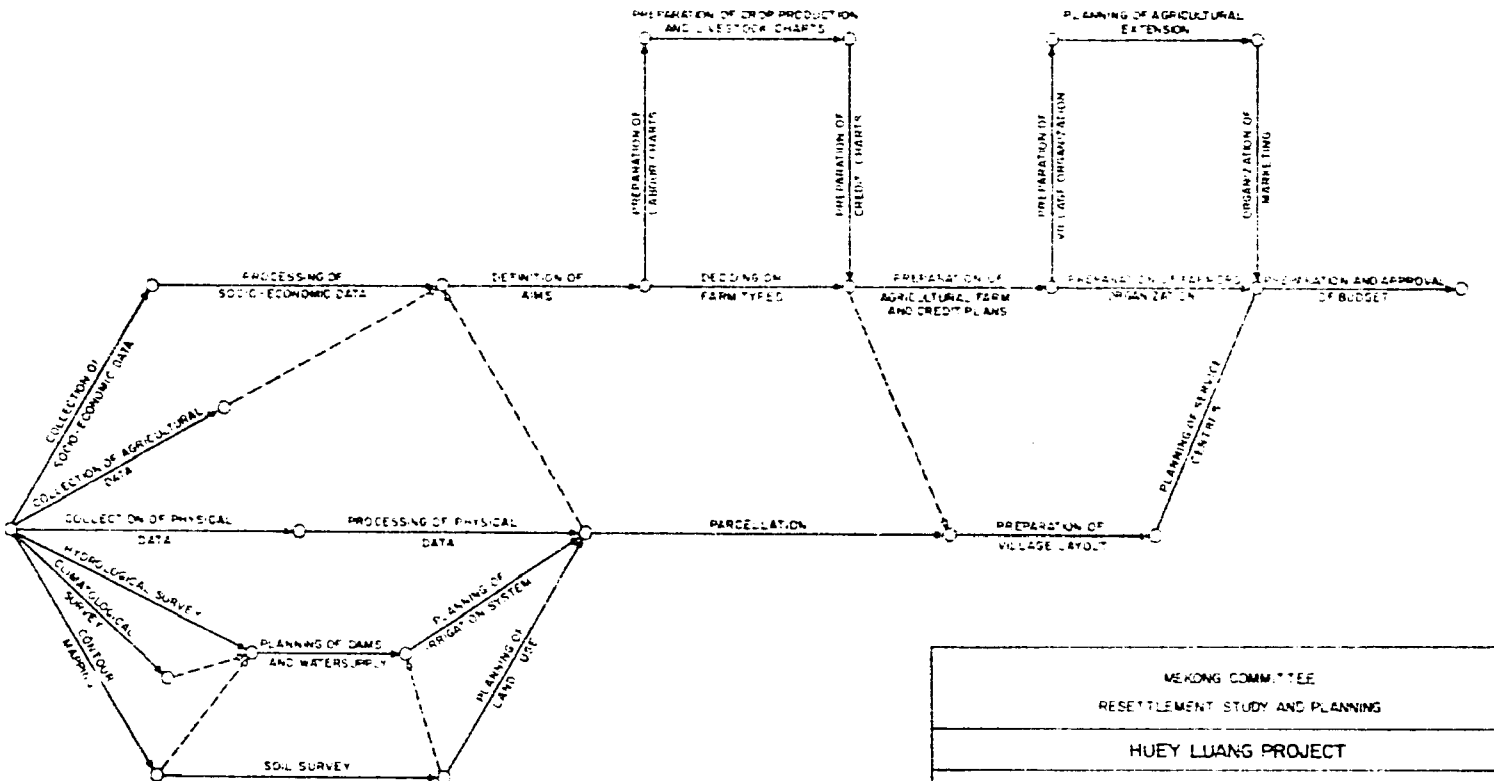
| Reservoir Alternative | | | Resettlement Cost Components and Total (Thousands of Dollars) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | High Pool Level | Protection Dykes | Compensation | Communications Placement | Dislocation Allowance | Moving Allowance | Early Moving Allowance | Land Development | Social Overhead | Title Verification Protection | Downtime Allowance | Administration | Replacement Roads & Towns | Total |
| 1 | 290 m | None | 471,[illegible] | 16,[illegible] | 34,547 | 9,122 | 19,970 | 35,551 | 31,622 | 5,926 | 69,[illegible] | 14,[illegible] | 30,[illegible] | 742,478 |
| 2 | 250 m | None | 471,[illegible] | 13,[illegible] | 29,601 | 7,645 | 17,[illegible] | 27,822 | 27,128 | 4,283 | 59,202 | 12,016 | 25,853 | 626,026 |
| 3 | 260 m | Lost Valley Nam Ngum | 347,692 | 12,206 | 26,052 | 6,882 | 15,023 | 24,483 | 23,834 | 4,466 | 52,101 | 10,557 | 11,472 | 527,847 |
| 4 | 250 m | Lost Valley Nam Lik Nam Ngum | 202,196 | 8,002 | 16,830 | 4,482 | 9,784 | 15,859 | 15,522 | 2,909 | 33,661 | 6,875 | 8,603 | 324,683 |
| 5 | 240 m | None | 316,[illegible] | 11,434 | 24,327 | 6,430 | 14,043 | 22,614 | 22,279 | 4,175 | 48,635 | 9,868 | 18,681 | 499,637 |
| 6 | 240 m | Lost City Nam Lik Nam Ngum | 172,042 | 6,734 | 14,124 | 3,771 | 8,234 | 13,354 | 13,063 | 2,448 | 28,248 | 5,786 | 10,228 | 278,032 |
| 7 | 230 m | None | 202,332 | 6,131 | 17,252 | 4,554 | 9,943 | 16,177 | 15,773 | 2,956 | 34,463 | 6,986 | 10,499 | 349,006 |
| 8 | 230 m | Nam Lik Nam Ngum | 133,668 | 4,962 | 10,459 | [a]2,778 | 6,067 | 9,737 | 9,625 | 1,804 | 20,919 | 4,264 | 8,146 | 212,429 |

TABLE 5

COMPENSATION PAYMENTS BY COMPONENTS FOR VARIOUS PA MONG RESERVOIR ALTERNATIVES (1990)

(From Pa Mong Resettlement Costing Project, Reference 34)

| RESERVOIR ALTERNATIVE | | | ESTIMATED PAYMENT IN THOUSANDS OF DOLLARS | | | | | |
|---|---|---|---|---|---|---|---|---|
| No. | High Pool Level | Protection Scheme | Farmland | Urban Land | Private Structures Improvements | Perrenial Tree Crops | Public Property | Total |
| 1 | 260 m | None | 263,281 | 16,635 | 133,179 | 36,266 | 30,003 | 479,366 |
| 2 | 250 m | None | 217,397 | 12,947 | 113,047 | 31,336 | 25,832 | 400,582 |
| 3 | 250 m | Loei Valley<br>Vang Vieng | 206,938 | 2,264 | 91,250 | 28,765 | 11,471 | 340,692 |
| 4 | 250 m | Loei Valley<br>Nam Lik<br>Nam Mong | 112,287 | 2,217 | 62,139 | 16,909 | 8,603 | 202,156 |
| 5 | 240 m | None | 170,669 | 11,511 | 90,881 | 25,166 | 18,681 | 316,909 |
| 6 | 240 m | Loei City<br>Nam Lik<br>Nam Mong | 94,495 | 2,197 | 51,662 | 13,459 | 10,228 | 172,042 |
| 7 | 230 m | None | 132,553 | 2,189 | 59,149 | 17,942 | 10,499 | 222,332 |
| 8 | 230 m | Nam Lik<br>Nam Mong | 75,725 | 2,141 | 38,357 | 9,299 | 8,146 | 133,668 |

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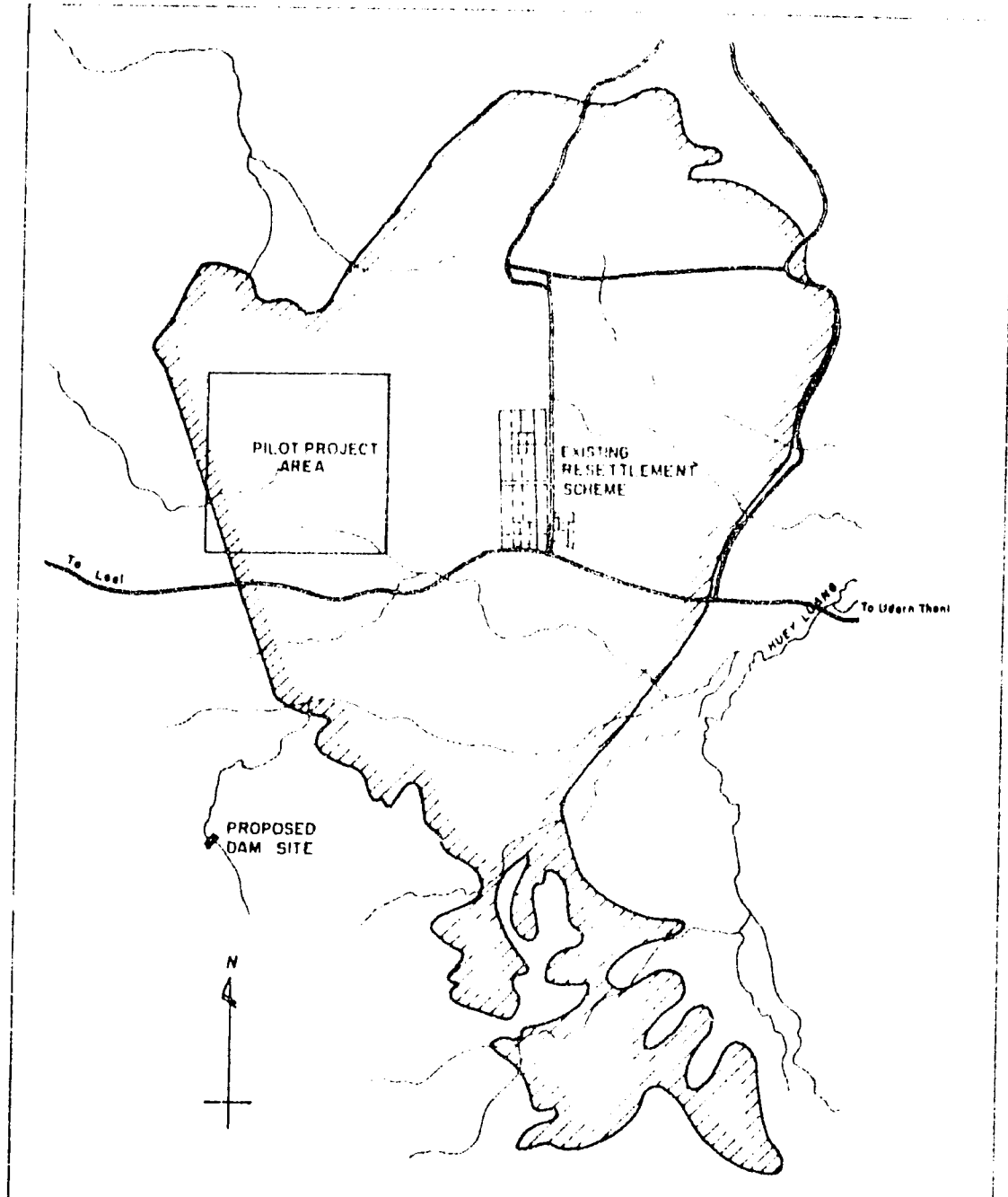
RESETTLEMENT STUDY AND PLANNING

HUEY LUANG PROJECT

NETWORK ANALYSIS OF RESETTLEMENT PLANNING

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HUEY LUANG PROJECT

LOCATION MAP OF THE PILOT PROJECT AREA

DATE JAN 1976 | FIG 2

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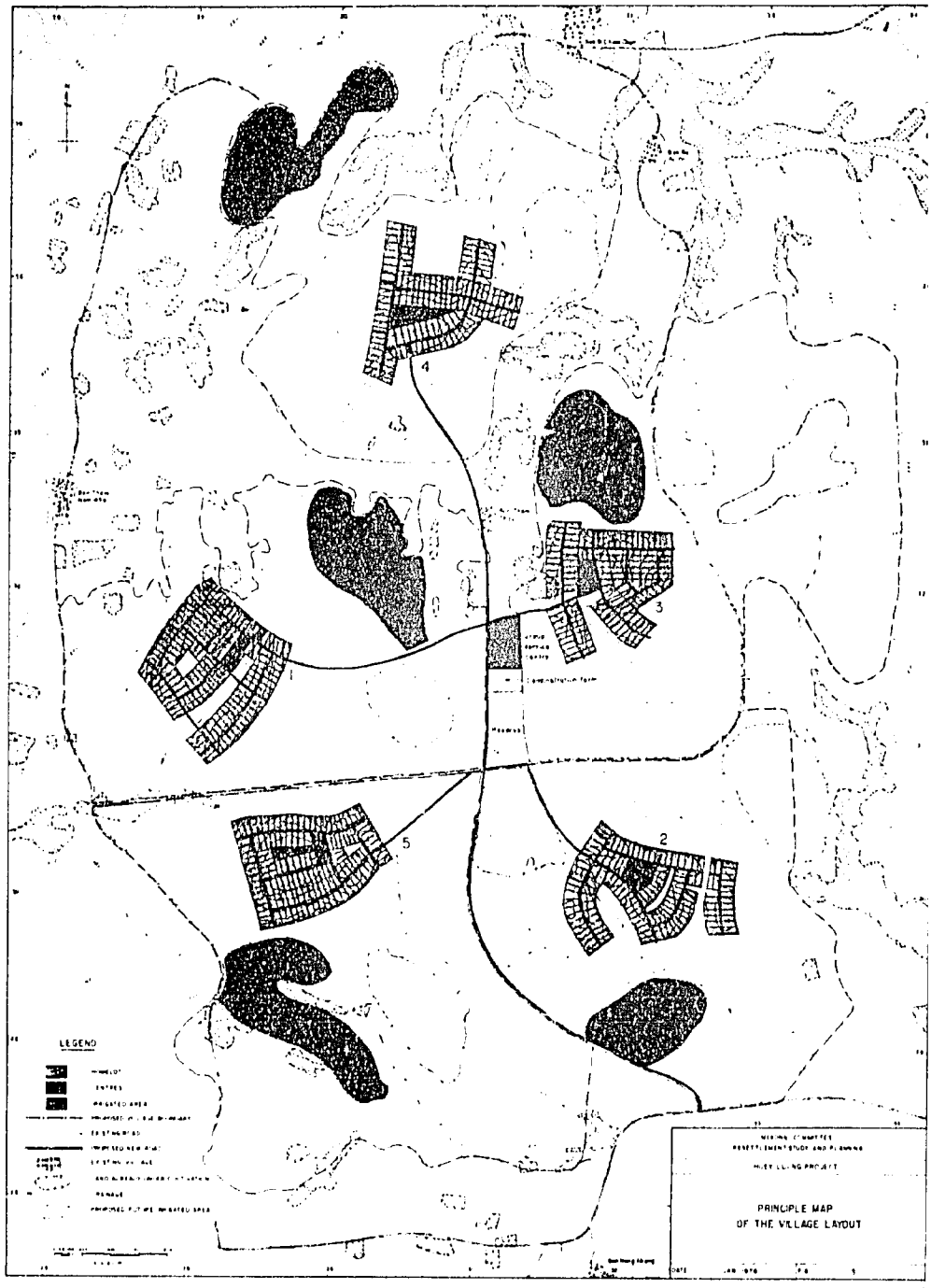

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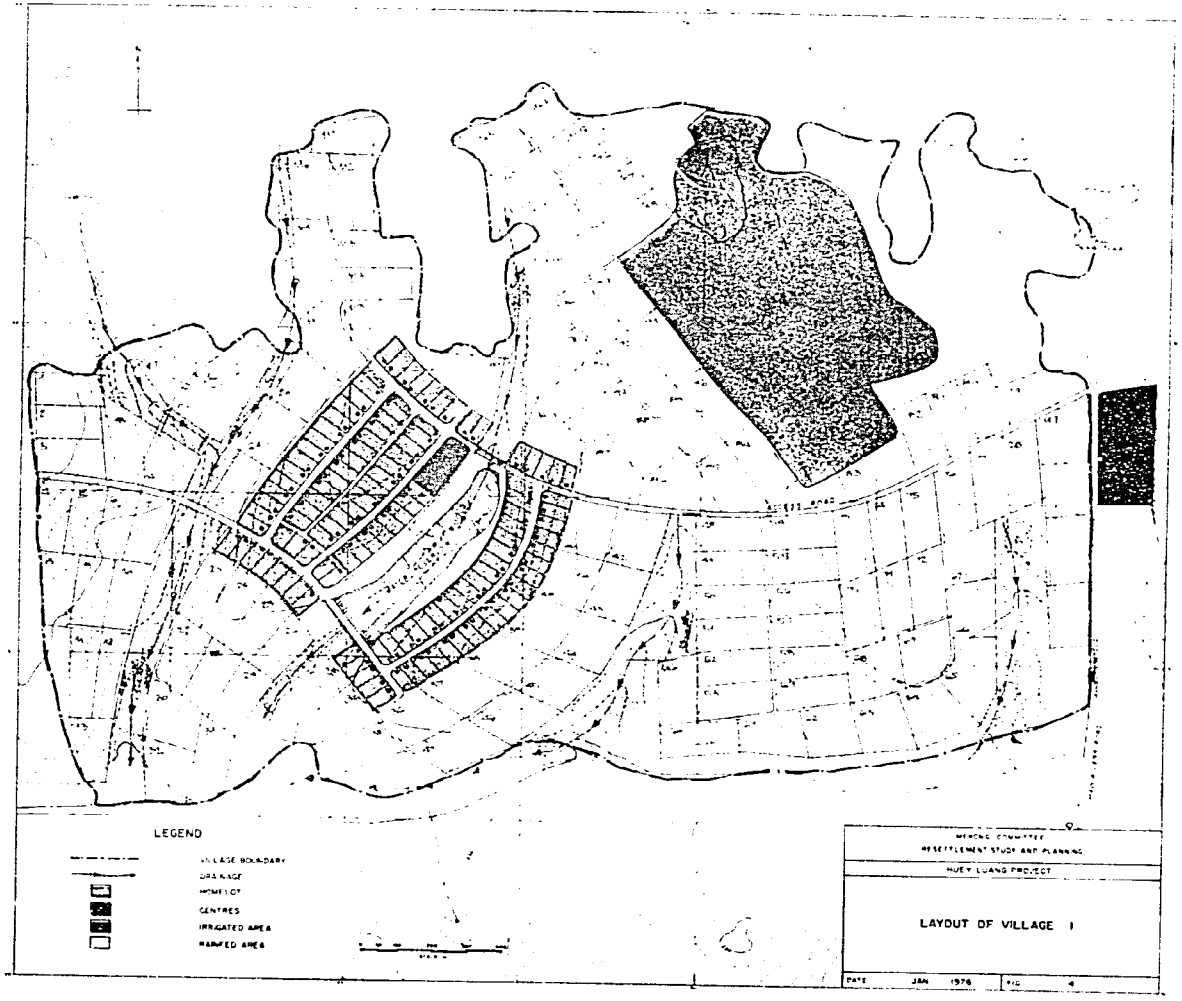

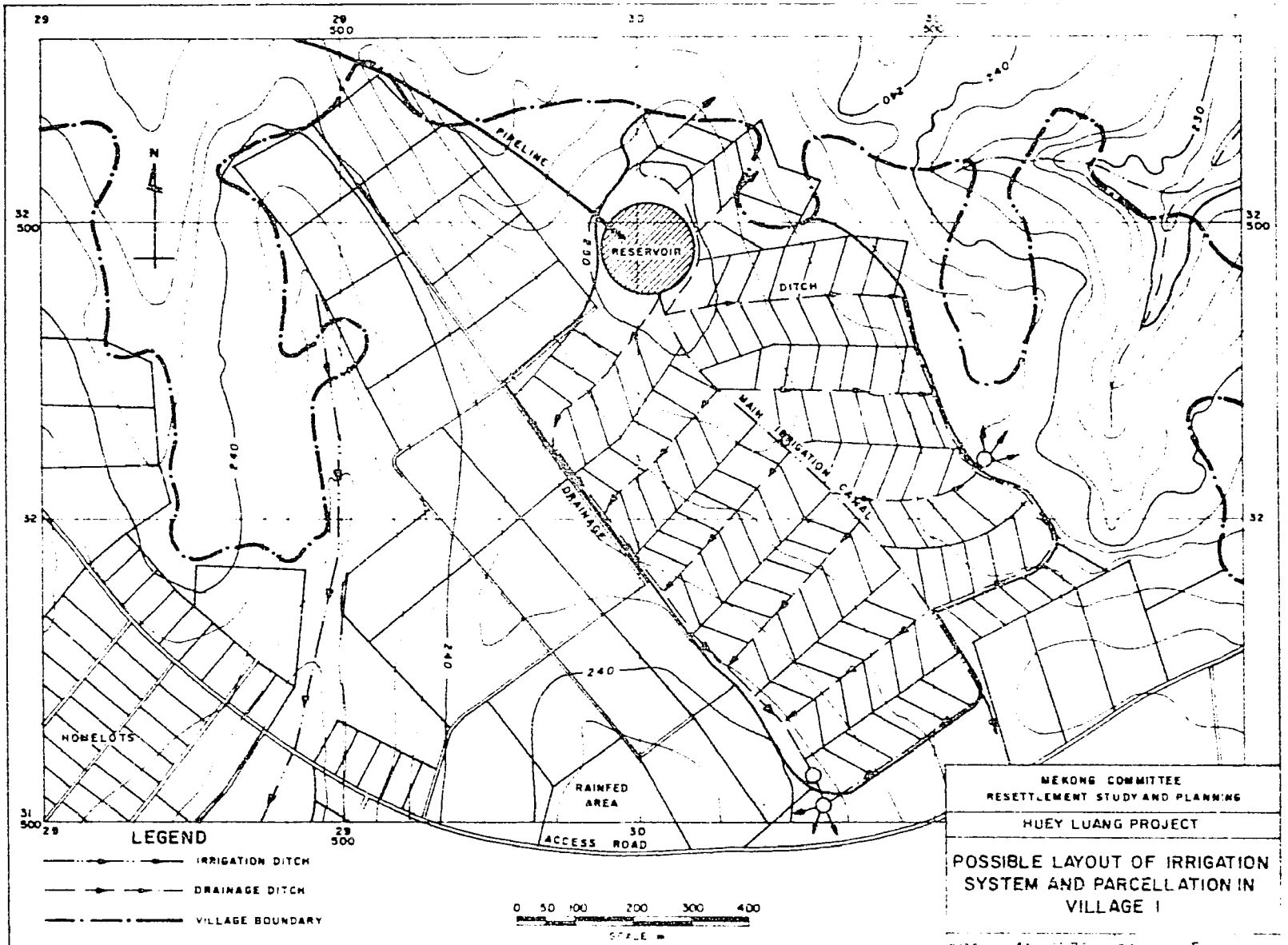
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RESETTLEMENT STUDY AND PLANNING
HUEY LUANG PROJECT
POSSIBLE LAYOUT OF IRRIGATION SYSTEM AND PARCELLATION IN VILLAGE 1

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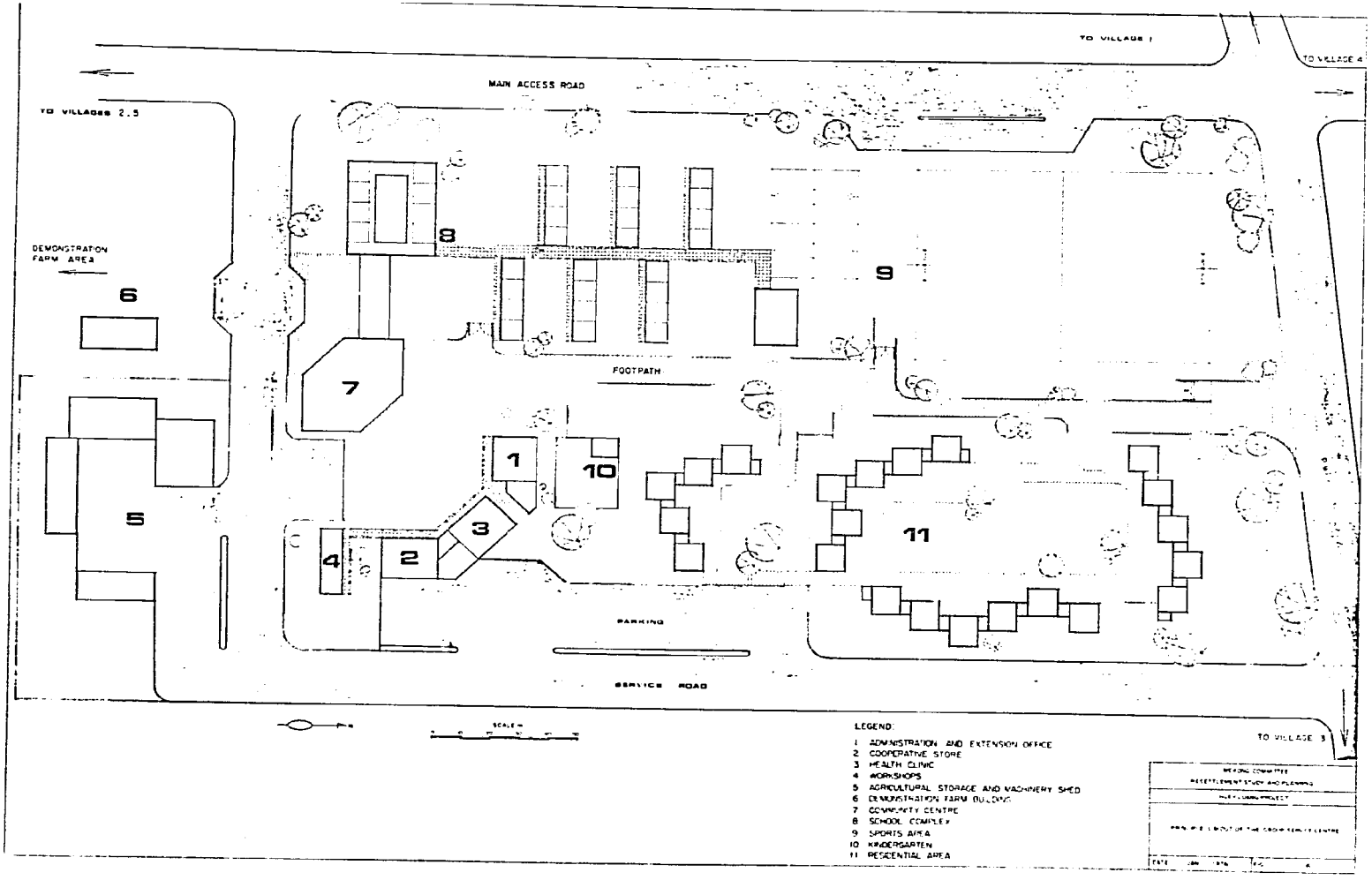

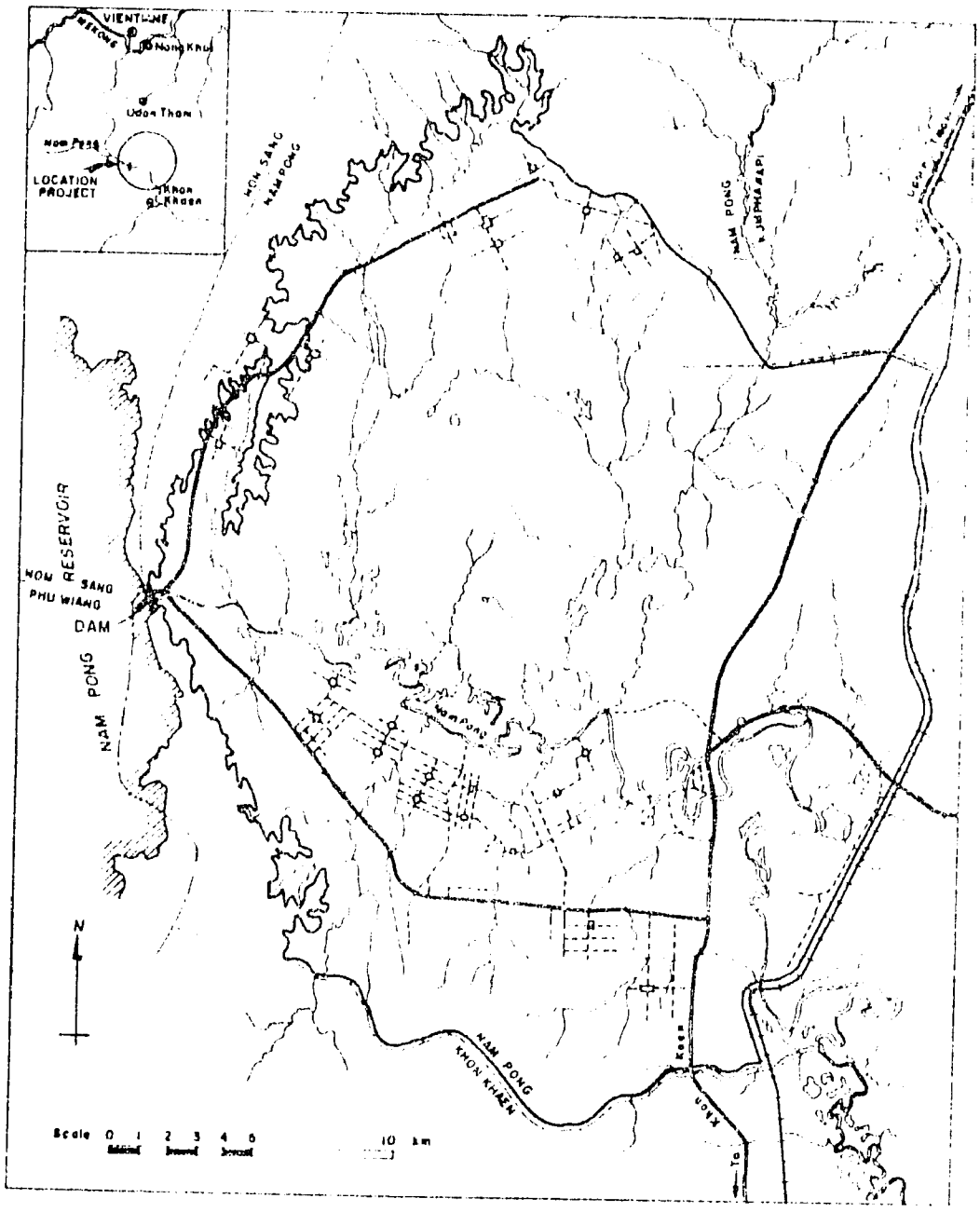


LEGEND

- MAIN ROAD
- VILLAGE ROAD
- RAILWAY
- BOUNDARY OF RESSETTLEMENT
- DISTRICT BOUNDARY
- STREAMS

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LOCATION MAP OF THE RESETTLEMENT AREA

DATE FEB. 1976 FIG 7

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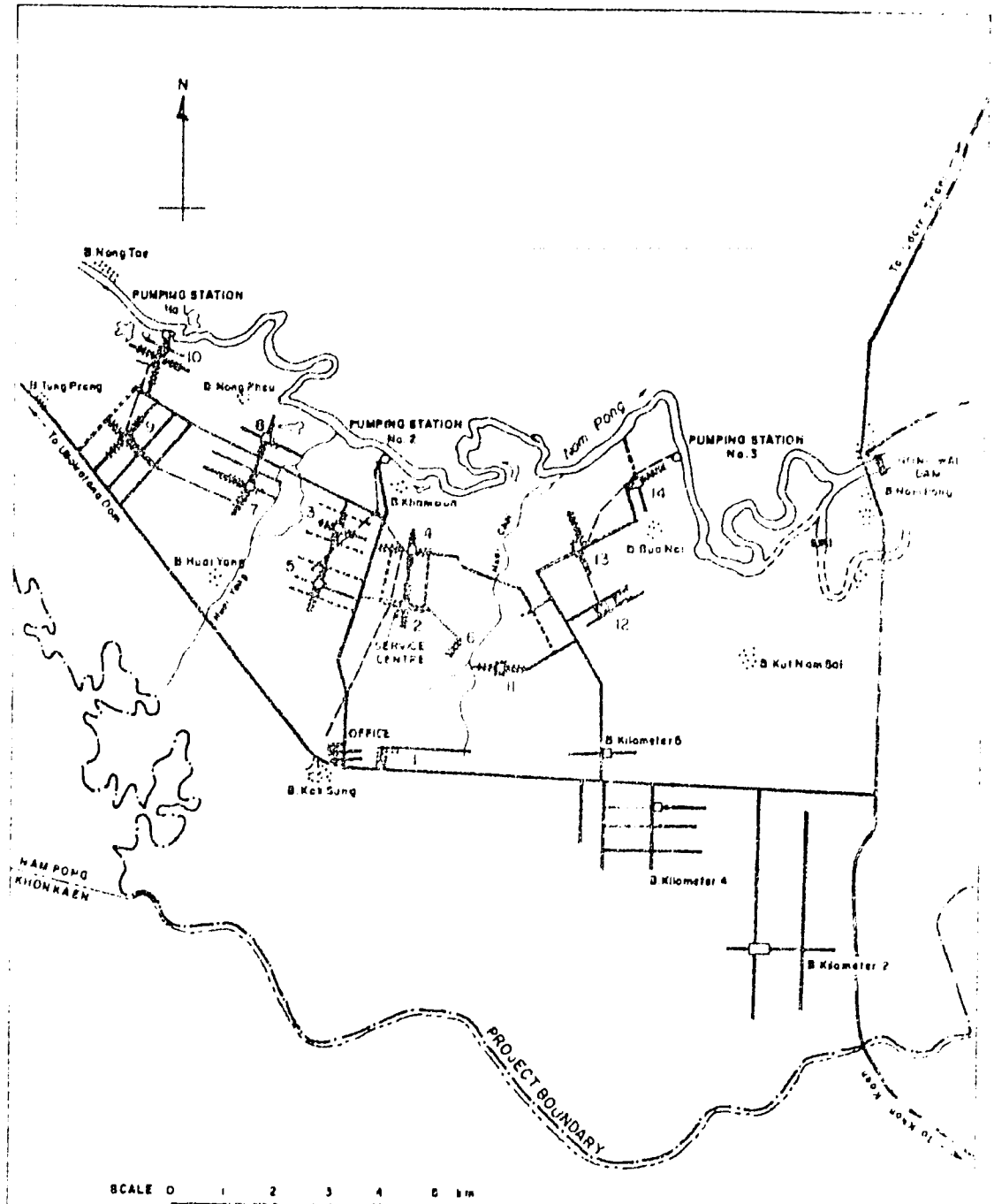


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NAM PONG PROJECT

LAYOUT OF THE IRRIGATION SYSTEM

DATE FEB. 1976 | FIG 8

512

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## SALINITY

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# PA MONG ENVIRONMENTAL ASSESSMENT

## SALINITY

### 1. Introduction

Of the 3.7 million hectares in the delta, more than 0.5 million are affected by salt water intrusion resulting from tidal fluctuations as much as three meters. The zone of significant salt water intrusion is generally limited to approximately the lower 30 km of the Bassac and Mekong rivers, but may extend as far as 180 km inland across the Plain of Ca Mau during the dry season.

Information on salinity intrusion serves two purposes, (1) as basic data for use in developing plans for rehabilitation of delta rice lands and reclamation of additional lands through water management, and for growing irrigated crops during the dry season, and (2) as basic data for evaluating the effects of upstream water resource developments such as storage or diversions which alter the flow regime. Sufficient data are needed to define the extent and configuration of present intrusion and how this is affected by flow regulation, so that changes in the salinity zone can be predicted for any proposed flow alterations. These changes are important for all delta water uses affected by salinity including agriculture, fisheries, and community water supplies. The salinity problem is delta-oriented, especially for the Vietnamese portion of the delta, hence detailed information on delta salinity phenomena can be found in various delta reports (Ref. 1 to 8).

The primary objective of the salinity studies sponsored by the Mekong Committee is to quantify the relationship between seawater intrusion, river discharges, and tidal effects so that the extent and concentrations of salinity will be known throughout the affected areas of the delta, both for natural conditions and for modified river flows resulting from water control by upstream projects including Pa Mong. The salinity studies thus far have produced sufficient information to permit approximate quantification of the extent of intrusion both in area and in concentration, sufficient to meet the needs for the present stage of basin water resource planning including planning of Pa Mong. The studies thus far show the limits of extraction of freshwater from the delta that can be made without adverse effects on agriculture for any given minimum dry season river flow to be maintained by Pa Mong releases. A summary of the extent and concentration of salinity in the delta is graphically portrayed in Figure 1.

A second main objective of the salinity studies is to develop practicable methods for alleviating and controlling seawater intrusion which would interfere with effective use of the dry season flow for irrigation purposes. The studies show that a major cause of salinity is extensive seawater intrusion into

into the smaller estuarine channels, rather than into the main river mouths. Also, some of these channels are not fed by streams but are interconnected by canals with the estuarine river branches, resulting in backflow of saline waters into the river channels during the dry season. As the delta construction programme evolves, it should be feasible to close off selected channels thus achieving significant improvement in the quality of water available for irrigation.

2. Salinity measurements and studies

The most comprehensive evaluation of delta salinity yet made is that carried out by the Dutch Delta Team engaged in preparing a basis for a master plan of agricultural development in the delta. "Working Paper IV, Hydrology" of the Dutch Team report of April 1974 (Ref. 4) includes a detailed presentation which incorporates and makes use of all the available information concerning salinity intrusion into the branches of the Mekong and the estuary of the Bassac. The salinity measurements taken in early years, from 1935-42, were sufficient to permit preparation of maps showing lines of equal salinity (isohalines) for various levels of salinity (NaCl) in ppt (parts per thousand), namely for 5, 4, and 0.4 ppt. These measurements involved weekly sampling at times of both high and low water. Additional information used by the Dutch Team included the salinity measurements made by the Viet-Nam National Committee on Hydrology from April through July 1973. In addition to the salinity data, the analysis made use of related information on river discharges, especially the river discharges downstream of Phnom Penh, on river bed configurations (especially minimum depths of the bars at the months of channels, which are important factors in estuary salinization), and on water movement by tidal action. The salinity stations involved are shown in Figure 1.

(a) Salinity vs. river discharge: The analysis placed primary reliance on salinities measured at high water rather than low water for several reasons, including the relative irregularity in the low water data and the fact that many smaller channels exist along the estuaries from which the salinity drains at ebb tide more slowly than from the estuaries. The measured salinities were plotted on semi-logarithmic scales as a function of river discharge. From these graphs salinity distribution zones were obtained in the logitudinal direction of the estuaries, for river discharges values of 2,000 and 6,000 $m^3$/sec. Salinity distribution curves were developed for most of the delta waterways showing limits of penetration, which are summarized in Figure 1.

(b) Salinity distribution: In order to estimate distribution of salinity over the river branches, an empirical relationship was established between salt concentration, fresh water discharge, and tidal flow volume, based on experience with other estuaries (especially in the Netherlands). The results of this analysis indicate a

decided preference for the Mekong river to discharge via the southern estuaries over the northern ones. This results in net canal movements from north to south, for example, the connecting canals between the Mekong and Bassac in the upper courses of the river show large net transport of water toward the Bassac.

(c) Complicating factors: A problem for accurate analysis of the salinity data is the frequent large inequality of daily tidal movement. Also, a yearly fluctuation exists in average tidal levels in front of the estuaries, with higher levels in the dry season which may be more of a factor in salinity intrusion than the low river flows. Also, the salinity is less than seawater salinity at the mouth of the branch because a considerable gradient in salinity exists between the bars and the sea. In addition, the distance of transport of water particles is much farther during a tidal cycle for the channel than for water near the banks (where all the earlier salinity measurements were made), and the earlier samples were taken 1 m below water surface, which is representative at low but not at high river flows. During the dry season the sea waters penetrate the smaller estuaries which are not fed by fresh water streams, which are interconnected with the Mekong and Bassac by a complex system of canals. As soon as the dry season begins, the salinities in the rivers may be significantly affected by "backflow" from these smaller estuaries into the river.

(d) Future programme: The April 1974 report includes recommendations for an expanded hydrologic data collecting programme to be conducted over a period of 2 to 3 years, after which the extent of the measuring network and the frequency of measurements can be considerably reduced. The overall hydrologic programme, needed for calibration of the tidal model, includes measurements of discharge (including stage measurements), salinity, acidity (relative to acid sulfate soils), rainfall, sediment, and water quality. The salinity measurement network includes 35 river stations and 20 canals stations, with measurements to be taken over 6 months, and with each sampling period including one day under spring, mean, and neap tide conditions. The recommended number of samples per week is approximately 100 for the rivers and 25 for the canals.

In 1974 the Mekong Committee approved a proposal for aerial photography of the delta zone using infrared techniques which are sensitive to changes in salinity of surface waters (Ref. 9). Such information could considerably enhance knowledge about the extent and concentration of seawater intrusion. This programme has been held in abeyance pending arrangements for the necessary aerial photography.

3. Probable environmental effects

(a) Fisheries: With respect to possible effects on fisheries resulting from Pa Mong's influence on salinity, it is believed that the estuarine zone of varying salinity is very important for reproduction of aquatic wildlife both for fresh water and marine species. The basinwide fisheries assessment now underway will produce basic information on the role of the brackish water zone in fisheries and hence on the probable effects of Pa Mong. The effects on fisheries that can now be envisioned as resulting from Pa Mong appear to be negligible. The effects on the salinity zone during the wet season (when the intrusion is minimal) would be very small. During the dry season the higher fresh water flow, if permitted to flow to the sea, would have the effect of shifting the brackish water zone downstream, but in the long run an increasing share of the extra fresh water flow is to be extracted for irrigation. To the extent Pa Mong may serve to increase the fresh water flow in the dry season, this should be beneficial to the estuarine fisheries.

(b) Coastal fringe ecosystem: There will be significant changes in the dry season salinity gradient patterns in the smaller channels or branches to be enclosed by gates (for minimizing intrusion). The ecosystem of the mangrove swamps bordering the sea could be significantly altered by such gates. Although the design of these gates is not part of the Pa Mong project per se, they would be related assuming the gates are built to realize maximum irrigation advantages from Pa Mong. The design of such gates and enclosure systems, when the delta development programme reaches this stage, should carefully consider effects on salinity and seek to minimize unfavorable impact on the delta ecosystem.

4. Effect of different pool levels

Thus far the quantification of salinity in the delta has been accomplished essentially by empirical methods, with limited use of modeling. To proceed to a better level of accuracy in analysis will require an improved field hydrologic data collecting programme (including river flow and tidal stage as well as salinity measurements). This is the next step in the programme plan, to be carried out over a period of two to three years. Eventually the information produced will permit a master model used to guide flow releases from Pa Mong to include effects on delta salinity in establishing the pattern of releases.

As the delta modeling program progresses it will become possible to assess with some precision the specific effects of releases from Pa Mong, hence of the probable differences in salinity effects in the delta of different Pa Mong pool levels. The extent of the effects will be essentially a function of the minimum dry season flow in the river discharge reaching the delta.

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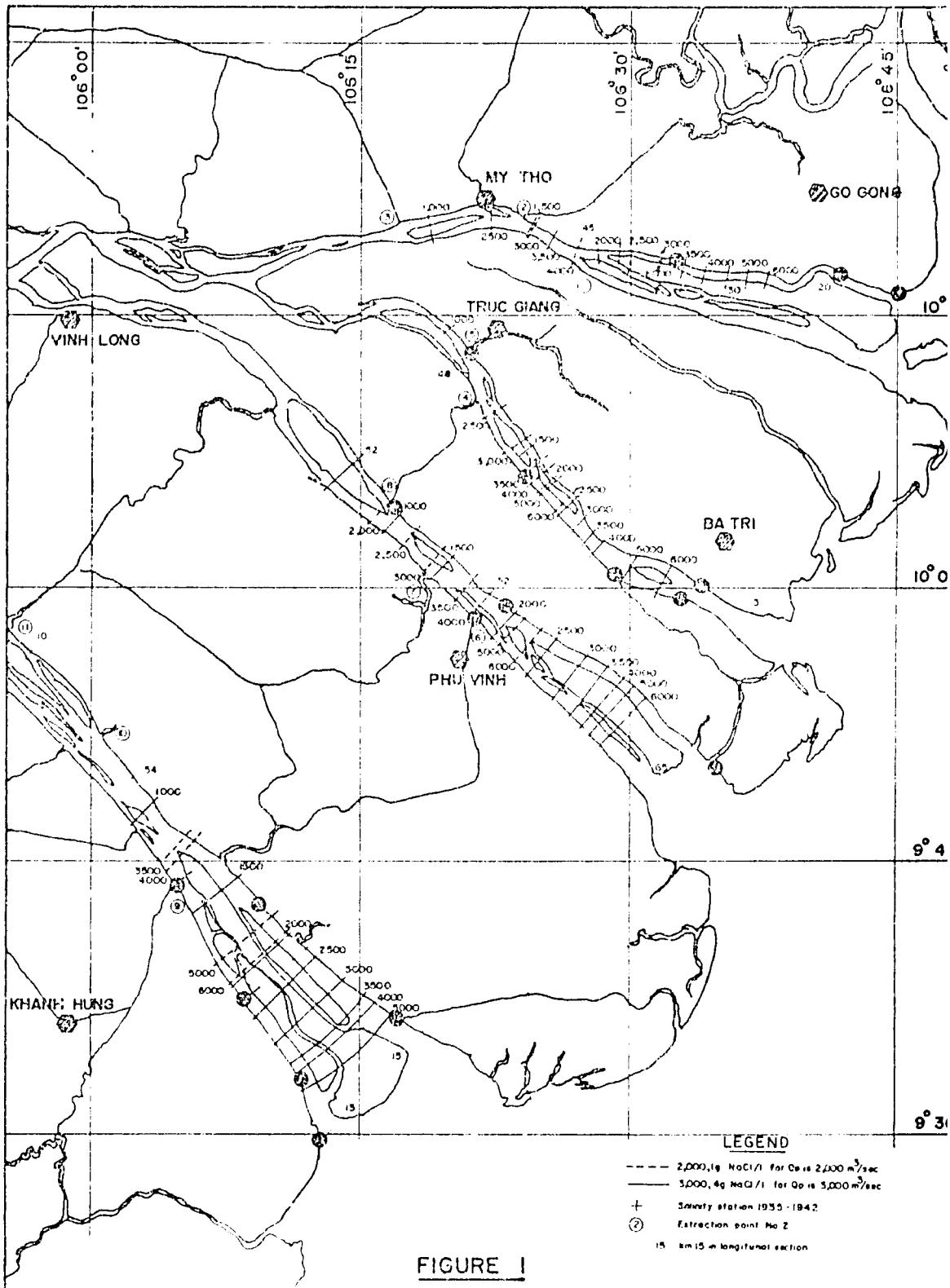


FIGURE I

SALINITY STATIONS AND SALINITY INTRUSION IN MEKONG DELTA

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## SEDIMENTATION AND EROSION

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# PA MONG ENVIRONMENTAL ASSESSMENT

## SEDIMENTATION AND EROSION

### 1. Introduction

Sedimentation and erosion, i.e., the picking up, transport, and deposition of silt, are important influences in the operation of most dam and reservoir projects. Generally the problems of greatest concern are trapping of silt in the reservoir and erosion downstream.

In the upper basin, the Mekong river generally flows through steep, rugged terrain at relatively high velocity, and as a result is capable of transporting sediment of considerable size. Proceeding into the lower basin the river enters an alluvial plain in the vicinity of Vientiane, and from this point to the China Sea, except for those reaches where falls and rapids occur, the slopes become flatter. Because of this general decrease in velocity, the ability for transporting sediment diminishes, per unit of flow volume; however, the increased volume of flow is such that the total quantity of sediment transported downstream is increased.

With the construction of Pa Mong dam many factors comprising the natural regime of the river will be significantly changed, such as the flow discharge, sediment transport, and bed slope of the river channel. New cycles of sedimentation processes will begin in the river channel above and below the dam. Due to trapping of silt in the reservoir, the releases from the dam will be essentially sediment free and discharge of this clarified water into the downstream river will create a powerful erosive agent which will cause scouring of the river bed. The extent of this degradation will depend primarily on the amount and pattern of the flow releases. The degradation will have important effects on many downstream environmental values.

### 2. Sediment basic data collection programme

The basic data required for evaluation of sedimentation and erosion are the sediment concentration and particle size distribution, for both the sediments in suspension in the flow and the sediments deposited in the river bed.

## 2.1 Development of programme

The initial work of the Mekong Committee's basic data programme on sediments was included as part of the initial hydrologic data contract carried out by the Harza Engineering Company beginning in 1958 (Ref. 29). The sediment sampling programme included collection and analysis of suspended sediments at 10 mainstream and 12 tributary stations for the year 1960-1962. Following completion of the Harza contract in 1962, primary responsibility for sediment sampling was assumed by the riparian country governments with assistance from the Mekong Committee. Sediment laboratories were set up at Saigon, Phnom Penh, and Vientiane, and in Thailand at both Bangkok and Ubon (close to the sampling area). For numerous reasons, however, since 1962 only Thailand has been actively engaged in this work, where the network was expanded from 7 stations in 1962 to 71 stations in 1975. Also, the USBR Pa Mong team made an extensive study of sediments at the Pa Mong damsite and in the Vientiane area in 1968-69 when approximately 90 samples were collected and analysed. A summary of the total sediment information collected in the period 1960-1970 is given in Tables 1 and 2.

(a) Particle size analysis: Some 20 samples were analysed for particle size distribution by Harza in 1961 and 1962. Since 1962 only Thailand has carried out this kind of analysis. The decantation method is used to analyse the particle size distribution of the suspended sediment, and the visual accumulation tube method for analysis of sand particle sizes. Approximately 94 samples were analysed from 1966 to 1970. Also, the analyses of the 90 samples taken by the USBR at Pa Mong in 1968-69 included particle size determination.

(b) Bed load sediment. No bed material samples were taken by standard bed load sampling methods prior to 1967. The USBR collected and analysed some bed material samples using the US BM-54 sampler during 1967 and 1968. These bed load data together with the suspended sediment data have been used to determine the total sediment discharge of the Mekong at the Pa Mong damsite.

## 2.2 Hydrologic yearbooks

Sediment sampling data, published in the yearbook since 1962, are limited to the concentration of suspended sediment. The sediment sampling procedures generally

follow those recommended by the U.S. Government agencies and ECAFE (now ESCAP), with special modifications for conditions in the Mekong. Each sample is taken from three vertical sections located so that each represents an approximately equal portion of the total stream discharge. Samples are taken with the U.S. P-46 and P-61 point integrating samplers. The depth-integration method is used whenever it can be used with a single traverse of the vertical. If the depths are such as to require two or more traverses to sample the complete depth, point samples at 0.2 and 0.8 of the total depth are taken instead of the depth-integration, and combined by the Straub method. Exceptions to this rule are the samples to be analysed for particle size determination, which are collected by the depth-integration method, even when two or more traverses are required.

The present sampling network (1975) include 25 stations located along the Mekong and tributaries as shown in Figure 1. This shows that the zone of river covered is more or less limited to the northern part of the basin.

A total of 1,092 sediment observations were reported for 1970 for all 63 stations, averaging approximately 44 per station. With respect to the Mekong mainstream, the average values by months proceeding downstream from Chiang Saen to Ban Dan are shown on Figure 2. The sediment concentrations are at a minimum (less than 50 ppm) in February throughout this reach. The peaks occur in August upstream but two or three months later downstream. Peak concentrations become much lower going downstream, ranging from more than 1,500 ppm near the Burma border to approximately 1,000 ppm in the vicinity of Pa Mong then to about 500 ppm in approaching the delta.

## 3. Review of previous studies

### 3.1 Sediment and erosion studies

The USBR Pa Mong team used the results of the 1960-62 sediment sampling programme, together with additional data collected in 1968-69, in preparing sediment and erosion evaluation for the Pa Mong Stage One report published in 1970. Some revisions were made for the Phase II report published in 1972. Because continuing controversy on the extent of downstream erosion to result from Pa Mong, several follow-up studies have been made including a report by Borland of the USBR in 1973 (Ref. 2), a report by Simons and Shen in 1974 (Ref.3), and most recently a report in July 1975 by the Delft Hydraulics Laboratory (Ref.6). Table 4 is a listing of these studies and of the methodologies used. While not exhaustive, these studies do permit general assessment of the probable effects of Pa Mong.

### 3.2 Sedimentation processes

Free flowing streams carry along with them a load of sediment that is kept in suspension by turbulence. When a stream enters a reservoir its velocity is greatly reduced,

hence a portion of the incoming suspended sediment load will be deposited or trapped in the reservoir. The rate of sediment deposition depends on many factors, such as reservoir geometry, surface geology, soils, climate, runoff, topography, ground cover, land use, upland slope erosion, channel erosion, sediment transport, etc., but in large reservoirs with long periods of detention, such as Pa Mong, practically all of the suspended material will be settled out.

Sediment deposition may cause significant reduction in the reservoir storage capacity. Examples of reservoirs that have experienced extreme rapid capacity losses due to sedimentation include the Guernsey reservoir on the North Platte river in Wyoming, USA, which lost 30 per cent of its capacity in only 26 years, and the Elephant Butte reservoir on the Rio Grande River in New Mexico, USA which lost 16.5 per cent of its capacity in 32 years (Ref. 7 )

Another problem that may be encountered is deposition of sediments in the stream channels just upstream of the reservoir, causing aggradation in the stream channel. Again, to cite an extreme example, in the period from 1914 to 1954, deposition in Elephant Butte dam raised the river valley and channel of the Rio Grande some 12 feet at a point just above the backwaters of the reservoir at maximum water surface elevation (Ref. 7 ). In general, a number of problems may be caused as a result of upstream aggradation including reduced channel capacity with consequent danger from flooding. Aggradation may also cause elevation of the ground water table, swamping or water logging of adjacent lands, and formation of stagnant pools.

As will be noted later, the extent of sedimentation expected at Pa Mong, both in the reservoir and upstream, should be well within tolerable limits.

3.2.1 Sediment loads

(a) Pa Mong reservoir: From the various studies the total annual sediment load to be trapped in the Mekong arm of Pa Mong reservoir is estimated to be 160 million metric tons assuming a trap efficiency of 100 per cent for a 250 m MSL high pool level (Ref. 3 ).

(b) Nam Mong and Nam Lik arms of Pa Mong reservoir. These two reservoirs are part of the Pa Mong reservoir system, being divided from Pa Mong by saddles at elevation 218 m for Nam Lik and 234 m for Nam Mong. Sediment inflows to the Nam Mong and Nam Lik arms of the Pa Mong reservoir were estimated from suspended sediment samples of the Nam Chi river in Thailand as collected and analysed by Harza. Total annual sediment loads of 0.16 and 6.9 million metric tons were estimated to be deposited in the Nam Mong and Nam Lik arms respectively (Ref. 2).

### 3.2.2 Sediment deposition for different Pa Mong pool levels

Most of the sediment studies were related to the case of Pa Mong high pool level 250 m MSL. Some were made for high pool levels of 230, 240, and 260 m MSL, but these were rough estimates for economic comparison purposes only (Ref. 24, page I-58 ). A summary of these results is given in Table 3. Sediment layers of about 18.3 m and 25.8 m were estimated to build up in Pa Mong reservoir with resulting reduction in reservoir capacity of about 6.7 and 13.4 per cent in 50 and 100 years respectively.

## 3.3 Existing river conditions

### 3.3.1 Geology of river

Below Pa Mong damsite at about range 10** the river emerges from the mountains to enter an alluvial plain. Above this point the course of the river is more or less defined by the rocky terrain making up the mountainous area. The river below this point has meandered and formed a fairly extensive alluvial plain, and there are a number of islands in the river channel. With the exception of the bends at and below Vientiane, the bends in the river are fairly gradual. From about range 8 upstream to range 10, some rock outcrops do influence the course of the river. Downstream from range 8 there are practically no rock outcrops; however, there are some moderately soft clay stone or mudstone outcrops at low stage associated with gravel deposits, which do modify the course of the river at low stage (Ref. 2).

The Mekong overflows at a discharge of about 16,500 $m^3$/sec on the Laos side between range 3 and 3A where the bed of the stream is composed of fine sand with a mean grain diameter of 0.32 mm (Ref. 2 ). However, some of the gravels were observed in isolated deposits on the bed of the river and along the banks with sizes as large as 40-100 mm.

### 3.3.2 Erosion and sedimentation

A comparison was made between aerial photographs and maps from the photographs for aerial surveys of 1959-1960 and 1966-1967 (Ref. 2 ). During this period the 1966 flood occurred with a peak discharge of 26,000 $m^3$/sec, representing a frequency of once in 75 years.

In general, there was more erosion of the banks than accretion. Accretion seemed to occur on some of the islands, especially Don Man, in the vicinity of range 8. There was

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** The term "range" was used by the USBR in the 1968-69 study to designate the river cross-sections used for hydrologic evaluations (See Figure 1).

scour in the next island downstream, Dong Siang Sou, in the vicinity of range 5 and 5A. The channel around Don Tiane Island in the Vientiane bend, between range 2 and range 1A, was undergoing filling at the lower end and considerable accretion was occuring opposite the Wat Sop gauge on a low silt and sand bar along the right hand side of the channel farther downstream.

A short distance upstream from the Tha Bo bank at range 22, there was considerable accretion on the left side at the lower end of the slip-off point on the bend. Just upstream scour was occurring. In the vicinity of Don Tang Island at range 23 accretion took place on the north side, immediately across from Ban Hon, and scour on the opposite side. The sharp bend at range 25 showed considerable accretion taking place around the slip-off point with very little erosion occurring on the opposite bend.

Erosion and scour were common along both banks upstream from range 8 to the damsite where there were rock outcrops of the Khole Kruat formation.

There was extensive scour on the left bank downstream from the Wat Sop gauge and above Tha Bo. Some of the worst erosion observed occurred in the steep silt loam left bank at Ban Hom (range 24). The lower part of the Tha Bo bend was being severely attacked by the river and gradually the clay loam bank was giving way.

## 3.4 River regime after completion of Pa Mong

Completion of Pa Mong will result in degradation of the streambed and banks downstream from the damsite, and there has been considerable concern about this degradation, especially in the vicinity of the city of Vientiane. As noted earlier the clarified water released from Pa Mong will have the potential to pick up its former load of sediment, by removing material from the bed and banks of the downstream channel.

The rate of degradation will depend on many factors such as (a) size, gradation, and distribution of bed material both vertically and laterally, (b) sediment load, both amount and size before initiation of the degradation process, (c) resistance of the bank material and its distribution in the reach of river under study, (d) hydraulic and sediment transport characteristics of the river including the magnitude and duration of flows before and after initiation of degradation, (e) sediment load of tributaries joining the river in the degradation reach, including both their flow pattern and size and amount of sediment transported, and (f) the presence of geologic controls and manmade structures. These various factors will result in a change in sediment transport capacity and supply, from point to point, and thus a change in the rate of scour. Eventually a stable condition or limit will be attained.

### 3.4.1 Vertical degradation

The extent of channel degradation expected to occur downstream from Pa Mong was studied by the USBR during 1968 for the Stage One report. Bed material was collected at all range cross sections from the damsite to 8 km downstream from Nong Khai and bank materials were randomly sampled along this reach. Predictions of river channel degradation were made for the reach from range 8X (degradation control section P.IV-36 Ref. 16) upstream to range 14, representing a reach of about 19 km, which is the adjacent downstream section near the damsite. The river bedrock outcrop was one of the criteria included in the study.

An additional study was made by USBR for the Phase II report, which evaluated degradation downstream from range 8X, the river reach included in the study extending some 160 km from Pa Mong (as far as range 64). Many possible degradation alternatives were examined and the conclusion was drawn that the river bed would scour down to the geologic bedrock at depths from 3 to 6 m. Figure 3 shows a comparison of the channel bed before and after degradation as presented in the Phase II report.

### 3.4.2 Lateral degradation

The potentials for lateral bank erosion or horizontal degradation were also studied as part of the Stage One and Phase II reports. It was realized that the Mekong channel would widen after construction of Pa Mong dam, that this widening would start as soon as storage begins, but it was not believed this would become important until a significant amount of vertical degradation had taken place.

A more detailed analysis was made in the 1973 supplemental study (Ref. 24), extending downstream to range 64, and conclusions were drawn that the bankful width of the river would be nearly doubled while lowering the water surface by as much as 8 metres. On reviewing the 1973 report, Simons and Shen concluded it would take about 60 years for the flow to achieve a stabilized degraded channel with an average of about three metres of bed degradation and 100 metres of widening (Ref. 19). Assuming an average of 3 m depth of degradation, the extent of widening would be about 100 m before the average hydraulic conditions would be within the bank stability limits. The 1975 study by the Delft Hydraulics Laboratory (Ref.28) concluded that the 1974 report by Simons and Shen had overestimated the speed of degradation, and that 50 per cent of the total volume of degradation to take place from Pa Mong over the reach extending 200 km downstream would occur within 133 years with an average depth of degradation of 2 m.

### 3.4.3 Vientiane bend

A sharp bend in the Mekong river occurs at Vientiane, forming a pronounced loop ending at Nong Khai. To form this loop, the river turns at an angle of roughly 90 degrees, hence downstream from Nong Khai the river flows to the northeast. While the general alighment of the river is not unusual in the vicinity of Vientiane, the Vientiane bend is most unusual. The city of Vientiane is on the outside of the sharp 90-degree bend, near Range 2, which is the side that would normally be expected to be subject to continuing scouring. However, the city has been at its present site for many years (Ref. 8). It is apparent that the deeper part of the channel is on the inside of the bend, on the Thai side, and that the sandbar or slip-off point forms the outside of the bend, on the Lao side, resulting in the formation of Dan Diane Island. The outside of the bend has not been eroded to any significant extent for the past 100 to 150 years (Ref. 8). At the present time the inside of the bend is eroding even though the soil materials contain considerable laterite.

The 1973 study concluded that construction of Pa Mong would cause some erosion of the slip-off point and might endanger the islands; however, most of the erosion would occur on the Thai bank and would not seriously affect the outside of the bend and the city of Vientiane. If erosion started along the Lao side, bank protection would be required to protect the city.

### 3.4.4 Downstream sand transport rate

Estimates were made of the average annual sand transport rate of the channel, i.e., the amount of sand conveyed downstream, according to Toffaleti's method as applied by Simons and Shen (Ref. 3.4.5 for the regulated flow after the completion of the project. The rate was estimated to be 29.7, 30.7, 35.0 and 28.8 million metric tons for high pool water levels at Pa Mong of 260, 250, 240, and 230 m MSL respectively. The summarized results of the study are included in Table 5.

### 3.4.5 Water surface profile for degraded channel

After vertical and horizontal degradation takes place the water surface profile will be changed. As the river bed is scoured down for some 3 to 6 m, the water surface profile would also be lowered by more or less the same amount. This phenomenon will take place over a number of years but will be faster near the damsite. Results of a study of tailwater elevations downstream from the dam for various discharges with different conditions are presented as follows (Ref. 11).

| River discharge ($m^3$/sec) | Tail water elev. m MSL | | |
|---|---|---|---|
| | Present condition | Vertical degradation | Vertical and horizontal degradation |
| 2,000 | 162.6 | 158.6 | 158.6 |
| 10,000 | 168.8 | 163.2 | 162.0 |
| 20,000 | 172.8 | 168.3 | 165.0 |
| 30,000 | 174.8 | 172.3 | 167.8 |
| 40,000 | 176.8 | 175.1 | 170.2 |

## 3.5 Downstream silt studies

The effects of storage at Pa Mong, in modifying downstream silt deposition of value for agricultural purposes, are reviewed elsewhere (See discussion on agriculture).

## 4. Summary of erosion and sedimentation effects of Pa Mong

### 4.1 Bank stability and erosion

Degradation downstream of the dam will both deepen the channel and increase its width and lower its gradient. Because the Mekong normally carries sizeable amounts of silt, its eroding capacity will be significant and scouring of areas downstream must be expected. Increased bank erosion will be one of the more significant effects and over long periods of time, could result in channel widening of many metres. People living along the river banks would be troubled by such effects and eventually bank protection works may be required. Although such long-term downstream erosion could alter the channel significantly, these effects will be gradual at most localities and can be minimized by good planning. As the stream recovers its full silt capacity for its readjusted gradient, the processes of erosion and deposition will approach a stable condition. Some continuing erosion and deposition as is characteristic of all streams, will occur.

Terracing of river banks and other bank protective measures may be desirable at selected locations where experience indicates their feasibility following construction of Pa Mong. Experience under natural conditions furnishes guidelines to indicate likely problem areas. For example, erosion and scour have been common along both banks upstream from range 8 to the damsite where there are rock outcrops of the Khok Kruat formation. Also, extensive scour has taken place on the left bank downstream from the Wat Sop gauge and above Tha Bo, in the steep silt loam of the left bank at Ban Hom (range 23), and in the clay loam bank of the lower part of Tha Bo bend.

### 4.2 Sediment deposition in reservoir

With the construction of Pa Mong dam sediment will be deposited at the head of each valley entering the reservoir. As previously noted, the total annual sediment inflow and deposition in the Mekong arm of the reservoir is estimated at

160 million tons. For a reservoir with a 250 m MSL high pool level, the accumulation of sediment load is expected to reduce the reservoir storage capacity from 98.3 billion m3 at the beginning to about 91.9 billion m3 within 50 years after closure. The sediment deposition in the reservoir was estimated to fill the reservoir from the original bed level of 155.4 m MSL to the level of about 178.3 m MSL within a 50 year period and to 185.8 m MSL in 100 years. The losses in reservoir capacity will be 6.7 and 13.4 per cent, respectively, for 50 and 100 years.

4.3 Alterations in groundwater hydrology

After sedimentation has taken place in Pa Mong reservoir for a long period of time, consolidation of such deposits would occur. This will gradually reduce the percolation rate of groundwater recharge, and consequently change the groundwater hydrology of the basin. More details concerning this particular subject are discussed elsewhere (See discussion on groundwater).

4.4 Alterations in drainage patterns

Erosion of the land due to precipitation and runoff from overland flow, especially in the sandy soil areas, may cause deposition in the natural drainage system with reduction in capacity. Proper vegetative covering of the surface together with drainage system maintenance will be needed to maintain an effective system. As previously noted, scouring of the river bed downstream from Pa Mong will cause lowering of the water surface profile of the river for a considerable distance downstream, i.e., as much as 160 kilometres (Ref.24). The lowering of water level in this reach will be beneficial to drainage of the surrounding areas.

4.5 Upstream river flow modification

Normally reservoir storage results in creation of delta like formation at the head of the reservoir, where upstream sources deposit their load when the flow reaches the standing water of the reservoir. Slowly the deposited sediment will be carried along the stream beds. This will result in channel aggradation for several kilometres depending on natural channel conditions and channel hydraulics.

4.6 Inundation

The upstream aggradation as previously described will result in raising of the water surface profile depending on the channel characteristics. This will cause an increase in the extent of inundat areas depending on topography. In contrast, the areas downstream of the dam will have less risk from inundated than before construction of the dam because of the lowering of the water surface profile in the river.

## 4.7 Agriculture

Lowering of the river bed and water level, because of degradation in the channel downstream of the dam, will decrease the extent of lands which can be irrigated from the river by gravity, especially during periods of low streamflow. However, this process would take at least 20 years and perhaps considerably longer after closure of Pa Mong dam. Pump irrigation may be substituted in the downstream area to overcome some of these effects.

## 4.8 Ground erosion control

Precipitation and runoff often causes damage to lands by washing away of top soil due to overland flow. While such soil losses will occur with or without the Pa Mong project, under with project conditions certain protective measures may be desirable as part of the overall project investment. In addition to construction of surface drainage systems for protection of valuable lands, use of vegetative covering may also be desirable, especially on the higher terrace lands which contain sandy textured soils and steeper surface gradients. To reduce unnecessary erosion and the resulting deposition in the reservoir, soil conservation measures should be practised throughout the area. Terracing is sometimes a useful adjunct to other control or protective measures.

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(5) "Definitive Computation of Sand Discharge in Rivers". F.B. Toffaleti, Journal of Hydraulics Division, ASCE, Vol. 95, No. HYI, Proc. Paper 6350, p. 225-248, January 1969.

(6) "Remarks on Degradation Below the Proposed Pa Mong Dam". Delft Hydraulics Laboratory, July 1975.

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(10) "Report on the Hydrologic and Meteorologic Network in the Lower Mekong Basin". Information Note by the Secretariat MKG/R. 94, 30 Aug. 1974.

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TABLE 1

NUMBER OF SUSPENDED SEDIMENT SAMPLING TAKEN DURING 1960-1974

MEKONG RIVER

| Location | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEMOCRATIC KAMPUCHEA | | | | | | | | | | | | | | | |
| Stung Treng | 4 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kratie | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phnom Penh | 4 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LAO PDR | | | | | | | | | | | | | | | |
| Luang Prabang | 8 | 105 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Vientiane | 3 | 95 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pakse | | 109 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THAILAND | | | | | | | | | | | | | | | |
| Pa Mong Camsito | | | | | | | | | | | | | 81 | 67 | 46 |
| Chiang Saen 1/ | 22 | 20 | 5 | 0 | 0 | 0 | 0 | 0 | 47 | 66 | 89 | 65 | 62 | 29 | 37 |
| Chiang Khong 2/ | | | | | | | | | 13 | 32 | 36 | 34 | 0 | 0 | 0 |
| Chiang Khan 3/ | | | | | | | | 95 | 56 | 45 | 69 | 50 | 52 | 42 | 26 |
| KM 1601 & Vicinity | | | | | | | | | 15 | 3 | 0 | 0 | 0 | 0 | 0 |
| Nakhon Phanom | 4 | 59 | 51 | 18 | 32 | 21 | 6 | 25 | 26 | 50 | 63 | 39 | 47 | 33 | 23 |
| Mukdahan | 9 | 60 | 73 | 32 | 42 | 38 | 45 | 43 | 45 | 74 | 83 | 53 | 73 | 71 | 69 |
| Khong Chiam 4/ | | | | | | | 49 | 24 | 12 | 16 | 0 | 0 | 12 | 26 | 34 |
| Sop Kok | | | | | | | | | | | | | 60 | 34 | 37 |
| Nong Khai | | | | | | | | | | | | | 78 | 97 | 74 |
| VIET-NAM | | | | | | | | | | | | | | | |
| My Thuen | | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chau Doc (Bassac) | 2 | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tan Chau | | | | | | | | | | | | | | 6 | 0 |

Notes: 1/ established by NEA in 1968

2/ established by NEA in 1967

3/ established by USBR in 1968

4/ established by NEA in 1966

TABLE 2

NUMBER OF SUSPENDED SEDIMENT SAMPLING TAKEN DURING 1960-1974

MEKONG TRIBUTARIES

| River | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEMOCRATIC KAMPUCHEA | | | | | | | | | | | | | | | |
| Se Kong | 5 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tonle Sap | | 45 | 0 | 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Stung Sen | | | | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LAO PDR | | | | | | | | | | | | | | | |
| Nam Ou | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nam Suong | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nam Khan | | 32 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nam Lik | | | | | | | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nam Ngum | 8 | 6 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Se Bang Fai | | 15 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Se Bang Hieng | | 18 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nam Ca Dinh | | | | | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THAILAND | | | | | | | | | | | | | | | |
| Nam Mae Lao | | | | | | | | | | | | | 25 | 38 | 14 |
| Nam Mae Fang | | | | | | | | | | | 24 | 40 | 20 | 31 | 34 |
| Nam Mae Kok* | | | | | | | | 30 | 39 | 36 | 61 | 60 | 66 | 66 | 48 |
| Nam Mae Kok* | | | | | | | | | 18 | 36 | 56 | 64 | 37 | 47 | 53 |
| Nam Mae Kok | | | | | | | | | | 35 | 30 | 0 | 0 | 0 | 0 |
| Nam Mae Ing* | | | | | | | | | 19 | 32 | 32 | 33 | 32 | 20 | 31 |
| Nam Heung* | | | | | | | | 47 | 46 | 40 | 46 | 25 | 40 | 30 | 28 |
| Nam Man* | | | | | | | | 30 | 25 | 22 | 26 | 30 | 16 | 19 | 20 |

Notes: Stations in Thailand not including those operated by RID

* Stations established by NEA

TABLE 2 (Cont'd)

NUMBER OF SUSPENDED SEDIMENT SAMPLING TAKEN DURING 1960-1974

MEKONG TRIBUTARIES

| River | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| THAILAND | | | | | | | | | | | | | | | |
| Nam Loei* | | | | | | | | 31 | 28 | 18 | 24 | 32 | 33 | 26 | 26 |
| Huai Nam Lai* | | | | | | | | 30 | 24 | 23 | 22 | 0 | 0 | 0 | 0 |
| Nam Songkhram* | | | | | | | 40 | 12 | 66 | 47 | 60 | 0 | 39 | 28 | 25 |
| Nam Pung* | | | | | 2 | 0 | 27 | 42 | 43 | 64 | 77 | 50 | 43 | 34 | 30 |
| Nam Kam* | | | | | | | | 39 | 40 | 63 | 76 | 0 | 0 | 0 | 0 |
| Huai Bang Sai | | 8 | 0 | 0 | 3 | 0 | 0 | 17 | 41 | 45 | 42 | 27 | 26 | 22 | 39 |
| Huai Bang-i* | | | | | 3 | 0 | 23 | 39 | 43 | 67 | 52 | 42 | 43 | 39 | 38 |
| Nam Chi | 4 | 20 | 13 | 8 | 8 | 7 | 7 | 42 | 46 | 56 | 102 | 87 | 60 | 53 | 45 |
| Nam Pong* | | | | | 11 | Construction of dam | | | | | | | | | |
| Nam Mun | 4 | 21 | 21 | 12 | 13 | 15 | 15 | 43 | 29 | 40 | 74 | 49 | 54 | 45 | 38 |
| Nam Mun* | | | | | | | | 18 | 0 | 57 | 43 | 0 | 24 | 18 | 46 |
| Nam Mun* | | | | | | | | | | 39 | 42 | 0 | 0 | 0 | 34 |
| Lam Dom Noi | | 12 | 5 | 6 | 3 | 6 | 32 | 34 | 40 | 52 | 19 | 0 | 0 | 0 | 0 |
| Lam Dom Yai* | | | | 6 | 2 | 6 | 34 | 37 | 46 | 85 | 90 | 46 | 50 | 38 | 31 |
| Lam Dom Yai* | | | | | | | | | 137 | 140 | 117 | 75 | 43 | 24 | 11 |
| Lam Ta Kong* | | | | | | | | 56 | 20 | 9 | 51 | 0 | 0 | 0 | 0 |
| Lam Ta Kong | | | | | | | | 49 | 48 | 36 | 0 | 0 | 0 | 0 | 0 |

Notes: Stations in Thailand not including those operated by RID

* Stations established by NEA

TABLE 3

SEDIMENTATION LOAD STUDY FOR PA MONG

| Description | Pa Mong MSL | | | |
|---|---|---|---|---|
| | 230 | 240 | 250 | 260 |
| Sediment volume in 50 year period (x $10^6 m^3$) | 6,318 1/ | 6,367 1/ | 6,640 | 6,450 |
| Elevation of sediment at dam in 50 year period (m MSL) | 182.7 | 181.0 | 178.3 | 176.8 |
| Sediment volume in 100 year period (x $10^6 m^3$) | 12,718 1/ | 12,900 1/ | 13,301 | 12,900 |
| Elevation of sediment at dam in 100 year period (m MSL) | 196.0 1/ | 190.0 1/ | 185.8 | 184.0 |
| Original reservoir capacity (x $10^6 m^3$) | 40,500 2/ | 65,000 2/ | 98,276 | 139,640 |
| Final capacity after 50 year period of sedimentation (x $10^6 m^3$) | 35,400 2/ | 59,000 2/ | 91,680 | 133,190 |
| Final capacity after 100 year period of sedimentation (x $10^6 m^3$) | 30,000 2/ | 53,000 2/ | 85,101 | 126,740 |
| Reduction of reservoir capacity (%) : | | | | |
| After 50 year period | 12.5 | 9.2 | 6.7 | 4.6 |
| After 100 year period | 25.9 | 18.4 | 13.4 | 9.2 |

Note: (1) Bottom of Pa Mong reservoir 160 m MSL (bottom of Mekong river - at damsite)
(2) Bottom of Nam Lik reservoir 173 m MSL ( " " " " " " )
(3) Bottom of Nam Mong reservoir 186 m MSL( " " " " " " )
(4) Sediment load to Pa Mong reservoir - 160 x $10^6 m^3$/year

1/ Extracted from Table I-13 of Reference 24.

2/ From relationship between reservoir elevation and capacity, Fig. I-30 of Reference 24.

TABLE 4

REVIEW OF STUDIES OF PA MONG DOWNSTREAM EROSION

| Study | Reference No. | Date of Study | Magnitude of Study | Methodology Used | Conclusion |
|---|---|---|---|---|---|
| Stage One report | 15<br>15 | 1970 | Data collection for sedimentation and degradation study. | Field investigation data collection and analysis. | The river bedrock elevations ad determined from soundings during sedimentation investigations were used as guide limits of degraded channel. It was recommended that the river bar upstream from Vientiane not be considered as a source of aggregate for the dam since it would seem advisable to consider it as riverbank protection for the city. |
| Phase II report | 18 | 1972 | Extending of study reach farther downstream (approximately 160 kilometers from damsite). | Field investigation data collection and analysis by tractive force. | The future graded bed of the stream would scour down to geologic bedrock and further horizontal degradation or bank scour would occur. It was realized that the Mekong channel would widen after construction of Pa Mong dam. The sediment load of Mekong was estimated to be 132 million $m^3$ annually. It would take 27 years to remove 3,530 million $m^3$ of bed material from the channel reach between ranges 14 and 62. |
| Borland report | 24 | 1973 | Extension of scope of study both on sedimentation and degradation. | Analysis by tractive force theory. | It was estimated that the bank full width of the river will be nearly doubled and the water surface will be lowered as much as 8 meters for medium and lower stage flows. The average annual sediment load of the Mekong of 160 million $m^3$ was considered to be accurate within plus or minus 20 per cent. |
| Simon and Shen report | 20 | 1974 | Review of Borland report. | Analysis by Tractive force theory. | The average annual sediment load of 160 million $m^3$ was still recommended for the Mekong river. It would take about 60 years for the flow to achieve a degraded channel with an average of about three meters of bed degradation and 100 meters of widening. It is anticipated that a strong meandering tendency will occur after the completion of the project. |
| Delft hydraulics laboratory report | 28 | 1975 | Review of previous degradation studies. | Analysis by diffusion equation, i.e. variation of bed level is function of place and time. | Fifty per cent of final degradation is reached, in a reach 200 kilometers downstream from damsite, in 133 years after closure of the dam while the average erosion within this reach is about 2 meters. |

TABLE 5

SUMMARIZED RESULTS OF ESTIMATES OF AVERAGE SAND TRANSPORT LOAD

(BY TOFFALETI'S METHOD AFTER SIMON & SHEN'S REPORT, 1974

EXTRACTED FROM TABLE 13, REF. 20)

| Pa Mong HWL | Average Sand Transport Load | |
|---|---|---|
| | Thousands Tons/Day | Million Tons/Year |
| 230 | 106.3 | 38.8 |
| 240 | 95.8 | 35.0 |
| 250 | 84.2 | 30.7 |
| 260 | 81.3 | 29.7 |

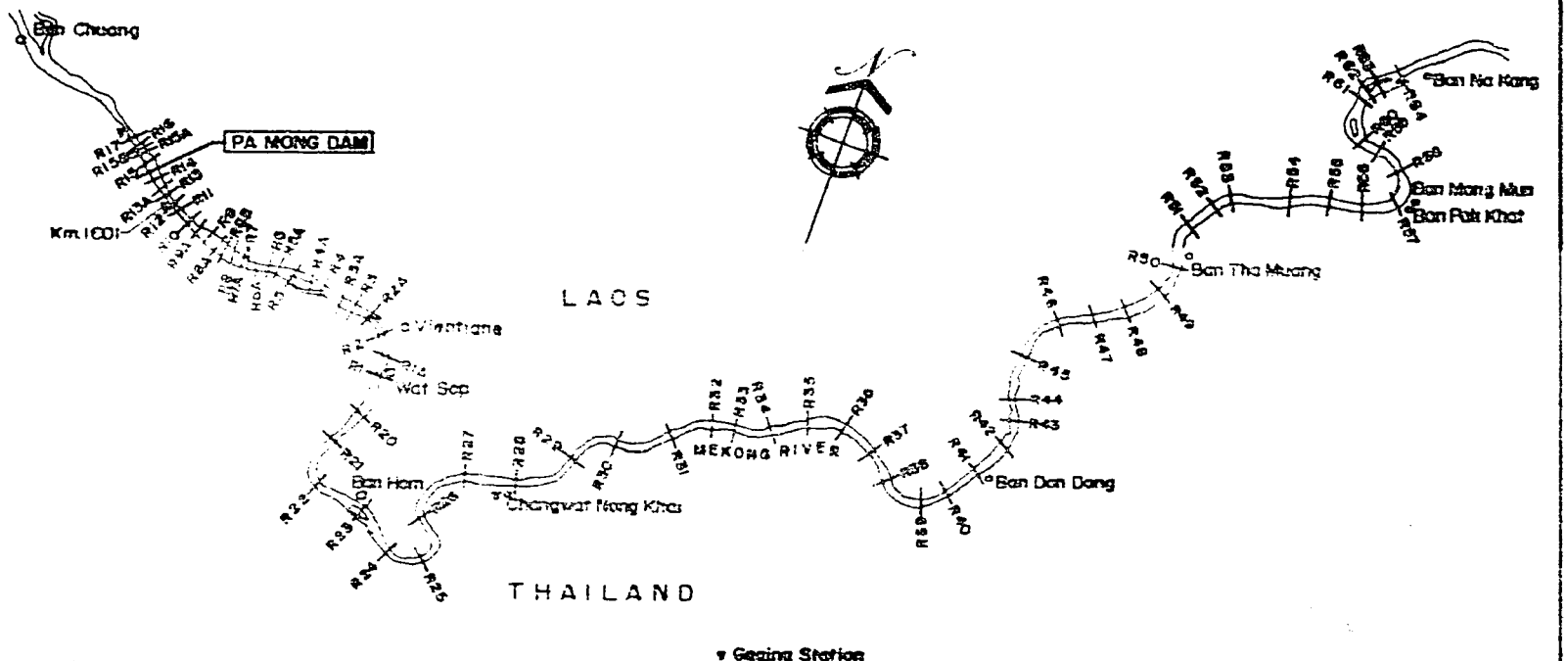


FIGURE I

LOCATION OF RIVER CROSS SECTIONS OF MEKONG RIVER

(Taken from Pa Mong Phase II Supplement to Main Report, Volume 2, Bureau of Reclamation, 1973, Reference 24)

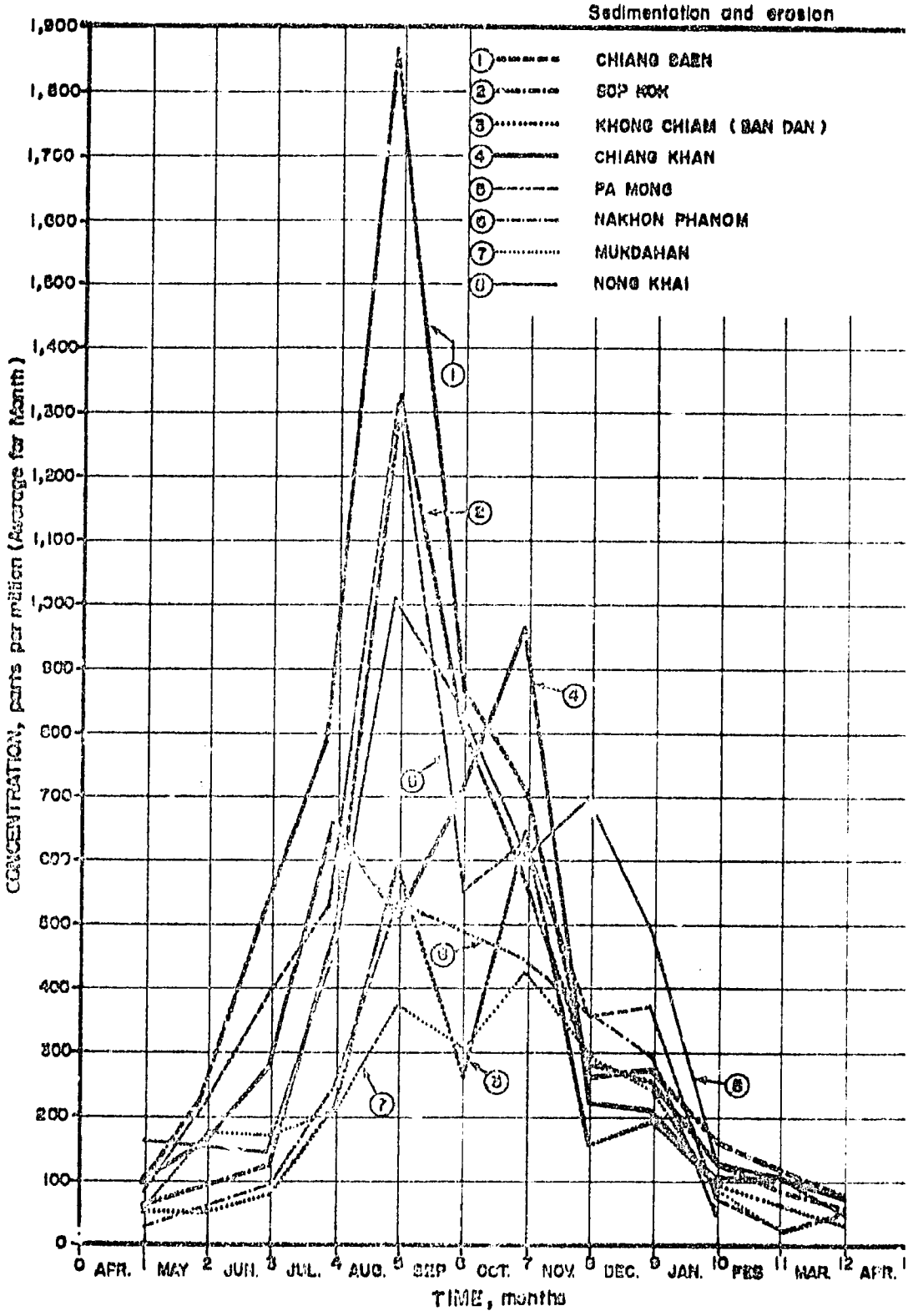


FIGURE 2

SUSPENDED SEDIMENT IN MEKONG RIVER IN LOWER BASIN ( 1972 )

BEST AVAILABLE COPY



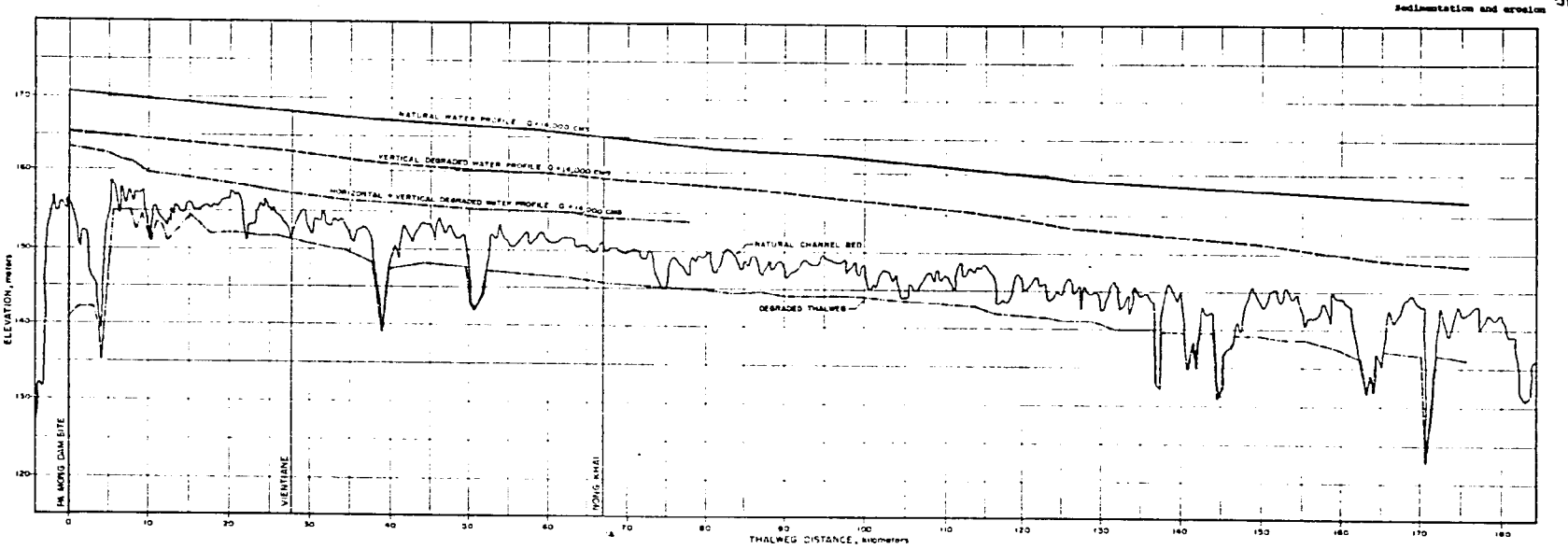


FIGURE 3

RIVER CHANNEL PROFILE - DEGRADATION STUDY AND COMPARATIVE WATER SURFACE PROFILES

(Extracted from Figure IV-47, Reference 24)

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## SOCIO-ECONOMICS

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Table 3: Summary of selected economic impacts from Pa Mong Phase II irrigation

# PA MONG ENVIRONMENTAL ASSESSMENT

## SOCIO-ECONOMICS

### 1. Introduction

One of the most sensitive environmental issues for major dam and reservoir projects, in addition to the resettlement problem (which is separately discussed), is whether the quality of life of the affected rural farming population will in fact be improved by the project as intended. A key aspect in making such an evaluation is to gain a competent picture of the existing socio-economics of the rural population, including attitudes towards the proposed Pa Mong project, to serve as a basis for project planning which is realistic in terms of the response of the affected population which can be expected when the project is built.

To obtain such background information the Mekong Committee has over the past decade implemented an impressive programme of studies dealing with the lower basin in general and with the areas to be most affected by Pa Mong in particular (Ref. 1-33). These studies are too numerous to describe in any detail, but Table 1 has been prepared to indicate their content and also to cite references which describe the details. A significant contribution is the recent report of the Netherlands Economic Institute (Ref. 31) on methodology for economic planning studies in the lower basin, including macro-economic considerations, agro-demand projections, production costs of agricultural commodities, agro-industrial potentials, power demand projections, studies of power oriented industries, coordination of national and basin development planning, and methodology for making economic appraisals of proposed projects including methods for estimating resettlement costs.

Of particular important in evaluating the socio-economic effects of Pa Mong are the bench mark surveys (Item 1a of Table 1), which are listed in Table 2, the surveys of farmers response to irrigation (Item 5a, Table 1), and the rural development seminars (Item 1e, Table 1).

### 2. Feasibility of irrigated agriculture

As a key aspect of the Mekong Committee's policy that the benefits of Pa Mong and other water resource projects in the lower basin will be used to improve the quality of life for the basin's inhabitants, the Pa Mong project plan provides for the irrigation ultimately of up to a million hectares in northeast Thailand and Lao PDR, and also will greatly enhance irrigation potentials in the delta by

maintaining an assured minimum dry season flow. This commitment will certainly have profound impacts on the socio-economics of the rural population, and the extent of these impacts will depend upon the decisions yet to be made on alternative strategies for irrigation development.

Irrigated agriculture, in contrast to traditional rainfed rice monocropping, requires the imposition of modern technology and related controls, including proper land preparation, choice of appropriate seed varieties, use of appropriate agricultural chemicals for fertilizer and weed and pest control, use of some mechanized equipment, storage facilities, access roads and transport, availability of adequate markets with fair prices, availability of timely and reasonable credit, and training of farmers through extension services and other means.

Assuming the irrigation system has been provided, to put this to good use will require transforming the attitudes, habits, customs, and social institutions to suit the new farming methods. This means drastic changes in the traditional socio-economic patterns including reorienting the processes of rural education to focus on rural agricultural needs, upgrading the agricultural extension services, creation of farmers cooperative organizations, provision by government of access roads and of trucks for transport, control of lending institutions to insure proper credit, management of land tenure so that the farmers will remain free owners and not become share croppers, and many other transformations.

The Mekong Committee's programme in socio-economics has encompassed a variety of studies including extensive field surveys in the projected Pa Mong irrigation areas in northeast Thailand and Lao PDR with the objectives of ascertaining the facts, namely, the existing socio-economic conditions in the rural villages (e.g., the bench mark surveys), the attitudes of the farmers toward changing from traditional to accelerated methods, and the potentials of the government supporting services for furnishing their share of input into the new type of agriculture.

The Mekong Committee studies show (Table 2) that the typical farm family has from 5 to 7 members, including about 3 workers, has from 2 to 6 hectares of land, depends primarily on rainfed rice monoculture, is tradition oriented in farming methods (still depends mostly on water buffalo power), consumes much of his own rice product (hence is not too concerned about the business aspects of selling the rest), depends for labor primarily on his own family (has few funds for hiring labor), realizes significant extra income from non-rice agricultural activities (gardening, fishing), seeks non-farming employment during the dry season to supplement his income, has an education level of about four years of schooling, often does not have formal legal title to the land

he thinks he owns, sometimes has too little land due to fragmentation on inheritance, and has a total income in cash and kind usually in the range of US$400-850 per year, just enough to meet his immediate needs, and can be regarded as "poor" compared to his urban compatriots.

The studies and surveys also show that the farmer in the projected irrigation areas will generally be interested in and willing to change his traditional methods and convert to irrigation and multiple cropping, primarily out of desire to increase his income. He must, however, receive assistance of the types noted above if he can be expected to do his best to be successful. In fact, the studies show that many existing irrigation projects in tributary areas have been something less than successful because the necessary guidance and assistance was not forthcoming, hence these irrigation projects scarcely justify their costs judging from their productivity records.

For the governments to provide assistance would of course require that the governments assume proper responsibility for their new role and especially to devote a sizeable share of the national resources (always in short supply in the developing nations of Southeast Asia) to this purpose. While the lower basin governments have yet to make the strategic decisions as to the extent to which such assistance will be given, the studies to date all point to a basinwide policy that some basic minimum "package" of assistance of both improved social institutions and community facilities will be provided in the irrigated areas to insure a significant improvement in the quality of life.

The Mekong Committee's studies have included examination of virtually all aspects of the problems of conversion to irrigated farming, including (a) agricultural research of the experimental farms to determine the best selections and techniques for multiple cropping; (b) public health studies including investigation of malaria, schistosomiasis, and other diseases which might be caused or intensified by environmental changes due to irrigation, and including methods for furnishing community water supply and sanitation systems suited to irrigated farming villages; (c) potential new fisheries through fish farming made possible with an assured supply of irrigation water; (d) investigation of agro-industrial potentials; and (e) a variety of socio-economic investigations for statistical evaluation of the current economic and social conditions in tributary areas in the same region where irrigation has already been practised for many years. The total of all these studies indicate the Mekong Committee now has a fairly firm understanding and appreciation of the existing socio-economic values and has sufficient study findings for preliminary planning of the contemplated socio-economic aspects of irrigated farming communities. However, because of the admitted complexity of the subject, involving as it does the very basic philosophies

of lower basin governments and social concepts, a system of pioneer agricultural projects, i.e., full-scale farming communities, is being implemented as the only sure method for proving out the validity of the new concepts -- to make sure they will result in higher production and in satisfaction both to the farmers and to the national governments. Within a period of about five years, the accumulated experience of these farms -- which will be carefully monitored as to performance and results -- should be sufficient to permit the national governments to make their strategy decisions on such basic questions as educational requirements, community facilities, etc., and in turn to permit the Mekong Committee to prepare detailed plans for implementing the proposed wide-scale application of irrigated agriculture to be associated with Pa Mong.

A beginning effort to demonstrate the feasibility of irrigated agriculture in the lower basin has been made by the Mekong Committee's resettlement study and planning project through pilot operations carried out at Huey Luang and at Nam Pong in northeast Thailand in 1974-75 (Ref. 32). These pilot projects, including detailed attention to both rainfed and irrigated farming of the resettled family's allocated land plot, establishment of a farmers cooperative, and agricultural extension services, have succeeded in increasing family income levels to reach the desired target levels (See discussion on resettlement for further details).

To sum up, the types of irrigated farming communities contemplated will require extensive changes in the socio-economics of farmers accustomed to rainfed rice cropping, but in return the farmer will enjoy a higher income and a significantly better quality of life. Moreover the farmers will tend to be drawn together into more closely-knit communities which will enhance the national political stability. All this is a great expectation, and certainly transcends the actual results of irrigation projects in the region to date. The difference lies in the Mekong Committee's programme of studies which have carefully evaluated the key problem areas and have been working toward evolution of realistic solutions.

3. Need for irrigation agriculture

The various Mekong Committee studies indicate the population in the projected Pa Mong irrigation areas will probably double within about 30 years. Whereas some 80 per cent of the existing population is engaged in rural farming, it appears there will be insufficient new lands available to maintain this ratio. As growth proceeds, an increasing percentage must locate in urban zones. However the extent of industrial growth will not be sufficient to absorb all the growth, hence very substantial numbers must be farmers. This will require greater productivity per unit of available land, i.e., will require conversion to irrigated farming for large areas, which in turn will require development of a mainstream dam project with large storage capacity, such as Pa Mong, as

the only source of the necessary water. In northeast Thailand, for example, of the total area of 17 million ha, eliminating areas not suitable for farming (due to soils, floods, erosion, topography, or urban use) leaves only 6 million ha of which 5 million ha were already under cultivation in 1970. To convert from rainfed paddies to irrigated agriculture will require an assured supply during drought years of about 42 billion $m^3$ including 14 billion $m^3$ for dry season irrigation. The total watershed runoff in drought years is about 14 billion $m^3$, hence the deficit of 28 billion $m^3$ must come from another source, the Mekong river.

The conclusion of these studies is, while the Pa Mong project may be financially viable for its power production alone, the agricultural potentials of the project, including both irrigation and reclamation of lands through flood control, may prove to be even more important.

4. Specific effects of Pa Mong

(a) Economic impacts: Some of the economic impacts of the Pa Mong project Stage One irrigation service area development which can be quantified are listed below:

(1) Increase in annual paddy rice production by about 194,000 metric tons, in the annual quantity of paddy rice milled by existing rice mills by about 194,000 metric tons, and in annual paddy rice storage requirements by about 70,000 metric tons.

(2) Increase in annual use of commercial fertilizer by about 21,600 metric tons.

(3) Increase in total length of farm to market roads in the Stage One area from 30 to more than 1,200 km, which will increase the ratio of kilometres of roads per square kilometre of cultivated land from 0.19 : 1.0 to 2.56 : 1.0.

(4) Increase in per capita gross receipts of trades and service industries by about four times plus doubling of the number of firms and of the number of persons engaged in these businesses.

(5) Temporary employment opportunities for a substantial number of workers in the labor force required to construct the project, and temporary employment for skilled and unskilled workers to harvest and market timber in the reservoir areas prior to inundation.

(6) Permanent employment for a sizeable force of technicians to operate and maintain the irrigation facilities and the dam-dike-reservoir complex, power plant and power transmission lines, and for training the farmers in irrigation methods.

(7) Fish farming opportunities for about 2,130 families and increase in total annual fish catch by 210,000 metric tons in the Pa Mong reservoir and Stage One area.

(8) New agricultural farming opportunities for about 1,700 families in the Stage One area.

(9) Provision of a monthly market for about 17,000 metric tons of ice and about 420 metric tons of fish feed, which will encourage investment in facilities and provide added employment opportunities.

Some of the economic impacts that would result from development of the Pa Mong project Phase II project are presented in Table 2.

(b) Social impacts: The Pa Mong project will have social effects on a great many people and institutions. The lives and livelihoods of farmers, businessmen, professional men, laborers, and people engaged in transportation, trade, finance, public services, and utilities will all be affected. Farmers will need to work in the fields all 12 months of the year instead of the traditional 6 months. Existing social structures will be disrupted temporarily during construction of the project dam and distribution facilities and on-farm development facilities. Village life will change with respect to the operation and maintenance of the irrigation facilities in that farmers will find that organization is necessary to assist each other in the common goal of operating and maintaining these facilities. Extra schooling will eventually be required as the need for more advanced technology develops, and increased agricultural extension training will also be required to assist the farm operators in improving farm management practices.

Two special impacts are the following:

(1) Political stability: The project will have an important social effect on political stability in the area, which can be expected to result from the banding together of communities for the operation and maintenance of the irrigation facilities for cooperation in a common cause. Much of the new stability will result from the change or shift from near-subsistence farming to a more intensive, double-cropping system producing more crops for sale on the commercial market and thereby increasing cash farm income and national benefits.

(2) Improved living conditions: Substantially improved living conditions will result from development of the Pa Mong project. Homes can be enlarged and improved, and more and better food will be available. Availability of potable domestic water will be a definite asset to community living. Health and sanitation conditions will improve. More family income will be available with which to acquire the necessities or luxuries of life.

(c) Pa Mong islands: The numerous islands to be created in Pa Mong reservoir will definitely contribute to the new order of socio-economics. Some 133 of these islands (for a 250 m pool level) will be large enough (exceeding 25 ha) for establishing fishing villages, recreational sites, and special facilities such as biological research stations. Agricultural resettlement will be possible on 60 islands, and 34 are suitable for wildlife refuges. The islands can also serve as stations in the vast water transportation system expected to be created by the reservoir. Proper use of the islands for human settlements will require careful planning including provision of community facilities for sanitation and water pollution control.

(d) Effect of different pool levels: The nature of the socio-economic impact of Pa Mong will be the same regardless of pool level. The extent of the effect will depend primarily on the extent of the irrigation service area, i.e., the numbers of farmers to be involved. Another factor will be the size and extent of the periphery of the new lake, which will be dependent not only on pool level but on the pattern of protection methods selected for Loei and Vang Vieng. The larger the lake and its periphery, the greater will be the potentials for new communities and related farming and agro-industries to be built around the lake, and the greater the potentials for navigation and recreation.

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(b) "Annex II: Long-Term Projections of Domestic and Foreign Demand for Agricultural Products for the Countries of the Lower Mekong Basin".

(c) "Annex III: Projections of Power Demand for the Countries of the Lower Mekong Basin, 1973-2000".

(d) "Annex IV: Power-Oriented Industries in the Countries of the Lower Mekong Basin, A Macro-Economic Approach".

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TABLE 1

ORGANIZATION OF MEKONG COMMITTEE'S SOCIO-ECONOMIC STUDIES PROGRAMME

| Type of Study | References |
|---|---|
| 1. Social planning | 15, 25 |
| (a) Bench mark surveys | 3, 4, 5, 6, 7, 8, 14, 32 |
| (b) Development and support communication service | 10 |
| (c) Physical planning | 15, 25 |
| (d) Rural land use affected by irrigation | 25, 34 |
| (e) Rural development seminars | 21, 22, 23, 24 |
| 2. Manpower planning | 15, 25 |
| (a) Report of preparatory mission | 1, 2 |
| (b) Pa Mong project reports | 26, 27 |
| (c) Present manpower planning programme | 15, 25 |
| 3. Agro-economic institutions | 15, 25 |
| (a) Agricultural cooperatives | 15 |
| (b) Land tenure | 15, 20 |
| (c) Agricultural credit | 15 |
| 4. Basin planning programme | 15, 25 |
| (a) Economic studies | 16, 17, 18, 31, 33 |
| (b) Socio-economic statistics | 15, 28, 33 |
| 5. Socio-economic aspects of Pa Mong planning | 15, 25 |
| (a) Surveys of farmers response to irrigation | 9, 11, 12, 13 |
| (b) Pa Mong Stage I and Phase II reports | 26, 27 |
| (c) Pa Mong islands | 19 |

Note: See also discussion of resettlement.

TABLE 2

SUMMARY OF SOCIO-ECONOMIC BENCH MARK AND RELATED SURVEYS SPONSORED BY MEKONG COMMITTEE

| | Name (Country) | | Type of Community | Year Started/ Completed | Cooperating Agencies | References (In addition to Annual Reports) | No. Families Affected | No. Families in Sample | Family Size: Total | Family Size: Children | Family Size: Adult Workers | Family Size: Elders | Average Size Farm, ha | Paddy Production tons: Per ha | Paddy Production tons: Per family | Av. Family Income (year): Total | Av. Family Income (year): Rice | Debt | Committed to mechanized rice cultivation | Amt. rice family consumed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Nam Pong (T) | (a) | Resettlement villages at Nam Pong/Non Sang | 1966/68 | Thai National Statistical Office | | | | | | | | | | | | | | | |
| | | (b) | Irrigation (Nong Wai) | 1967/69 | RTG. Dept. Land | 3 | | 217 | 7.0 | | | | 18 rai | 1.2 | 3.0 | Bt 8,705 | | Bt 472 | No | 50 % |
| | | (c) | Electric power impact | 1967 | | | | | | | | | | | | | | | | |
| | | (d) | Social studies | 1967/68 | USOM, USBR | | | | | | | | | | | | | | | |
| | | (e) | Fisheries | 1970/72 | | | | | | | | | | | | | | | No | |
| | | (f) | Resettlement pilot project | 1974/75 | Netherlands | 32 | 479 | 230 | 6.4 | 2.3 | 3.5 | 0.1 | 23.2 rai | | | | | | | |
| 2 | Pa Mong (T/L) | (a) | Irrigation area | 1966 | USBR, USOM, NEA | | 1,500 | | | | | | | | | | | | | |
| | | (b) | River fishing area | 1967/66 | RTG | | 3,451 | | 7.0 | | | | | | | | | | | |
| 3 | Vientiane Plain (L) | (a) | Irrigation area | 1972/72 | | | 3,000 | | | | | | | | | | | | | |
| | | (b) | Irrigation area | 1966 | | | | | | | | | | | | | | | | |
| 4 | Phetchaburi and Suphanburi (T) | | Irrigation areas (existing) | | USBR | | 500 | | | | | | | | | | | | | |
| 5 | Lve Dom Noi/Nam Don (T) | | Resettlement | 1970 | | | 1,000 | | | | | | | | | | | | | |
| 6 | Prek Thnot (C) | | Pioneer agriculture project | 1970/70 | Netherlands | 6 | 2,770 | | | | | | 2.05 | | | 9,100 riels $ 165 | | 2,196 riels | No | Most |
| 7 | Kalasin (T) | | Experimental farm | 1969/70 | Indonesia, NEDB | 5 | | 200 | | | | | | 2.1-2.5 rai | | Bt 8,767 | | 2,887 Bt | Yes | 52 % |
| 8 | Mekong River | | Pump irrigation | 1971/72 | NEA | | | | | | | | | | | | | | | |
| 9 | Cai Sen (SVN) | (a) | Pioneer agriculture | 1971/73 | University of Can Tho | 4 | | | 6.7 | 2.4 | 3.3 | 0.3 | 2.8 | 2.4-4 $/ha | | Piasters 134,000 | | | Yes | 47 % |
| | | (b) | Out-of-School youth project | 1973 | World Council of Churches | 4 | | | | | | | | | | | | | | |
| 10 | Lam Pao (T) | | Tributary irrigation project | /72 | | | | | | | | | | | | | | | | |
| 11 | Muk Kampoul (C) | | Pioneer agriculture project | 1972/75 | Democratic Kampuchea Dept. Agriculture | | | | | | | | | | | | | | | |
| 12 | Mae Nao (L) | | Nam Ngum irrigation | 1972/75 | | | | 200 | | | | | | | | | | | | |
| 13 | Ba Cong (SVN) | | Pioneer agriculture | 1974 | University of Can Tho | | | | | | | | | | | | | | | |
| 14 | Tha Ngone (L) | | Irrigation | 1974/75 | Government Lao PDR | 14 | | 103 | 7.6 | 53.5 % | 47.2 % | | 6.2 | 4.2 | | $ 660 | $ [illegible] | $ 44 | No | |

TABLE 3

SUMMARY OF SELECTED ECONOMIC IMPACTS THAT WOULD RESULT FROM DEVELOPMENT OF POTENTIAL PA MONG PROJECT PHASE II IRRIGATION DIVISIONS

(from Pa Mong Phase II Report)

| Items | | Pa Mong Project Phase II Irrigation Divisions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Nam Lik | Vientiane | Laos pumping | Udorn | Kum-phawapi | Lam Phaniong | Huai Pong | Khon Kaen | Nai Nah |
| Increased annual rice production | (M.T.) | 155,000 | 72,000 | 225,000 | 836,000 | 128,000 | 721,000 | 1,040,000 | 309,000 | 187,000 |
| Increased paddy milled by existing rice mills per year | (M.T.) | 0 | 16,000 | 34,000 | 297,000 | 76,000 | 324,000 | 352,000 | 309,000 | 187,000 |
| Minimum additional large rice mills required 1/ | (No.) | 3 | 4 | 16 | 45 | 4 | 33 | 57 | 0 | 0 |
| Additional paddy rice storage requirement | (M.T.) | 70,000 | 30,000 | 100,000 | 340,000 | 50,000 | 330,000 | 420,000 | 120,000 | 60,000 |
| Increased annual commercial fertilizer use | (M.T.) | 12,200 | 7,200 | 22,500 | 90,600 | 15,300 | 61,900 | 102,700 | 28,100 | 22,200 |
| Irrigation OM&R personnel requirements | (No.) | 100 | 60 | 190 | 760 | 130 | 520 | 860 | 240 | 190 |
| Increased research and extension personnel requirements | (No.) | 8 | 6 | 22 | 66 | 7 | 60 | 77 | 14 | 11 |
| Increased annual fish harvest from fish farm 2/ | (M.T.) | 7,600 | 3,600 | 11,400 | 46,100 | 8,300 | 35,800 | 52,100 3/ | 17,700 | 11,200 |
| Increased annual ice requirements | (M.T.) | 7,600 | 3,600 | 11,400 | 46,100 | 8,300 | 35,800 | 52,100 | 17,700 | 11,200 |
| Increased annual fish feed requirements | (M.T.) | 3,900 | 1,800 | 5,800 | 23,500 | 4,200 | 18,300 | 26,600 | 9,000 | 5,700 |
| New fish farming opportunities | (No.) | 1,600 | 800 | 2,500 | 9,900 | 1,800 | 7,700 | 11,200 | 3,800 | 2,400 |
| New agricultural farming opportunities | (No.) | 1,400 | 2,000 | 7,500 | 14,200 | 100 | 18,700 | 17,600 | 6 | 400 |

1/ Rice milling capacity per mill estimated at 1,000 metric tons per month. Based on the USBR Pa Mong Phase II study area processor and handler survey.

2/ Productive water surface area (hectares) of farm fisheries shown in Table IV-21 of Appendix VI times 2.0 metric tons.

3/ Includes estimated annual fish harvest from Nam Thiang Reservoir, Huai Pong Irrigation Division.

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## SOILS

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# PA MONG ENVIRONMENTAL ASSESSMENT

## SOILS

### 1. Introduction

The soil resources of the lower Mekong basin will be significantly affected by the Pa Mong project, with the primary concern being the suitability of the soils for irrigated agriculture in the proposed irrigation service areas. Other effects will result from storage and reductions in floods to be achieved by Pa Mong, which may modify delta soil fertility and deposition of silt on levee bank farming areas (chamkars) in the delta in Democratic Kampuchea. Also, water control made possible by Pa Mong will introduce opportunities for reclamation of soils not now suitable for agriculture.

### 2. Suitability of soils for irrigation

Both the Pa Mong Stage One and Phase II reports include detailed evaluations of the soils in the proposed service areas and their suitability for irrigated agriculture, including detailed tabulations of field and laboratory soil characterizations (Ref. 1, 2, 2a). A summary of these findings is presented here.

### 2.1 Soil classification and characteristics

The soils in the service areas are highly variable because of differences in the natural processes and factors responsible for their development, namely the parent materials, climate, soil organisms, topography, drainage, and time. Classification of these soils was based essentially on the soil classification system developed by the U.S. Department of Agriculture (USDA), adapted for use in Thailand through consultations between soil scientists of the USBR, USAID, and the Thailand Soil Survey Division (Ref. 2, 2a, 5). This classification recognizes that two parameters, the cation exchange capacity (CEC) and the acid-base status, are among the most meaningful indicators of soil fertility in humid and tropical regions. The CEC is defined as the sum of exchangeable basic cations (Ca, Mg, Na) and exchangeable acidic cations (Al and H). The CEC may be expressed either as "effective CEC" meaning the CEC under natural soil pH conditions, or the "total CEC" which is the maximum CEC as measured in the laboratory under controlled testing conditions. Generally the CEC is indicative of nutrient retention capacity and also correlates well with soil water holding capacity. The exchangeable acidic cations, also called exchange acidity (EA), is a measure of liming requirements for upland crops. The CEC and EA are usually expressed in milliequivalents per 100 grams of drysoil.

### 2.1.1 River levees

The soils on the river levees are predominantly Entisols (Alluvial soils). They have deep open profiles that are brown or grayish brown and show only very weak genetic horizon development. The texture of their surface layers is usually fine sandy loam to silty clay loam. The subsoil layers are usually finer textured varying from loam to silty clay, and may be stratified. Internal drainage may be slow to medium depending mainly on local gradient and subsoil texture. The river levee soils usually have medium to moderately high CEC throughout their profiles. Base saturation is usually moderately high, exchange acidity and toxic exchangeable aluminum are low, and weatherable mineral reserves are relatively high. Normally, the pH ranges from medium acid to neutral.

Although they are of limited extent, occurring mainly along the Mekong river and the Nam Ngum, the river levee soils are quite important. They are among the most fertile soils in the region and are highly productive, for a wide variety of field crops, vegetables, and tree crops. Paddy rice is usually grown on the poorly drained parts of river levees in this area. The river levees along the Nam Ngum are in thinly populated areas and mostly remain under mixed open forest or tall bamboo cover.

### 2.1.2 Active flood plains

The soils of the active flood plain areas are mainly Inceptisols (Alluvial soils and Hydromorphic soils). They are usually very poorly drained, show relatively little genetic horizon development, and have predominantly grayish colors with considerable mottling and gleying. The tecture of their surface and root zone layers is usually clay loam, silty clay, or clay. The CEC in their root zone layers is usually moderately high to high. Most profiles are medium to strongly acid and contain considerable amounts of exchangeable aluminum with concomitant low base saturation.

Most of the active flood plain soils are used for broadcast or transplanted paddy rice production in the rainy season. In this use, they are quite productive and relatively high yields are obtained when flooding is not destructive. The low-lying areas with severe flood hazard remain under thick brush or bamboo cover. These soils are quite extensive, occurring along the larger streams in all parts of the study area.

### 2.1.3 Old lowland surfaces

These soils have undergone intensive weathering and leaching and show strong genetic horizon development. They are usually poorly drained. Alfisols (low Humic Gley soils) and Ultisols (Low Humic Gley soils and Laterite soils) occupy most of the old lowland areas. Although they are of minor extent, Saline soils are conspicuous in some areas (see Section 2.2).

Whether the Low Humic Gley soils on old lowland surfaces are classified as Alfisols of Ultisols in the USDA system usually depends on the degree of base saturation. Their other characteristics a e generally similar. Texture of their surface layers ranges from loamy sand to loam. Their color is usually grayish brown or brown with distinct mottling and gleying. The subsoils have loam to sandy clay or clay textures and are typically pinkish gray with prominent mottling. In some areas soft and hard lateritic nodules may comprise up to 10 per cent of some layers below 30 cm. The CEC is usually moderately low to very low in the root zone, but may be moderately high in the subsoils. The root zone layers are mildly acid to very strongly acid and exchange acidity varies from moderately low to high.

Paddy rice is grown on practically all of the Low Humic Gley soils. In this use they are moderately productive, with yields being generally lower than on most active flood plain and river levee soils. These soils occupy the greater portion of old low lowland surfaces in all irrigation service areas. The Alfisols tend to be most prevalent in the southern parts of the study area where annual rainfall is lower and more unevenly distributed, resulting in less intensive leaching conditions. Ultisols occupy the greater portion of the old lowland surfaces in the Lao PDR service areas at the northern end of the study area.

A significant portion of the old surfaces in some areas have Laterite soils. These soils contain high proportions of gravelly ironstone concretions at depths less than 50 cm. In a few places a consolidated lateritic layer is found.

### 2.1.4 Uplands

The extensive upland areas contain a wide variety of soils including Alfisols (gray Podzolic, gray-brown Podzolic, and red-yellow Podzolic soils), Ultisols (gray Podzolic and red-yellow Podzolic soils, Latosols, and Laterite soils), and Inceptisols (Regosolic-gray Podzolic soils). The Alfisols do not include lateritic material, are less acid than the Ultisols, and are most extensive where rainfall is lowest, similar to the relationships between these orders in the old lowland areas.

The Alfisols in upland areas generally have deep imperfectly drained to moderately well-drained profiles showing moderate to strong genetic development. The texture of their root zone layers ranges from loamy sand to clay loam but tends to be moderate; coarse in most areas. Subsoil layers are usually finer textured, ranging from fine sandy loam to sandy clay loam. The color of these soils ranges from yellowish-red through grayish-brown. Their root zone layers usually have moderately low CEC, are slightly acid

to medium acid, and contain moderate proportions of exchange acidity. Some of these soils in the Lam Phaniang and Huai Pong service areas have developed from calcareous materials and have a near neutral reaction with nearly 100 per cent base saturation. The Alfisols are the most fertile soils in upland areas. A significant proportion of these soils are cultivated, especially in the areas with the higher populations and good access roads. Crops such as kenaf, cassava, sugar cane, or upland rice are usually grown.

The deeper Ultisols of the upland areas have physical characteristics and general appearance similar to the range encountered in the Alfisols. However, they are usually strongly to very strongly acid, have low base saturation, have very low CEC in relation to clay content, and have low natural fertility. These soils and the Ultisols having lateritic material at very shallow depth are the predominant kinds of soils on uplands in the Lao PDR portions of the study area and in the northernmost portions in Thailand. They occupy a significant proportion of the uplands throughout the Pa Mong study area. The native vegetation in most areas is a rather sparse low open forest vegetation. A few areas have been cleared or partially cleared and are used for upland rice or kenaf in a modified shifting cultivation system.

The Inceptisols in upland areas are soils having very coarse texture (sand or loamy sand) to depths greater than 5 cm. Most attempts to cultivate these soils are unsuccessful and most areas remain under a sparse low open forest cover. These soils are extensive in the northern part of the Khon Kaen, in the southern part of the Udorn, and in the Kumphawapi service areas.

## 2.2 Soil salinity

Salt-affected soils are those which contain amounts of soluble salts or exchangeable sodium high enough to adversely affect crop production. Although they occur on less than 0.1 per cent of the total service area, salt-affected soils may occupy as much as 4 per cent of old lowland surfaces in semi-closed basin areas such as those in the vicinity of Udorn and Kumphawapi. Scattered patches of these soils may be found on old lowland surfaces in other areas, except for the Lam Phaniang and Huai Pong service areas.

The salt-affected soils are often adjacent to or intermixed with soils containing low amounts of salts in areas that are used for rain- or flood-fed paddy rice. The salt-affected areas may either be cultivated or left idle. Where farmed, they are discernable by yellowing of the rice as the water supply decreases, stunting or poor growth of rice, scattered barren spots, and yield depression. Non-cultivated areas may be completely barren or have only patches of salt-tolerant grasses or shrubs.

The development of salt-affected soils appears to be limited to areas where saline ground water is found at shallow depth. Whether soil salinization occurs in these areas is also related to local position and microrelief. The most severely salt-affected areas are local surfaces that are elevated slightly above the surrounding lands. They are never flooded, or undergo natural flooding or submergence for rice culture only for relatively short periods. In these areas, relatively little infiltration and leaching occur and the salts accumulate near the surface as a result of evaporation of upward or obliquely moving ground water. This situation exists on the slightly elevated portions of old lowland surfaces, especially where microrelief is uneven or hummocky and on the seepage surface of gently sloping areas that are transitional to uplands. In active flood plains and other areas that undergo prolonged inundation, the soluble salts and exchangeable sodium may be high in subsoil layers in some places, suggesting accumulation through downward displacement.

Salt-affected soils do not occur on uplands or river levees because shallow saline ground water may not be present, or because their elevation, gradient, and substratum conditions permit effective leaching and subsurface drainage. Although most of the lowland and flood-plain areas east of the Phu Phan Ridge are underlain by salt-bearing strata and shallow saline ground water, the total area of salt-affected soils in these areas has remained low and essentially stable. Apparently this is because of smooth microrelief and agricultural practices that result in periodic prolonged submergence, permitting downward displacement and diffusion processes to operate effectively.

Because of their small extent and the apparent equilibrium that has been attained, the salt-affected soils are not generally considered to represent a serious problem in the region, except in a few local areas. Although these soils produce relatively low yields when farmed, the farmers have adjusted their cultural practices to obtain the largest practical yields under present conditions.

With project development, low salinity levels would be maintained in the soils of irrigated uplands and river levees because their substratum permeability and gradient conditions permit the required leaching. Because of the very slow subsurface drainage in the old lowland and active flood-plain areas, salinity control in these areas apparently cannot be based on leaching and subsurface drainage. However, salinity control over most of these areas is expected to be maintained through the periodic downward displacement and diffusion processes that will continue to occur with irrigation. These lands are expected to be used mostly for irrigated paddy rice, with the water ponded on the surface for about 225 days each year. Irrigation water applications

are expected to result in displacement of the salts initially in the soils, plus the small amounts added in the irrigation water, below the shallow root zone of rice. During the period of submergence, some diffusion into the surface water will occur. Salts that might move upward into the root zone between crops would again be displaced below the root zone by rainfall or irrigation preceding the next crop. Through these processes, both soluble salts and exchangeable sodium are expected to be maintained at low levels and there should be no significant reduction in rice yields.

The combination of anticipated land development together with irrigation development will enable efficient irrigation water distribution and application, and effective surface drainage. These developments plus the increased availability of water for displacement indicate the effect of irrigation will be to control and reduce salinity, hence a large portion of the presently salt-affected lands is expected to be reclaimed.

## 2.3 Effects of irrigation

### 2.3.1 Soil properties

The texture, structure, aggregation, and tilth relationships of the soils are considered to be favorable for their planned uses in the irrigation service areas. For example, consistence characteristics of the clayey flood-plain soils would not adversely influence crop yield or costs of production under the expected wetland rice culture in these areas. The planned land development involving bench terracing would permit efficient irrigation and erosion control on the gently sloping areas with highly erodible coarse-textured soils. However, available water capacity would be only moderately favorable in coarse-textured soils used for upland crops. Areas with steep slopes or excessively coarse-textured soils were excluded from consideration for irrigation development.

Laterite is not expected to be a problem with irrigation development. Soils having laterite at very shallow depth were not considered for irrigation. Also, soil erosion control is planned; soft forms that harden are not found in the project area; and "new laterite would not form during the planned life of the project.

With respect to the hazard of toxic products resulting from anaerobic conditions in paddy areas, it is expected the pH would stabilize at favorable levels when the riceland soils are flooded and toxic quantities of reduction products are not expected to accumulate. Also, toxic quantities of soluble salts or exchangeable sodium are not expected to accumulate in the soils.

It is concluded that the principal soil problem in irrigation of both upland crops and rice will be attaining and maintaining soil fertility. Except for some river levee and active floodplain soils and certain upland soils developed on basic rocks, available and reserved supplies of most plant nutrients are low or very low. Nitrogen and phosphorus deficiencies currently limit rice yields in most areas. Under the flooded conditions some of the nitrogen can be lost through denitrification and leaching. The low cation exchange capacities and low base saturation percentages of many of the soils indicate that their available supplies and immediately accessible reserves of nutrient cations such as potassium, calcium, and magnesium are low. Most of the soils do not contain free carbonates or sulfates of calcium or magnesium, and weatherable minerals containing these elements and potassium (e.g., plagioclase, feldspars, micas, and chlorites) are usually scarce. Deficiencies of micro-nutrient elements such as boron, molybdenum, zinc, copper, and cobalt can be expected under the prevailing acid conditions, especially when available supplies of the major nutrient elements are made adequate.

It is concluded that rather high fertilizer inputs will be required for most of the lands to be irrigated in order to attain the sustained high yields of upland crops and wetland rice expected with project development. Many major and micronutrient elements would have to be applied as fertilizers or liming materials in quantities approaching those removed by crops, plus amounts to compensate for leaching losses, fixation in nonavailable form, and inefficient absorption by the plants.

### 2.3.2 Soil zones

As previously noted, the river levee soils are considered to be the most fertile in the region. They are highly suitable for production of irrigated wetland rice and also for a variety of dry-foot crops. Also, irrigated upland crops would produce well on the better drained areas with proper soil and water management practices.

The active floodplain soils are well suited to production of wetland rice under irrigation. Although base saturation is relatively low and exchange acidity is high in most areas, these factors are not critical for rice production, and the CEC of these soils are relatively high. Available nutrient levels are probably below those required for optimum yields but these soils tend to retain added nutrients against leaching and have some weatherable reserves. Rice would respond strongly to moderate balanced fertilizer inputs and perhaps to liming. Power requirements for tillage may be moderately high but rice is well adapted to their usual moderately fine and fine textures. Water requirement would be the lowest of any project area ricelands.

The soils of arable lands on the old lowland surfaces are generally of moderate suitability for rice production with irrigation. They are relatively highly weathered and have lower CEC and plant nutrient status than the soils of river levees and active flood plains. However, economically favorable rice yield response should be obtained when balanced fertilizers are supplied. A significant proportion of the lands in the old lowland surfaces was considered nonarable because of coarse-textured soils with low CEC, shallow depth to lateritic materials, and in a few places, salt-affected soils.

A relatively large proportion of the upland areas were classified as nonarable because of intertile coarse-textured soils and soils with shallow depth to lateritic materials. The areas with deep moderately coarse- or medium-textured soils usually meet minimum criteria for arable ricelands, and are considered to be of moderate suitability for irrigation. The fertility status of these soils is about the same as that of ricelands on the old low-land surfaces. A very minor portion of the upland areas was classified as arable diversified croplands; however most of these lands are marginal for this use because of low soil fertility and inadequate drainage. A suitable alternative use under irrigation would be wetland rice culture.

## 3. Effects of Pa Mong storage and flood control

These effects are reviewed in the discussion on agriculture. Summaries only are presented here.

### 3.1 Delta soil fertility

Because of apprehension that trapping of silt by Pa Mong reservoir would result in lessening of silt deposition in the Mekong delta and hence in impairment in delta soil fertility, a study was completed in 1974 (Ref. 3) for evaluating this problem. Based on mineralogical, chemical, and physical analyses of sediments and soils in the Vietnamese delta, it was concluded that the annual deposition of sediment does not measurably increase the fertility of the delta soils in that area and moreover that water control, not soil fertility, will be the dominant factor by which large increases in delta agricultural productivity can be realized. Another interesting finding of the study was that soils near the river contained the same levels of mineral nutrients as soils away from the river.

### 3.2 Soil deposition on Chamkars

Another apprehension, in Democratic Kampuchea, is due to concern that flood control by Pa Mong would lead to impairment of chamkar agriculture (on the back slopes of river levees) because of lessening of silt deposition by

colmatage (channels carrying silt-laden flood waters to the chamkars for deposit of the silt at desired locations). A study of this problem completed in 1975 (Ref. 4), based on hydrographic analysis, showed there will be some reduction in the normal pattern of silt deposition, but that this can be largely overcome by use of efficient engineered colmatage systems rather than depending on natural creeks which are only partially effective, and also that another effect of Pa Mong flood control will be to extend the usable chamkar areas by virtually doubling the usable areas.

## 4. Reclamation of poor soils

The fact that Pa Mong will enable varying degrees of water control throughout the lower basin, including the delta where a sustained dry season flow will enable a large increase in agricultural productivity, will set the stage for development of feasible measures for reclaiming vast areas of non-arable soils now useless in the lower basin.

As noted in Section 2.2 above, salt-affected soils occupy as much as 4 per cent of the old lowland surfaces in the planned irrigation service areas. Irrigation of these lands is expected to reclaim a significant portion of these salt affected soils through downward displacement and diffusion processes expected to result from irrigation.

The discussion on agriculture notes the pilot project started in 1974 in Viet-Nam for developing methods for achieving multiple cropping on heavy clay delta soils under conditions of water control. Also, proposals are being considered for developing practicable methods based on water control for reclaiming extensive saline soil lands both in northeast Thailand and in the Mekong delta, and extensive acid sulfate soils in the delta (about 1 million ha in the Plain of Reeds area). These might represent very attractive potentials that the advent of Pa Mong could bring to reality.

## 5. Summary and conclusions

Detailed studies of the soils in the proposed Pa Mong irrigation service areas, both for the Stage One and Phase II project evaluations, have permitted classification of the soils according to their properties and physiography (river levees, active flood plains, old lowland surfaces, and uplands), and have established their general suitability for agricultural production under conditions of irrigation. Most of the soils are arable, and the nonarable soils, including soils which are saline, are excluded from the planned development. Availability of water control should permit reclamation of a significant portion of the saline soils.

Storage at Pa Mong, by reducing flood flows, will cause a reduction in downstream silt deposition in Democratic Kampuchea in chamkar areas, but on the other hand will significantly extend the total chamkar areas and with use of engineered colmatage systems adequate silt deposition can be maintained.

The availability of water control made possible by Pa Mong should make it feasible to develop programmes for reclamation of large areas of nonarable soils in the Mekong delta including saline soils, heavy clay soils, and perhaps even the acid sulfate soils (See discussion on agriculture).

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# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## SURFACE WATER

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# PA MONG ENVIRONMENTAL ASSESSMENT

## SURFACE WATER

### 1. Introduction

The control of the surface waters of the Mekong river at Pa Mong is, of course, the primary objective of the Pa Mong dam and reservoir project, to enable these waters to be used as efficiently as possible for beneficial purposes throughout the lower Mekong basin. Details regarding particular uses are given in the discussions on power, irrigation and drainage, flood control, fisheries, and other sections of this chapter.

The objective of this section of the chapter is to review the overall picture on surface waters, namely to assess the Mekong Committee's programme for basic data collection and use, which is fundamental to virtually all aspects of Pa Mong project planning, to review the application of these data for various uses in the lower basin, and to review the extent to which the surface water resources will be used for and distributed among these various uses. Of particular interest, from the point of view of environmental concerns, is assurance that the proposed project will utilize the surface water resources wisely and in a manner which will accommodate the multipurpose needs of the developing region of the lower basin.

### 2. Basic hydrologic data

Basic data on the quantity and quality of streamflows in the lower basin are essential to the planning of all water resource development projects including Pa Mong. Systematic measurement of discharge in the Mekong river and major tributaries was generally started in 1959, but the recording of river stages at some locations on the Mekong river was initiated more than 50 years ago. Table 1 summarizes the history of stream-gauging at various stations along the river from Chiang Saen to the delta. Since 1959 it has been possible to reconstitute the historical flow data from available stage records based on established stage-discharge relationships (Ref. 1). The records of streamflow data are somewhat variable in extent and quality, some being subject to adjustment due to inadequacies in field measurement.

The hydrologic basic data programme operated by the Mekong Committee (Ref. 1 to 10), which has evolved over the past 15 years, includes both collection, evaluation, and publication of basic hydrologic and meteorologic data, and applications of the data to meet specific needs of the overall Mekong Committee programme for project development. The hydrologic data collection and monitoring programme now includes streamflow measurements at a network of 216 stations throughout the basin including both the mainstream and tributaries. Streamflow measurements are made (when possible) at all stations, and at selected stations additional measurements are made for sediment content (amount

and particle size distribution) and also for selected water quality characteristics. Additional stations are used in the delta zone for measurement of salinity. In addition, a network of meteorological stations is maintained.

All the work has been carried out by the riparian governments, with the Mekong Committee serving in a supplementary role for furnishing technical guidance, equipment, and supplies, and in collecting, collating, and publishing the data on a basinwide basis. The Mekong Committee's activities have been guided by the Chief Hydrologists of the riparian countries, who, under Mekong Committee sponsorship, began meeting annually in 1969. The Mekong Committee has also sponsored a number of training courses for riparian personnel, on the technology of streamgauging and related programmes. The total investment by the Mekong Committee in the overall programme through 1975 is estimated at approximately $ 4 million.

This review and assessment is limited to the quantitative aspects of the overall data collection programme, i.e. the streamflow quantities and related data on rainfall and runoff. The overall programme includes collection and reporting of data on sediments, water quality, and salinity in the delta. The Hydrologic Yearbooks include the water quality data and a limited portion of the salinity and sediment data. These programmes are reviewed elsewhere (see discussion on salinity, sediments and erosion, and water quality).

## 2.1 Streamgauging

The basic objective of the hydrologic gauging programme is to establish rating curves at key points throughout the basin, based on correlating streamflow measurements with gage heights, so that the record of gage heights will serve as a continuous record of stream discharge. Because the Mekong is an alluvial river, with the channel continually changing, streamflow measurements must be made each year to reestablish or rejustify the rating curves to keep them up to date. The frequency of discharge measurement needed varies from river to river depending on hydraulic characteristics, but is about 50 annually for key stations, with about one-third of the measurements made during the period of high flow (which exists about 10 per cent of the year). For reaches under tidal influence a series of discharge measurements must be made over the tidal cycle.

(a) Extent of network: The hydrologic network existant in 1973, shown in Figures 1 and 2, comprised 191 hydrologic stations in the four riparian countries, including 80 stations on the mainstream and 111 on the tributaries and the delta canals (Ref. 5). The network has been continually expanding, up to 1975, at a rate from 5 to 10 per cent per year. In terms of adequacy of numbers of stations and their location, the present programme is considered reasonably comprehensive. The operations programme in Thailand is good, but in the remaining countries the work has experienced serious problems in budget, security,

and availability of trained personnel. To help ensure the smooth operation of the hydrologic network in the basin, a work programme is prepared by the Mekong Committee for each hydrologic year to help in guiding and coordinating the overall programme.

Reference 5 contains detailed information (Tables 1-4) on the streamgauging stations and measurement programmes in each of the riparian countries.

(b) Hydrologic Yearbooks: The streamflow data, published in the hydrologic yearbooks, are presented in a series of five pages, plus two pages for the data on gauge heights. The first page is the station description, which provides pertinent information on the location of the gauge, the type of gauge and its datum elevation, the drainage area above the gauge, the records available at the stations, the average discharge, and the extremes of flow. The average discharge for a station is the average of all complete years and is published only if there are five or more complete hydrologic years of record.

The second page includes the current hydrograph at the station with two different scales giving the discharge in cubic metres per second per square kilometre. The monthly and annual averages are indicated by dotted lines. The third page gives the standard rating curve (or curves) used during the year. The fourth page shows the daily mean gauge height in metres.

The fifth page contains the daily discharge and the following monthly values:

(a) Monthly volume in $m^3$/sec-days.

(b) Mean monthly discharge in $m^3$/sec.

(c) Monthly maximum daily discharge in $m^3$/sec.

(d) Monthly minimum daily discharge in $m^3$/sec.

(e) Mean monthly discharge in litre/sec/$km^2$.

(f) Monthly runoff as average depth over the drainage area in millimetres.

(g) Monthly runoff in millions of cubic metres.

(h) Annual values of maximum mean daily discharge in $m^3$/sec, and total runoff in millions of cubic metres.

The data for each gauge height station are presented on 2 pages. The first page is the station description and the second page gives daily gauge height in metres from 1 April to 31 March.

## 2.2 Meteorology

(a) Extent of network: Information on rainfall, evaporation, wind magnitudes and velocities and related data are obtained from a network of meteorological stations throughout the lower basin (Figure 3). Tables 5 to 8 of Reference 5 present current information on these stations (August 1975). These include 40 stations in the Democratic Kampuchea, 52 in Lao PDR 137 in Thailand, and 32 in Viet-Nam. Field visits by the Mekong Secretariat in 1975, for checking the operation of the stations, included 62 in Thailand but, due to security, only 1, 11, and 13 in Democratic Kampuchea, Lao PDR, and Viet-Nam respectively.

(b) Hydrologic Yearbooks: The assembled meteorological data are published each year as Volume II of the Hydrologic Yearbooks, for the calendar year period, in accordance with WMO's recommended format and technical regulations. The data include the station location, altitude, years of observations, number of rain days, the monthly and annual isohyetal maps, and a map of seismic epicenters in Southeast Asia.

(1) Precipitation data: Data on precipitation consist of monthly and annual precipitation (in mm) and rain days in parentheses. Daily values, mostly from recording rain gauges, are also shown where records are sufficiently complete. A rain day is a period of twenty-four hour in which at least 0.1 mm of precipitation is recorded. The isohyetal maps have been developed from the monthly and annual data of the total of 378 stations.

(2) Evaporation and wind data: The evaporation and wind data are obtained from Class A evaporation pans and totalizing anemometres. The evaporation data are supplemented by a table giving the wind movement in kilometres. Both evaporation and wind movement are tabulated for 24-hour periods beginning at 7:00 a.m. on the day indicated in the first column of the tables.

(3) Seismological data: One of the maps in the Hydrologic Yearbook, Volume II shows locations of seismological stations in Southeast Asia and earthquake epicentres for the region for the year.

(c) Tele-automatic raingauges: The Secretariat staff has devised a tele-automatic raingauge, specially suited to Mekong conditions, which requires a minimum of maintenance and should be reliable for installation in remote areas. Tests were begun in 1975 when it is perfected it will be used first in selected subbasins for helping improve the flood forecasting programme.

## 2.3 Problem areas

Difficulties in operating the hydrologic data system stem from essentially three sources:

(a) Security problems: The operation of the hydrologic and meteorologic network has been affected significantly by security conditions, particularly in Lao PDR, the Democratic Kampuchea and the tributary basins of the Viet-Nam highlands.

(b) Financial problems: The budget situation for the programme, like most basic data collection programmes everywhere, has been tight from the beginning. The total basic data collection operation for the years 1973-77 has been budgeted to include $ 350,000 per year in foreign exchange, which would be made available from both the riparian and donor countries. The four riparian governments are expected to assume all operation and maintenance costs beginning in 1978.

(c) Personnel: Provision of an adequate number of trained personnel is a third main problem. This is being solved largely by the training courses previously mentioned. Over the past ten years eight special courses have been conducted, on various aspects of the programme, usually of two weeks duration. Additional training has been provided by fellowships and other specially funded programmes for selected individuals.

Despite these difficulties, the overall programme has been significantly improved over the years by persistent continuing efforts by the Mekong Committee staff, participating riparian governments, and donor countries. Key factors in overcoming these problems are the annual reviews including the meetings of the Chief Hydrologists, and the work programmes prepared each year by the Mekong Committee staff for furnishing guidelines to the riparian countries to help insure the best results for the year. The recommended work programme for the year 1975, for example (summarized in Reference 6), included addition of 4 hydrologic stations in Democratic Kampuchea, 5 hydrologic stations in Thailand, and for Viet-Nam the reactivation of those stations used for the delta mathematical model network.

## 2.4 Adequacy of data

Discussions with the engineering and planning staffs of the Mekong Committee engaged in design of water resources development structures and systems indicates that the basic data programme, despite its limitations, has provided, at this stage of planning, a sufficient information base to meet the current planning and design needs, most of which are at the feasibility level. This is especially the case for the Pa Mong project which is located in the upper part of the basin where the bulk of the data so far have been obtained.

The status of the basic data programme still leaves much to be desired, as is characteristic everywhere of most basic data programmes covering large regions. For this reason the Mekong Committee plans to continue with an annual critical review and analysis of the programme, in collaboration with the Chief Hydrologists, so that improvements can be steadily realized over the years. With respect to the basic network of streamgauging stations, the network of 216 stations (1975) represents a fairly comprehensive system so far as numbers of stations is concerned. The problem is in operations which have been hampered for numerous reasons primarily security and budgets. It is estimated that about two-thirds of the stations were reasonably operative in 1974-75. The expansion rate over the past several years, with 5 to 10 per cent more stations added to the network each year, seems adequate.

While the programmes in sediments, salinity, and water quality also need continuing improvement, still the data base now available has been sufficient for the needs of feasibility studies and preliminary analyses, particularly for the mainstream, and significant improvements are being realized each year.

In the delta zone, the hydrologic and other data now being obtained in recent years in Viet-Nam represent a very decided improvement, but Democratic Kampuchea needs strengthening especially on the frequency or discharge measurements. The work programme recommended for 1975 represents the minimum programme believed to be adequate for the needs of the next several years. The needs for expanding the programme to include more stations will depend upon the additional studies to be made, including mathematical modelling projects, both in the upper and deltaic portions of the basin.

To summarize, adequate basic hydrologic data are essential for the competent design of any water resource development project, both for the design of the structures and systems for storing and utilizing the water and for insuring proper attention to affected environmental values. Despite the magnitude of the problem, considering the size of the lower Mekong basin, the paucity of data to begin with, and the complexities of security, financing, and training of personnel, the Mekong Committee has over the years made sound progress in developing a basinwide hydrologic data system adequate for meeting all the essential needs of feasibility planning.

## 3. Hydrology of surface water

### 3.1 Streamflow characteristics

The Mekong river above the Pa Mong damsite has a very long narrow drainage area totalling about 305,500 km$^2$. The basin is nearly 2,500 km long, but in places narrows down to less than 20 kilometres in width. The source of the river is in the high Tibetan plateau in China. The stream is fed partly by snowmelt, and partly by runoff from rains and tropical storms. The Mekong flow follows an annual cycle in which the general pattern of

flow is to rise slowly at the start of the rainy season in May, reach a peak in August or September, and then recede during the ensuing dry season. At Vientiane, except in critical years, the low flow has seldom dropped much below 1,000 $m^3$/sec in April. Peak flows range from 13,000 to 26,000 $m^3$/sec in August - September. At Kratie, the average low flow is as little as 1,764 $m^3$/sec compared to an average flood flow of 52,000 $m^3$/sec and an average flow of 14,116 $m^3$/sec (Ref. 1). The summary hydrographs of maximum, average, and minimum flows for selected stations at Chiang Saen, Vientiane, Pakse, and Phnom Penh are shown in Figure 2 (Ref. 18).

Two tributaries of special interest to the Pa Mong project are the Huai Mong and Nam Lik rivers, because of the inclusion of Nam Mong and Nam Lik reservoirs in the Pa Mong project complex. The Huai Mong river drains a saucer-shaped area of 1,296 $km^2$ above the Nam Mong damsite. The source of water is mostly from wet season rains. During the dry season there are many periods of no flow, hence this area is a low producer of runoff (Ref. 14).

The Nam Lik drainage area of 5,115 $km^2$ above the Nam Lik damsite is rectangular shaped, the length being about twice the width. Mountains along the northern side of the basin have peaks with elevations over 2,000 m. The river water is clear with little turbidity most of the time, because of the heavy forest cover and possibly the limestone formations that appear throughout the drainage area. The river maintains a steady base flow of about 35 $m^3$/sec throughout the dry season. During the rainy season the flows have a tendency toward sharp peaks and recessions, indicating the floodflows are quickly responsive to rains (Ref. 14).

## 3.2 Mekong river runoff

Mekong river data and the contributing drainage area and average annual runoff of all countries bordering the Mekong river are summarized in Table 2. The total average annual runoff of the Mekong river is approximately 544,000 million $m^3$. The Lao PDR is the largest contributor of runoff at 41 per cent and Democratic Kampuchea is second with 18 per cent. The 1951 to 1969 monthly runoff summaries of streamflow measured at the selected stations are presented in Tables 3 through 7.

## 3.3 Pa Mong water supply

The source of water supply for the Pa Mong project will be surface water, primarily the annual runoff of the Mekong river reaching the damsite 20 km upstream from Vientiane. This runoff will be augmented by runoff from Huai Mong and Nam Lik. The total annual water supply of these three rivers averaged about 152,500 million $m^3$ for the period 1929 - 1960. The combined storage of about 98,285 million $m^3$ in the three adjoining reservoirs, for a Pa Mong high pool level of 250 m MSL, will store most of the flood flow for project use (Ref. 15). Historical records of the monthly runoffs at the selected stations are mentioned briefly below.

(a) Mekong river at Vientiane: The 1929 to 1969 historical record of the monthly runoff of the Mekong river at Vientiane is given in Table 3. The average annual historical runoff of the Mekong river at Wat Sop, Vientiane, is 143,900 million $m^3$. August and September normally contribute 23 and 31 per cent of the annual runoff, respectively, most of which is flood flow.

(b) Nam Ngum at damsite: The runoff of the Nam Ngum at the damsite was measured from 1966 to 1972. By reconstruction the monthly runoff record was extended back to 1929. The total average annual reconstructed runoff is about 11,300 million $m^3$. July, August, and September contribute about 18, 27, and 23 per cent of the annual runoff respectively.

(c) Nam Lik at Ban Hin Heup: The historic runoff record of Nam Lik at Ban Hin Heup (1967 to 1974) was correlated with the concurrent historic runoff record of Nam Ngum and the Nam Lik monthly runoff record was extended back to 1929. Approximately 8,400 million $m^3$ of the average annual runoff could be stored in the Nam Lik portion of the Pa Mong reservoir. Normally, about 19, 28, and 25 per cent of the annual runoff occurs in July, August, and September, respectively.

(d) Huai Mong at Km 18: The historic runoff record of Huai Mong at Km 18 (1957 to 1969) was extended back to 1929 by using monthly concurrent historic runoff and rainfall data correlation. The Huai Mong drainage basin contributed about 215 million $m^3$ per year, or less than one per cent of the total inflow into Pa Mong reservoir.

(e) Combined Pa Mong inflow: The combined runoff of the Mekong river at Vientiane, the Huai Mong at Km 18, and the Nam Lik at Ban Hin Heup is given in Table 4. The Nam Ngum runoff, added to the combined runoff, is given in Table 5.

## 3.4 Water balance

A water balance was made for the 32 contributing drainage basins which had reliable runoff gauging stations. Most of the runoff records were for the 1951-69 period. The details of the studies are given in Appendix III of Reference 14. In this study it was assumed that the basin divide is a vertical boundary and that all water flowing into and out of the basin is measured at a gauging station. The changes in storage both in soil moisture and ground water are considered to be insignificant on a long-term basis. The basin retention (surface storage and ground water storage) is considered equal to basin rainfall minus net evaporation. Net evaporation was assumed to be the positive summations of average monthly potential evapotranspiration, minus measured monthly average rainfall. This amount includes rainfall interception plus evaporation from water, ground, and plant surfaces.

The Pa Mong study area has a weighted average annual rainfall of about 1,796 mm, 807 mm of net evaporation, and about 600 mm of runoff depth. This leaves an average of 389 mm for basin retention (Ref. 15).

### 3.5 Reservoir area and capacity

The following tabulation summarizes the Stage One and Phase II area and capacity estimates (Ref. 15):

| Reservoir | Elevation | Stage One Area | Stage One Capacity | Phase II Area | Phase II Capacity |
|---|---|---|---|---|---|
| | (m MSL) | ($km^2$) | (million $m^3$) | ($km^2$) | (million $m^3$) |
| Pa Mong | 250 | 2,582 | 75,571 | 2,390 | 66,128 |
| | 230 | 1,517 | 35,010 | 1,351 | 29,318 |
| Nam Mong | 250 | 800 | 20,742 | 832 | 21,318 |
| | 230 | 471 | 7,934 | 578 | 7,640 |
| Nam Lik | 250 | 465 | 11,107 | 500 | 10,839 |
| | 230 | 250 | 3,946 | 250 | 3,501 |
| Combined | 250 | 3,847 | 107,420 | 3,722 | 98,285 |
| | 230 | 2,238 | 46,890 | 2,119 | 40,399 |

Figure 5 shows a schematic diagram of the initial Phase II Pa Mong reservoir inactive and active storage capacity. These capacity amounts were used for initial reservoir operation studies.

## 4. Surface water requirements and utilization

The Pa Mong project area has a tropical monsoon type of climate. Normally, about 88 per cent of the annual rainfall or approximately 1,580 mm occurs during the wet season, generally from May through October. This results in an excess of water during the wet season and water shortage during the dry season months of December through April. The estimated net evaporation (before project operation) is about 807 mm/year in the Pa Mong area. Water requirements for various uses of the Pa Mong project are summarized from the Pa Mong Stage One and Phase II reports (Ref. 14, 15) and presented below.

### 4.1 Irrigation

(a) Existing situation: The main crop in the Pa Mong project area is transplanted rice, the basic food crop in the area. The present use of agricultural land in the potential Pa Mong project service area is primarily for transplanted rice production in paddies during the wet season (May through October). The growing season is generally from July through November. Normally, about 88 per cent of the average annual rainfall occurs during the wet season. The occurrence of large rainfall variations and seasonal flooding makes agricultural production unpredictable without irrigation, drainage, and flood control.

Irrigation development in northeast Thailand consists of projects varying in size from very small privately developed stream diversions, and relatively small governmental tank projects and river pumping projects, to major project storage or diversion projects. Irrigation development in the Vientiane plain of Lao PDR is generally confined to small privately developed stream diversions or small diversions and pumping projects developed under Lao PDR government auspices with the aid of foreign institutions and governments. The Nam Ngum project with a large storage reservoir (located about 60 km north of Vientiane) was completed in 1972, and provides ample water for irrigation in this vicinity.

Present rice paddy farming provides for conservation of rainfall in meeting crop water requirements. The following tabulation compares the estimated rice crop water use as it occurs in the Stage One and Phase II service areas:

| Month | Service area (1951-69 Avg.) in Millimetres | | | |
|---|---|---|---|---|
| | Stage One | | Phase II | |
| | Rain | Crop Water Use | Rain | Crop Water Use |
| May & June* | 455 | 220 | 372 | 220 |
| July | 225 | 148 | 187 | 157 |
| August | 294 | 168 | 205 | 177 |
| September | 318 | 176 | 302 | 179 |
| October | 71 | 169 | 98 | 171 |
| November | 8 | 109 | 12 | 104 |
| Total | 1,371 | 990 | 1,176 | 1,008 |

* Rice paddy demands for seeding nursery, land preparation, and establishing water layer before transplanting rice.

Excess rainfall of about 200 and 165 mm in September in the Stage One and Phase II service areas, respectively, must be stored to meet additional water requirements during October and November. Optimum crop production can be experienced if a full irrigation water supply is available during the dry season and a supplemental water supply is available during the wet season.

(b) Projected irrigation use: Little verified information has been published on measured irrigation water requirements for projects in the Mekong basin. Published studies from Thailand, the Philippines, Malaysia, Taiwan, Lao PDR, and the United States were used to formulate empirical methods to estimate crop water requirements, effective rainfall, and irrigation efficiencies. Details

of these studies are given in References 14 and 15. For Pa Mong Phase II irrigation, the estimated monthly unit diversion requirements (for 1951-69) are summarized as follows (in millions of $m^3$ per 10,000 ha):

| Country | Annual | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thailand | 167.8 | 36.0 | 32.2 | 30.0 | 15.5 | 3.0 | 6.9 | 7.0 | 5.8 | 0.8 | 9.8 | 3.6 | 18.1 |
| Lao PDR | 158.9 | 29.1 | 32.0 | 30.8 | 21.1 | 0.8 | 2.9 | 4.4 | 1.8 | 0 | 16.4 | 10.1 | 9.5 |

The initial Pa Mong reservoir operation is to provide a full-water supply for 10,540 and 29,250 productive hectares of irrigable land in Lao PDR and Thailand, respectively. The total average annual diversion requirements will be 166 and 462 million $m^3$ for Lao PDR and Thailand, respectively. For the 50-year study, a total annual irrigation diversion of 11,800 million $m^3$ was used for the total service area of about 822,000 ha.

## 4.2 Fish farms

The Phase II report and other publications (see discussion on fisheries) provide the primary data for proposed development of nonarable lands in the Pa Mong project service area for intensive fish culture. Irrigation canals in the service area will be used to supply water to the fishfarms, hence these canals would be more fully and efficiently utilized than those used for irrigation alone because water demands for farm fisheries can be adjusted to minimize conflicts with the more critical irrigation requirements. The fishfarms will be formed by constructing contour dikes to enclose a pond with water depths varying from 0.6 to 1.8 m. A standard irrigation service unit turnout will supply water to a group of ponds from a project canal or lateral.

Water requirements for fish farming operations under the above criteria have not been measured under field test conditions although a number of full-scale fishfarm units are planned to be built and operated in the next several years as demonstration projects. The monthly unit fishery water delivery requirements were derived empricially by procedural steps detailed in Reference 15. The estimated ratio of farm fishery area to irrigable area is 12.7 per cent. Water requirements were estimated assuming average seepage and evaporation losses for similar soils and areas in northeast Thailand and Lao PDR. Once the ponds are filled, about 15,100 $m^3$ of water will be required annually per hectare of pond area to maintain desired pond water levels. For the 50-year study, the average annual water requirement was estimated to be 1,361 million $m^3$ for the total farm fishery area of 104,000 ha, and the average monthly water requirements are given below (in millions of $m^3$ per 10,000 ha):

| Annual | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 151.2 | 11.4 | 10.3 | 23.7 | 17.5 | 4.1 | 2.5 | 14.7 | 12.5 | 7.8 | 12.4 | 17.1 | 17.2 |

4.3 Community water supplies

(a) Existing situation: Domestic, municipal, and industrial (DM & I) water supplies in the Pa Mong project area are now obtained from a variety of source including rivers, streams, ponds, reservoirs, irrigation systems and wells. The present supply of DM & I water is generally adequate during the wet season, but very inadequate during the dry season. Water quality also becomes a serious problem during the dry season as the limited available surface water stagnates and is usually contaminated by human and animal wastes. In rural areas, there are only a few rural communities with community water supply systems. Most rural water supplies come from polluted ponds, lakes, and streams with water hauled great distances during the dry season at considerable effort and cost. Therefore, a dependable supply of clear water for community uses is a very necessary aspect of the Pa Mong project.

(b) Project DM & I water requirements: After the start of Pa Mong project operation, water for DM & I uses in the project area will be supplied mostly from the irrigation distribution system. An estimate of the amount of water required to meet this demand was made on the basis of per capita daily use. An average rate of 50 litres per capita per day for the initial study and 400 litres per capita per day for the 50-year study were used. The average annual DM & I requirements (for 200,000 people) for the initial study was only a small fraction of the available water supply and will not register as a significant number. For the 50-year study, the average annual DM & I requirement (for 7.7 million people) was estimated to be 60 and 1,068 million $m^3$ in Lao PDR and Thailand, respectively.

4.4 Other water requirements

Water requirements for other purposes such as navigation, fish and wildlife, and recreation will be nonconsumptive uses and will be met by minimum stream releases, power releases, and return flows from irrigation and fishery diversions. More details on power releases, minimum stream releases, and return flows are discussed in Section 4.5 below.

4.5 Water utilization

(a) Pa Mong project plan: The Pa Mong project will be one of the world's largest river development projects. The Phase II studies (Ref. 15) presented data for a

project at 250 m MSL capable of providing flood control and 16.9 and 7.0 billion kilowatt hours of hydroelectric firm and secondary power respectively. In addition, about 7.7 million people will be supplied DM & I water and about 822,000 and 104,000 ha of irrigable and fishery lands, respectively, will receive water to produce year around food supplies. The main features of Phase II Pa Mong project (for a 250 m MSL high pool level) include a reservoir of 98,000 million $m^3$ formed by Pa Mong, Nam Mong, and Nam Lik dams; a 4,800 megawatt hydroelectric power plant at the Pa Mong damsite; 1,880 km of main canals and a full system of lateral irrigation distribution and surface drains; eight pumping plants and three regulating reservoirs; plus irrigation and fishfarm development (Ref. 15).

(b) Regulation and planned use: The Pa Mong project average annual water utilization summary based on records for the 1951-69 period is given in Table 8. Pa Mong reservoir will provide about 13,900 million $m^3$ of surface water annually for 822,370 irrigable hectares and 104,450 hectares of fishfarms plus DM & I water for 7.7 million people in the project area. About 2,500 million $m^3$ of return flow will be reused to help meet the total project water requirements. The Pa Mong project supply is entirely surface water. The ground water in the project area is generally not a reliable source of water supply (Ref. 15), especially during the dry season.

(c) Regulation and depletory effects: After the Pa Mong reservoir is put into operation, the historic streamflow patterns of the Mekong river below Pa Mong will be changed significantly. The average reduction of Mekong runoff (during 1951-1961) at Vientiane was estimated to be about 15,600 million $m^3$. Most of the reduction would be the 13,900 million $m^3$ to meet the Pa Mong water requirements (Ref. 15). Mekong flood runoff will be stored in the reservoir and released as power releases and water requirement diversions during the dry season. Figure 6 shows the 1951-1969 historic and modified hydrograph of the Mekong river at Vientiane. As noted in References 15 to 17, Pa Mong reservoir operation would affect the Mekong river flow and water surface elevation from the damsite as far downstream as Phnom Penh.

The regulation study indicated the return flows from irrigation and fishery diversions amounted to about 4,000 million $m^3$. Approximately 62 per cent of the return flows are to be reused in the downstream irrigation divisions. Consequently, the average net return flow from 13,900 million $m^3$ diverted from Pa Mong reservoir will be 1,500 million $m^3$ (Ref. 15).

The Pa Mong project will therefore modify and deplete the Mekong runoff below Pa Mong damsite. However, the net effect will be great benefits for the downstream countries and people (Ref. 15). Tables 9 and 10 show the summarized data on disposition of the Pa Mong flows by months based on the records for 1951-69. As noted in Reference 15, the total Mekong depletion at Pakse will be about 14,100 million $m^3$ average over the 1951-1969 period.

## 4.6 Transbasin diversions

As noted in the discussion on irrigation and drainage, four possible alternate schemes of transbasin diversions were studied and presented (Ref. 15), simply to show possible means of basin diversions, but were not analyzed to determine feasibility. To determine the amount of water to be diverted it was necessary to consider the following factors:

(a) Inventory of existing and potential storage available to regulate diverted water.

(b) Estimate of the amount of water needed to supplement the present water supply to develop the potential land resources.

(c) Determination of the amount of Mekong river water allocated to Thailand for export from the lower Mekong basin.

A preliminary rough estimate of the first two factors was attempted by the USBR for the Mekong Committee (Ref. 15). The third factor is far beyond the scope of the present investigations. Past rough estimates indicate the unit irrigation diversion requirements for the wet season would be 9.0 and 7.0 million $m^3$ per 10,000 ha for the upper and lower Chao Phya basin, respectively, and for the dry season, the unit irrigation diversion requirements would be about 147 and 151 million $m^3$ per 10,000 ha for the upper and lower basins, respectively. Approximately 16 per cent of the diversion requirements may be reused for downstream irrigation or other purposes.

Transbasin diversions from Pa Mong reservoir into the Chao Phya basin were estimated for four schemes, for which the annual supplemental irrigation requirements in million $m^3$ are as follows:

| Scheme | Wet Season | | Dry Season | | Annual | | Power Reduction at Pa Mong |
|---|---|---|---|---|---|---|---|
| | Present | Potential | Present | Potential | Irr. | Div. | $10^6$ kwhr/year |
| I-Nam Pa Sak | 350 | 361 | 4,784 | 9,493 | 4,720 | 4,000 | 685 |
| II-Upper Nam Pa Sak | 350 | 431 | 4,799 | 11,007 | 6,289 | 5,500 | 907 |
| III-Nam Phak | | | | | | | |
| Upper | 99 | 495 | 1,619 | 8,096 | 6,873 | 5,800 | - |
| Lower | 895 | 1,007 | 9,705 | 21,786 | 12,193 | 10,200 | - |
| Total | 994 | 1,502 | 11,324 | 29,882 | 19,066 | 16,000 | 2,740 |
| IV-Sirikit | | | | | | | |
| Upper | 99 | 495 | 1,619 | 11,040 | 9,817 | 8,300 | - |
| Lower | 895 | 1,147 | 9,705 | 21,786 | 12,333 | 10,300 | - |
| Total | 994 | 1,642 | 11,324 | 32,826 | 22,150 | 18,600 | 3,185 |

For further analysis, an inventory of existing and potential storage to regulate diverted water should be made, followed by a system operation study to size and set up operation criteria. The transbasin diversion scheme would greatly aid future development of the lower Chao Phya basin. Approximately 2.2 million hectares could produce two crops per year and provide food for about 20 million people.

## 5. Probable effects of Pa Mong

Environmental considerations relative to the effects of Pa Mong water control of surface water include the following:

(a) Modification of streamflow patterns and characteristics upstream and downstream from the Pa Mong damsite.

(b) Effects of modification of streamflow patterns and characteristics on other environmental components, e.g., flood control, navigation, water quality, aquatic resources, fishery, agriculture and waterbased recreation, community and urban development, etc.

This discussion is limited primarily to the changes in flow patterns, volumes, and stages of the Mekong river. More specific and detailed discussions of Item (b) are included in other sections of this chapter.

### 5.1 Effects on riverflows and stages

Inasmuch as Pa Mong will be the first dam on the Mekong mainstem, and will have a relatively large storage capability, the effects of Pa Mong regulation will be very significant (Ref. 15). The general effects of Pa Mong reservoir will be to reduce river flow peaks and volumes considerably during the wet season and to increase volumes during the dry season, for the

river reaches downstream from Pa Mong. For the upstream reaches, Pa Mong will increase the river stages, reduce the velocity of flow and inundate some free flowing streams. Generally the effects will be greater for the areas close to the damsite, and will gradually diminish proceeding upstream and downstream.

(a) Upstream effects: After Pa Mong goes into operation, the river reach immediately upstream from Pa Mong will be inundated to a great depth by the storage of reservoir water, and the river stages for the affected reaches upstream will increase significantly over the historic river stages, particularly in the dry season. River currents will also be reduced and water would cover previously exposed rapids, rock obstructions, and some free flowing streams.

As noted in the discussion on reservoir ecology and on power, the reservoir drawdown caused by the releases of water, together with inflow to the reservoir during the wet season, will cause seasonal water surface fluctuation in the reservoir, which in turn will affect the water level of the river reaches upstream. The total drawdown of the reservoir will vary from about 12 to 18 m, with the drawdown process extending over a period of about eight months. The rate of reservoir drawdown is not great, because Pa Mong is a large reservoir, however, the total drawdown can create navigation and other environmental problems in the reservoir. The effect of fluctuation as related to the human uses of the reservoir and shoreline, including navigation, will not be severe provided the facilities used for these purposes are properly designed.

(b) Downstream effects: Regulation of Mekong flows by the Pa Mong project as an isolated unit will result in significant changes in seasonal flow patterns, volumes, and stages of the Mekong as far downstream as the general reach of river above Pakse. As noted in the discussion on power, the net effect of Pa Mong flow reduction will be greatest in the reach of river above Pakse during the wet season. During the dry season, the effect of storage releases for power will have a significant effect on stage and flow volumes all the way down to the delta (Ref. 15). A short-range effect of Pa Mong operation will result from daily variations in power plant output. As a result, river stages in the vicinity of the power plant will rise and fall with consequent effects on navigation and other river-based activities, such as farming on the riverbanks during the dry season and fishing.

The annual runoff at Pakse is double that at Pa Mong and the annual runoff at Stung Treng is about triple that at Pa Mong. The preponderance of annual

inflow contribution from the middle section of the lower Mekong comes principally during the wet season. Hence, Pa Mong regulation will not have a pronounced effect on high stages. However, during the dry season, the storage released from Pa Mong would result in significant raising of seasonal flow volumes, depending on method of operation, amounts of irrigation withdrawals, etc.

The stage of development of the Pa Mong project will have a significant effect on the degree of regulation provided downstream. During the early stages, with only part of the power units installed, the river regime will be little affected by power releases and irrigation operations; however, rule-curve operation for flood control will result in significant effects locally. Interim spills during the dry season for downstream purposes may be made to evacuate storage to meet flood retention space requirements. .

As power plant installations increase to ultimate size and the national or international systems to be served grow in size, the operation would change greatly. For full output of at-site prime power capability, for instance, there would be periods as long as 2 to 3 years with no surplus spill whatever from Pa Mong. As irrigation develops and areas increase, irrigation diversions would result in corresponding decreases in dry season secondary power releases.

Downstream effects inferred from initial project operation studies (Ref. 14, 15) indicate that historic low stages of the Mekong may be raised from 1 to 3 m after Pa Mong goes into operation, with the least rise occurring in the Thakhek to Mukdahan reach and the largest rise in the Stung Treng and Phnom Penh reaches. During the flood season, as represented by the 1966 flood, it is probable that all overbank flooding would have been eliminated by Pa Mong as far downstream as Bungkan, with stage reduction of as much as 5 metres throughout the reach. Below Pakse, the overall effects of Pa Mong flood control will probably also reduce the volume and depth of floods in Democratic Kampuchea to a significant extent (Ref. 17).

As noted previously, diversions from Pa Mong for estimated year 50 irrigation, DM & I, and fishfarm uses would amount to about 13,900 million m annually. Of this amount, an estimated 2,500 million $m^3$ (or 18 per cent) of the irrigation diversions might reach the Mekong as return flow. Net evaporation from Pa Mong reservoir was estimated at about 1,400 million $m^3$ annually. Total annual project depletions would be 15,300 million $m^3$, or about 10 per cent of the annual average inflow into Pa Mong reservoir under the ultimate development level assumed.

(c) Different pool levels: With respect to different pool levels at Pa Mong reservoir, the effects will of course be greater for higher full pool levels, although the effects of a similar nature would be expected for the four alternative pool levels under consideration.

## 5.2 Modifications in overall utilization of Mekong river

The main effect of Pa Mong on utilization of the surface waters of the Mekong river will be to conserve flood waters, now being wasted to the ocean, for beneficial agricultural purposes including irrigation and farm fisheries plus supply of water through the irrigation system for community and industrial uses. The average beneficial use for these purposes, assuming Phase II in operation, will be approximately 13,900 million $m^3$/year, or about 10.3 per cent of the annual inflow into Pa Mong reservoir, for without project conditions, of approximately 153,000 million $m^3$/year. The present use of Mekong river water for these same purposes is estimated at not more than 0.6 per cent or 900 million $m^3$/year. Hence the net gain for beneficial uses will be about 8.6 per cent of the total annual flow. Also, of the 13,900 million $m^3$/year diverted to irrigation, approximately 4,000 million $m^3$ will be recaptured as return flow, of which about 2,500 million $m^3$ will be used for irrigation of service areas further downstream. Hence the consumptive use will be about 9,900 million $m^3$ per year, or 6.5 per cent of the annual inflow.

There will be additional gains from use of river water for irrigation below the Phase II service area, mainly in the delta. The increased usage of river water for irrigation made possible by Pa Mong will probably be as much or even more than for the Phase II service area, utilizing as much as 20,000 million $m^3$/year or 13 per cent of the annual runoff now lost to the ocean. The precise amounts of flows to be made available to the delta during the dry season will depend on the selected Pa Mong high pool level, now being evaluated in the Pa Mong optimization and downstream effects study. For pool levels of (a) 230, (b) 240, (c) 250, and (d) 260 m MSL, assuming use of the dry season flow is limited to the four driest months of the year, the extra fresh water which can be and likely would be used in the delta would be respectively (a) 10,000, (b) 15,500, (c) 20,000, and (d) 22,500 million $m^3$/year.

The Pa Mong project would also alter the losses of river water due to evaporation. The new reservoir of about 3,700 $km^2$ (for 250 m MSL high pool level) will result in annual evaporation losses of about 4,600 million $m^3$/year, but in a reduction in evaporation losses from areas now inundated during the flood season estimated at roughly 2,400 million $m^3$/year (from about 22,200 to about 19,800 million $m^3$/year). Hence the net additional evaporation loss (for no useful purpose) due to Pa Mong would be about 2,200 million $m^3$/year.

The net overall gain in beneficial uses due to Pa Mong would be roughly of the order of 30,000 million $m^3$/year or about 20 per cent of the total annual flow now lost to the sea, assuming little if any change in the existing pattern of fresh water outflow to the sea during the dry season (hence no significant change in salinity distribution due to change in river flow).

References

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(4) "Work Programme of Hydrologic Network Operation for Hydrologic Year 1973". Mekong Committee publication WRD/MKG/INF/L.562, 4 January 1973.

(5) "Report on Hydrologic and Meteorologic Network in Lower Mekong Basin". Mekong Committee publication MKG/R.94, 30 August 1974.

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(7) "Training Course in Sediment and Water Quality Analysis". Mekong Committee publication MKG/R.88, 28 August 1974.

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(10) "Final Report, Lower Mekong River Project". By Harza Engineering Company for USAID, July 1962.

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(14) "Pa Mong Stage One Feasibility Reports" (8 Volumes). Prepared by USBR for Mekong Committee, 1970.

(15) "Pa Mong Phase II Reports" (7 Volumes). Prepared by USBR for Mekong Committee, 1972.

(16) "Reports on Recommendations Concerning Agricultural Development with Improved Water Control in the Mekong Delta" (9 Volumes). Prepared by Netherlands Delta Team for Mekong Committee, April 1974.

(17) "Pa Mong Downstream Effects on Hydrology and Agriculture in the Cambodian Part of Mekong Delta, Draft Report". Agriculture Division, Mekong Committee, July 1975.

(18) "Evaluation of 1972 Flood Forecasting Operation". Mekong Committee publication WRD/MKG/INF/L.561, January 1973.

TABLE 1

LENGTH OF RECORD FOR SELECTED HYDROLOGIC STATIONS

ON LOWER MEKONG RIVER
(from Reference 1)

| Station | Distance 1/ from Outlet-km | Period 2/ | Years of Data b/(Stage record) |
|---|---|---|---|
| 1. Chiang Saen | 2,370 | 1957-date | 19 |
| 2. Luang Prabang | 2,010 | 1914-18, 1920-23 1925-26, 1928-44, 1948-51, 1955-date | 53 |
| 3. Chiang Khan | 1,717 | 1964-date | 12 |
| 4. Pa Mong damsite (Ban Pha Tang) | 1,607 | 1960-date | 16 |
| 5. Vientiane | 1,584 | 1895-96, 1904-06 1909-10, 1913, 1915-19, 1921, 1923-10, 1942-44, 1947-date 1947-date | 64 |
| 6. Nong Khai | 1,550 | 1937-date | 39 |
| 7. Nakhon Phanom (Thakhek) | 1,216 | 1935-39, 1942-44 | 46 |
| 8. Mukdahan | 1,125 | 1914-18, 1920-22, 1925-27, 1929-39, 1924-44, 1947-date | 54 |
| 9. Khemarat | 1,040 | 1961-date | 15 |
| 10. Ban Dan | 910 | 1962-date | 14 |
| 11. Pakse | 869 | 1914-18, 1922-23 1927, 1932-44, 1952-date | 45 |
| 12. Ban Chan Noi | 767 | 1960-date | 16 |
| 13. Stung Treng | 668 | 1902-03, 1905-07, 1910-date | 71 |
| 14. Kratie | 545 | 1933-37, 1939-date | 42 |
| 15. Kompong Cham | 432 | 1927-28, 1930-date | 48 |
| 16. Prok Kdam | 362 | 1960-date | 16 |
| 17. Phnom Penh at Pumping House | 332 | 1930-date | 46 |
| 18. Phnom Penh at parking area (Monivong Bridge) | 319 (Bas) | 1960-date | 16 |
| 19. Neak Luong | 277 | 1926-44, 1947, 1949-51, 1954-date | 45 |
| 20. Chau Doc | 200 (Bas) | 1960-date | 16 |
| 21. Vam Cong | 136 (Bas) | 1961-date | 15 |
| 22. My Thuan | 112 | 1960-date | 16 |

1/ From Mekong Committee's hydrographic chart albums; survey 1961-1967.

2/ According to Mekong hydrologic yearbooks.

TABLE 2

MEKONG RIVER DATA

(From Reference 15)

| Mekong River | | River reach | | | Average annual runoff ($m^3 \times 10^9$) | | | | | | Total reach |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Downstream point | River kilometer Km | Length Km | Contributing drainage $Km^2 \times 10^3$ | Description | China | Burma | Lao PDR | Thailand | Democratic Kampuchea | Viet-Nam | |
| China Boundary | 2,570 | 1,630 | [1]163 | Entirely within China | [1]87 | – | – | – | – | – | 87 |
| Chiang Saen | 2,400 | 170 | 26 | Boundary between Burma and Lao PDR | 0 | [1]3 | [1]3 | – | – | – | 6 |
| Lao PDR Boundary | 2,340 | 60 | 4 | Boundary between Thailand and Lao PDR | 0 | 0 | 1 | 1 | – | – | 2 |
| Chiang Khan | 1,720 | 620 | 97 | Entirely within Lao PDR | 0 | [1]1 | 43 | 2 | – | – | 46 |
| Vientiane | 1,600 | 120 | 7 | Entirely within Lao PDR | – | – | [1]1 | [1]3 | – | – | 4 |
| Pakse | 870 | 730 | 246 | Boundary between Thailand and Lao PDR | – | – | 130 | 37 | – | – | 167 |
| Democratic Kampuchea Boundary | 720 | 150 | [1]50 | Entirely within Lao PDR | – | – | 12 | – | – | – | 12 |
| Viet-Nam Boundary | 200 | 520 | [1]70 | Entirely within Democratic Kampuchea | – | – | 35 | – | [1]85 | [1]30 | 150 |
| South China Sea | 0 | 200 | 29 | Entirely within Viet-Nam | – | – | – | – | [1]10 | [1]60 | 70 |
| Total | | 4,200 | [1]692 | | [1]87 | 4 | 225 | 43 | [1]95 | [1]90 | 544 |
| Percent of total | | | | | 16 | 1 | 41 | 8 | 18 | 16 | 100 |

[1]Estimated.

TABLE 3

MONTHLY DISCHARGE OF MEKONG RIVER AT VIENTIANE, LAOS

(From Reference 15)

Units in Million Cubic Meters

Drainage Area 299,000 sq.km.

| YEAR | JAN. | FEB. | MAR. | APR. | MAY | JUN. | JUL. | AUG. | SEPT. | OCT. | NOV. | DEC. | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1929 | 3,810 | 2,984 | 2,805 | 2,802 | 3,892 | 10,983 | 25,765 | 49,671 | 31,838 | 18,695 | 8,568 | 6,343 | 168,156 |
| 1930 | 4,612 | 3,449 | 3,303 | 3,809 | 6,430 | 12,833 | 17,119 | 39,176 | 27,578 | 17,219 | 8,525 | 5,988 | 150,041 |
| 1931 | 4,190 | 3,220 | 3,031 | 2,925 | 3,461 | 4,525 | 9,459 | 24,072 | 24,780 | 11,803 | 6,070 | 3,713 | 101,249 |
| 1932 | 3,112 | 2,408 | 2,457 | 2,668 | 2,703 | 7,557 | 17,177 | 23,697 | 30,674 | 30,410 | 10,489 | 6,968 | 140,320 |
| 1933 | 4,848 | 2,786 | 2,497 | 2,154 | 2,661 | 3,734 | 21,443 | 30,039 | 22,310 | 14,156 | 8,307 | 5,457 | 125,362 |
| 1934 | 3,951 | 2,714 | 2,683 | 2,640 | 2,703 | 5,154 | 17,532 | 34,066 | 26,086 | 15,327 | 8,527 | 5,526 | 126,971 |
| 1935 | 4,335 | 3,007 | 2,942 | 2,729 | 3,910 | 8,256 | 12,304 | 37,479 | 24,463 | 21,453 | 13,714 | 7,590 | 142,152 |
| 1936 | 5,143 | 3,948 | 3,427 | 3,729 | 4,846 | 12,833 | 18,598 | 32,344 | 33,507 | 12,780 | 6,711 | 4,581 | 142,492 |
| 1937 | 3,515 | 2,732 | 2,753 | 2,295 | 3,826 | 8,768 | 20,445 | 37,135 | 35,402 | 18,010 | 9,159 | 7,802 | 151,924 |
| 1938 | 5,853 | 3,955 | 4,117 | 4,151 | 8,514 | 17,341 | 24,218 | 41,234 | 30,589 | 24,305 | 13,442 | 8,193 | 187,661 |
| 1939 | 6,082 | 4,248 | 4,059 | 4,154 | 5,950 | 15,273 | 28,664 | 42,371 | 30,221 | 22,330 | 10,867 | 7,932 | 183,381 |
| 1940 | 5,593 | 4,193 | 3,751 | 3,427 | 5,222 | 11,[illegible] | 22,715 | 39,920 | 28,680 | 14,172 | 8,254 | 5,791 | 146,538 |
| 1941 | 4,211 | 3,152 | 3,027 | 2,791 | 3,922 | 10,773 | 13,[illegible] | 35,422 | 35,339 | 23,093 | 13,491 | 7,615 | 162,191 |
| 1942 | 5,599 | 3,160 | 3,338 | 3,096 | 5,566 | 11,414 | 28,534 | 32,017 | 26,585 | 14,156 | 9,589 | 5,234 | 167,786 |
| 1943 | 4,633 | 3,249 | 3,344 | 3,401 | 3,759 | 8,207 | 15,552 | 30,303 | 23,238 | 21,[illegible] | 8,674 | 5,772 | 144,051 |
| 1944 | 4,557 | 3,684 | 3,207 | 2,677 | 4,[illegible] | 8,[illegible] | 20,674 | 28,572 | 26,744 | 14,072 | 11,373 | 6,501 | 141,008 |
| 1945 | 4,832 | 3,593 | 3,515 | 3,593 | 5,[illegible] | 10,[illegible] | 22,711 | 44,918 | 26,570 | 15,149 | 8,844 | 6,381 | 163,314 |
| 1946 | 4,577 | 3,244 | 3,138 | 3,372 | 5,727 | 12,681 | 19,621 | 37,466 | 46,791 | 26,862 | 12,691 | 7,493 | 181,330 |
| 1947 | 5,524 | 4,164 | 3,852 | 3,621 | 5,115 | 10,962 | 20,[illegible] | 37,543 | 37,748 | 21,[illegible] | 10,818 | 6,375 | 177,218 |
| 1948 | 4,857 | 3,639 | 3,377 | 3,374 | 5,628 | 9,[illegible] | 22,742 | 34,399 | 34,875 | 25,[illegible] | 12,446 | 7,764 | 168,299 |
| 1949 | 5,551 | 3,885 | 3,554 | 4,017 | 5,[illegible] | 7,[illegible] | 18,942 | 37,644 | 29,336 | 21,985 | 10,804 | 7,390 | 148,870 |
| 1950 | 5,479 | 4,195 | 3,593 | 3,662 | 4,[illegible] | 5,812 | 15,922 | 27,916 | 24,[illegible] | 14,[illegible] | 7,988 | 5,751 | 123,597 |
| 1951 | 4,735 | 3,548 | 2,922 | 2,774 | 3,671 | 10,[illegible] | 14,[illegible] | 34,910 | 27,[illegible] | 20,691 | 8,513 | 6,426 | 150,701 |
| 1952 | 4,912 | 3,212 | 3,241 | 2,894 | 3,964 | 6,324 | 17,272 | 30,833 | 27,664 | 20,460 | 8,446 | 4,298 | 148,909 |
| 1953 | 3,164 | 2,910 | 2,430 | 2,509 | 4,199 | 7,[illegible] | 16,[illegible] | 26,319 | 26,690 | 12,[illegible] | 8,285 | 5,711 | 117,470 |
| 1954 | 4,[illegible] | 2,941 | 2,281 | 2,359 | 3,[illegible] | 6,324 | 12,432 | 28,644 | 32,117 | 15,030 | 8,247 | 5,898 | 124,019 |
| 1955 | 4,237 | 2,957 | 2,669 | 2,804 | 3,[illegible] | 6,458 | 22,159 | 34,329 | 34,223 | 16,295 | 10,195 | 6,057 | 143,842 |
| 1956 | 4,388 | 2,796 | 2,402 | 2,726 | 2,944 | 7,[illegible] | 12,459 | 36,528 | 26,956 | 12,064 | 5,156 | 3,834 | 117,999 |
| 1957 | 3,375 | 2,766 | 2,727 | 2,399 | 3,031 | 5,424 | 13,464 | 17,750 | 14,720 | 15,34[illegible] | 5,017 | 3,384 | 84,426 |
| 1958 | 2,648 | 2,139 | 2,063 | 2,130 | 2,843 | 5,677 | 16,813 | 26,722 | 21,488 | 10,737 | 7,239 | 4,565 | 105,064 |
| 1959 | 3,432 | 3,070 | 3,254 | 3,022 | 4,003 | 9,643 | 14,797 | 29,577 | 31,173 | 19,460 | 10,375 | 5,932 | 137,742 |
| 1960 | 4,350 | 3,639 | 2,850 | 2,246 | 2,993 | 6,262 | 15,252 | 34,773 | 30,975 | 16,[illegible]47 | 8,753 | 6,447 | 135,401 |
| 1961 | 4,171 | 3,189 | 2,882 | 3,421 | 4,449 | 10,903 | 14,932 | 28,893 | 3[illegible],580 | 2[illegible],577 | 11,104 | 7,586 | 151,767 |
| 1962 | 5,139 | 3,595 | 3,281 | 3,072 | 4,606 | 11,598 | 16,610 | 39,489 | 24,[illegible] | 16,177 | 8,529 | 5,305 | 133,023 |
| 1963 | 3,895 | 2,912 | 2,876 | 2,513 | 3,704 | 6,312 | 20,174 | 35,571 | 25,452 | 16,760 | 16,873 | 8,135 | 146,427 |
| 1964 | 5,146 | 3,836 | 3,459 | 3,435 | 5,595 | 7,833 | 25,993 | 30,313 | 31,598 | 22,199 | 11,2[illegible] | 7,773 | 157,790 |
| 1965 | 5,340 | 3,830 | 3,410 | 2,990 | 3,510 | 10,[illegible] | 20,560 | 26,100 | 24,900 | 17,60[illegible] | 19,600 | 9,670 | 147,550 |
| 1966 | 6,282 | 4,230 | 3,560 | 3,740 | 4,450 | 11,6[illegible] | 22,995 | 42,300 | 48,800 | 23,300 | 13,600 | 8,[illegible] | 1[illegible],610 |
| 1967 | 5,[illegible] | 3,970 | 3,810 | 3,789 | 4,450 | 6,610 | 12,080 | 22,100 | 21,100 | 1[illegible],[illegible] | [illegible],135 | 6,430 | 1[illegible],750 |
| 1968 | 3,[illegible] | 3,[illegible] | 3,340 | 3,[illegible] | 3,340 | 7,[illegible] | 14,[illegible] | 24,[illegible] | 23,[illegible] | 17,[illegible] | 11,730 | 6,[illegible] | 1[illegible],410 |
| 1969 | [illegible] | 2,[illegible] | 2,445 | 2,870 | 2,[illegible] | 6,[illegible] | 15,[illegible] | 30,[illegible] | 20,100 | 11,[illegible] | 8,380 | 4,[illegible] | 1[illegible],910 |
| TOTAL | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1,364,[illegible]52 | 1,[illegible],[illegible]61 | [illegible] | [illegible] | [illegible] | [illegible] |
| AVER. | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Surface water

# TABLE 4

## MONTHLY INFLOW INTO PA MONG RESERVOIR

(From Reference15)

Units in Million Cubic Meters — Drainage Area 305,422 sq.km.

| YEAR | JAN. | FEB. | MAR. | APR. | MAY | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1929 | 3,894 | 3,043 | 2,859 | 2,857 | 4,032 | 11,949 | 27,839 | 52,972 | 34,032 | 19,374 | 8,775 | 6,307 | 178,133 |
| 1930 | 4,722 | 3,520 | 3,373 | 3,891 | 6,683 | 13,974 | 10,461 | 41,760 | 29,452 | 17,841 | 8,735 | 6,132 | 158,544 |
| 1931 | 4,784 | 3,286 | 3,091 | 2,984 | 3,583 | 4,906 | 10.179 | 25,372 | 26,453 | 12,214 | 6,211 | 3,795 | 106,558 |
| 1932 | 3,178 | 2,454 | 2,503 | 2,720 | 2,797 | 8,202 | 18,506 | 25,169 | 32,763 | 31,565 | 10,750 | 7,138 | 147,765 |
| 1933 | 4,960 | 2,844 | 2,513 | 2,194 | 2,751 | 9,544 | 23,143 | 31,968 | 23,818 | 14,694 | 8,535 | 5,585 | 132,549 |
| 1934 | 4,043 | 2,785 | 2,733 | 2,692 | 2,798 | 5,581 | 16,893 | 36,239 | 27,905 | 15,909 | 8,601 | 5,755 | 134,134 |
| 1935 | 4,442 | 3,066 | 3,037 | 2,782 | 4,053 | 8,972 | 13,251 | 39,920 | 26,230 | 22,252 | 14,068 | 7,780 | 149,853 |
| 1936 | 5,264 | 4,032 | 3,496 | 3,810 | 5,026 | 14,023 | 20,056 | 34,517 | 35,935 | 13,251 | 6,874 | 4,685 | 150,969 |
| 1937 | 3,505 | 2,785 | 2,806 | 2,340 | 3,564 | 9,743 | 27,051 | 39,798 | 38,090 | 18,662 | 9,394 | 7,995 | 161,213 |
| 1938 | 6,023 | 4,050 | 4,204 | 4,243 | 8,892 | 18,919 | 25,183 | 44,059 | 34,974 | 24,954 | 13,775 | 8,397 | 198,678 |
| 1939 | 6,228 | 4,343 | 4,143 | 4,193 | 6,175 | 17,148 | 30,900 | 45,756 | 32,554 | 23,713 | 11,150 | 8,129 | 194,482 |
| 1940 | 5,728 | 4,289 | 3,829 | 3,499 | 5,208 | 12,976 | 22,340 | 37,481 | 30,720 | 14,698 | 8,497 | 5,933 | 155,236 |
| 1941 | 4,307 | 3,234 | 3,067 | 2,846 | 4,044 | 11,797 | 17,724 | 34,581 | 36,698 | 30,338 | 13,816 | 5,109 | 171,610 |
| 1942 | 5,691 | 3,858 | 3,404 | 3,124 | 5,765 | 12,628 | 35,842 | 53,486 | 24,412 | 14,600 | 9,817 | 6,447 | 178,088 |
| 1943 | 4,739 | 3,293 | 3,419 | 3,474 | 3,974 | 9,050 | 16,793 | 35,073 | 25,648 | 22,201 | 8,184 | 5,510 | 152,494 |
| 1944 | 4,663 | 3,762 | 3,271 | 2,729 | 4,429 | 9,551 | 22,307 | 30,489 | 30,769 | 18,758 | 11,858 | 5,659 | 149,102 |
| 1945 | 4,944 | 3,676 | 3,585 | 3,628 | 5,723 | 11,402 | 22,338 | 47,992 | 39,382 | 15,955 | 8,710 | 6,547 | 173,483 |
| 1946 | 4,688 | 3,334 | 3,209 | 3,444 | 5,940 | 14,046 | 21,163 | 39,908 | 49,123 | 25,915 | 13,193 | 7,670 | 192,653 |
| 1947 | 5,659 | 4,255 | 3,930 | 3,659 | 5,720 | 11,790 | 31,527 | 40,389 | 40,629 | 22,551 | 11,065 | 6,528 | 187,752 |
| 1948 | 4,969 | 3,715 | 3,448 | 3,445 | 5,736 | 10,739 | 23,826 | 36,703 | 37,695 | 24,760 | 12,985 | 7,964 | 178,003 |
| 1949 | 5,685 | 3,967 | 3,627 | 4,105 | 5,921 | 8,614 | 20,490 | 29,467 | 31,493 | 24,876 | 11,194 | 7,571 | 157,003 |
| 1950 | 5,613 | 4,209 | 3,668 | 3,125 | 4,479 | 6,391 | 17,282 | 29,745 | 26,676 | 14,739 | 8,158 | 5,809 | 130,456 |
| 1951 | 4,845 | 3,638 | 2,977 | 2,850 | 3,762 | 14,555 | 20,502 | 40,101 | 29,348 | 21,377 | 8,715 | 6,584 | 159,534 |
| 1952 | 5,027 | 3,354 | 3,304 | 2,941 | 4,065 | 7,194 | 19,312 | 34,210 | 40,201 | 21,179 | 8,644 | 4,396 | 159,314 |
| 1953 | 3,249 | 2,503 | 2,474 | 2,559 | 4,312 | 8,195 | 17,472 | 28,581 | 24,245 | 12,606 | 8,494 | 5,848 | 125,292 |
| 1954 | 4,099 | 2,593 | 2,323 | 2,405 | 3,689 | 7,434 | 13,151 | 30,933 | 33,468 | 15,538 | 8,442 | 6,044 | 130,129 |
| 1955 | 4,396 | 3,017 | 2,720 | 2,659 | 3,494 | 7,160 | 22,559 | 41,935 | 36,339 | 18,773 | 10,445 | 5,168 | 151,936 |
| 1956 | 4,487 | 2,551 | 2,446 | 2,663 | 3,094 | 8,322 | 14,295 | 36,809 | 28,570 | 11,436 | 5,274 | 3,507 | 125,818 |
| 1957 | 3,470 | 2,827 | 2,772 | 2,429 | 3,103 | 5,596 | 14,754 | 14,123 | 15,942 | 15,928 | 5,251 | 3,501 | 90,096 |
| 1958 | 2,702 | 2,178 | 2,165 | 2,168 | 2,927 | 6,326 | 18,597 | 28,585 | 23,247 | 11,143 | 7,465 | 4,670 | 112,113 |
| 1959 | 3,506 | 3,131 | 3,321 | 3,083 | 4,134 | 9,969 | 16,818 | 32, 91 | 33,834 | 19,978 | 10,611 | 6,065 | 146,455 |
| 1960 | 4,466 | 3,744 | 2,896 | 2,261 | 3,077 | 6,533 | 16,216 | 37,029 | 33,192 | 17,391 | 9,079 | 6,615 | 142,452 |
| 1961 | 4,273 | 3,263 | 2,955 | 3,466 | 4,572 | 11,676 | 16,256 | 30,306 | 35,827 | 25,918 | 11,417 | 7,770 | 160,791 |
| 1962 | 5,264 | 3,676 | 3,350 | 3,143 | 4,756 | 12,307 | 18,131 | 32,322 | 25,420 | 16,851 | 8,760 | 5,537 | 139,511 |
| 1963 | 4,011 | 2,993 | 2,960 | 2,577 | 3,110 | 6,903 | 21,903 | 33,780 | 27,988 | 17,679 | 19,347 | 5,367 | 156,698 |
| 1964 | 5,302 | 3,785 | 3,550 | 3,532 | 5,816 | 8,937 | 27,075 | 32,073 | 33,866 | 23,196 | 11,564 | 7,967 | 166,615 |
| 1965 | 5,450 | 3,937 | 3,494 | 3,070 | 3,652 | 11,719 | 22,577 | 27,932 | 26,357 | 16,246 | 20,032 | 9,857 | 156,353 |
| 1966 | 6,403 | 4,318 | 3,641 | 3,318 | 4,675 | 12,202 | 25,457 | 46,046 | 50,986 | 23,393 | 13,840 | 9,104 | 233,783 |
| 1967 | 5,890 | 4,044 | 3,859 | 3,788 | 4,629 | 7,406 | 13,633 | 23,312 | 23,479 | 17,410 | 9,477 | 6,610 | 123,575 |
| 1968 | 5,325 | 3,979 | 3,424 | 3,241 | 5,674 | 7,929 | 15,695 | 26,602 | 25,871 | 12,899 | 12,049 | 6,234 | 133,332 |
| 1969 | 4,161 | 2,793 | 2,527 | 2,288 | 2,490 | 8,452 | 16,196 | 33,241 | 21,450 | 12,420 | 8,461 | 5,131 | 127,532 |
| TOTAL | 193,669 | 140,934 | 130,410 | 125,908 | 182,679 | 411,202 | 829,675 | 1,461,002 | 1,306,319 | 777,724 | 421,824 | 267,546 | 6,250,892 |
| AVER. | 4,724 | 3,437 | 3,181 | 3,071 | 4,456 | 10,029 | 20,236 | 35,634 | 31,910 | 18,969 | 10,288 | 6,526 | 152,461 |

Surface water

## TABLE 5

## MONTHLY INFLOW INTO PA MONG - NAM NGUM RESERVOIR

(From Reference 19)

Units in Million Cubic Meters

Drainage Area 313,882 sq.km.

| YEAR | JAN. | FEB. | MAR. | APR. | MAY | JUN. | JUL. | AUG. | SEPT. | OCT. | NOV. | DEC. | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1929 | 4,025 | 3,137 | 2,945 | 2,945 | 4,243 | 13,253 | 30,541 | 57,174 | 36,813 | 20,317 | 9,076 | 6,737 | 191,206 |
| 1930 | 4,885 | 3,631 | 3,475 | 4,018 | 7,044 | 15,498 | 20,237 | 45,103 | 31,875 | 18,709 | 9,033 | 6,349 | 169,857 |
| 1931 | 4,429 | 3,390 | 3,185 | 3,077 | 3,768 | 5,437 | 11,162 | 27,567 | 28,641 | 12,800 | 6,418 | 3,923 | 113,797 |
| 1932 | 3,282 | 2,527 | 2,575 | 2,803 | 2,939 | 9,101 | 20,282 | 27,171 | 35,459 | 33,118 | 11,118 | 7,392 | 157,767 |
| 1933 | 5,131 | 2,931 | 2,585 | 2,259 | 2,890 | 10,583 | 25,366 | 34,491 | 25,767 | 15,406 | 8,820 | 5,780 | 142,009 |
| 1934 | 4,180 | 2,870 | 2,813 | 2,775 | 2,940 | 6,187 | 20,712 | 39,054 | 30,194 | 16,678 | 9,102 | 5,953 | 143,458 |
| 1935 | 4,592 | 3,160 | 3,128 | 2,867 | 4,264 | 9,957 | 14,523 | 43,083 | 28,368 | 23,334 | 14,558 | 8,058 | 159,892 |
| 1936 | 5,446 | 4,162 | 3,603 | 3,934 | 5,294 | 15,547 | 21,982 | 37,351 | 39,061 | 13,891 | 7,105 | 4,845 | 162,221 |
| 1937 | 3,695 | 2,870 | 2,889 | 2,410 | 4,170 | 10,782 | 24,167 | 43,122 | 41,439 | 19,570 | 9,713 | 8,281 | 173,108 |
| 1938 | 6,235 | 4,151 | 4,338 | 4,383 | 9,379 | 20,974 | 28,767 | 47,712 | 38,053 | 26,194 | 14,254 | 8,700 | 213,170 |
| 1939 | 6,448 | 4,486 | 4,274 | 4,330 | 6,507 | 19,012 | 34,001 | 49,607 | 35,314 | 24,897 | 11,534 | 8,421 | 208,831 |
| 1940 | 5,927 | 4,427 | 3,949 | 3,610 | 5,484 | 14,414 | 24,554 | 40,607 | 33,366 | 15,410 | 8,752 | 6,139 | 166,639 |
| 1941 | 4,454 | 3,336 | 3,181 | 2,934 | 4,256 | 13,075 | 19,425 | 37,396 | 42,037 | 31,915 | 14,280 | 8,400 | 184,689 |
| 1942 | 5,892 | 3,981 | 3,508 | 3,226 | 6,073 | 13,958 | 33,877 | 57,875 | 30,768 | 15,372 | 10,154 | 6,676 | 191,360 |
| 1943 | 4,902 | 3,402 | 3,514 | 3,585 | 4,178 | 10,075 | 18,403 | 38,019 | 38,745 | 23,315 | 9,187 | 6,119 | 163,444 |
| 1944 | 4,824 | 3,882 | 3,370 | 2,812 | 4,665 | 10,580 | 24,471 | 32,993 | 33,414 | 19,711 | 12,058 | 6,895 | 159,675 |
| 1945 | 5,115 | 3,794 | 3,695 | 3,745 | 6,031 | 12,731 | 24,486 | 51,910 | 42,739 | 17,072 | 8,691 | 6,777 | 186,786 |
| 1946 | 4,851 | 3,442 | 3,312 | 3,555 | 6,255 | 15,577 | 23,197 | 43,149 | 53,628 | 28,274 | 13,626 | 7,938 | 206,804 |
| 1947 | 5,859 | 4,396 | 4,052 | 3,820 | 6,023 | 13,065 | 34,541 | 43,682 | 44,252 | 23,695 | 11,441 | 6,758 | 201,534 |
| 1948 | 5,140 | 3,833 | 3,553 | 3,554 | 6,044 | 11,861 | 26,097 | 39,668 | 40,997 | 28,059 | 13,413 | 8,250 | 190,469 |
| 1949 | 5,883 | 4,095 | 3,739 | 4,240 | 6,240 | 9,485 | 22,440 | 31,811 | 34,109 | 26,103 | 11,580 | 7,841 | 167,566 |
| 1950 | 5,811 | 4,344 | 3,783 | 3,223 | 4,715 | 7,045 | 19,493 | 32,089 | 28,871 | 15,442 | 8,462 | 6,095 | 139,373 |
| 1951 | 5,046 | 3,764 | 3,089 | 2,934 | 3,960 | 15,517 | 22,915 | 44,124 | 31,717 | 22,328 | 9,249 | 6,884 | 171,527 |
| 1952 | 5,228 | 3,510 | 3,418 | 3,045 | 4,210 | 8,263 | 21,977 | 43,426 | 44,138 | 22,175 | 9,178 | 4,696 | 173,264 |
| 1953 | 3,452 | 3,094 | 2,586 | 2,662 | 4,499 | 9,406 | 19,090 | 32,516 | 30,280 | 13,385 | 9,028 | 6,148 | 136,144 |
| 1954 | 4,300 | 2,724 | 2,435 | 2,509 | 3,914 | 8,162 | 14,139 | 33,909 | 35,181 | 16,226 | 8,976 | 6,344 | 138,819 |
| 1955 | 4,597 | 3,143 | 2,832 | 2,963 | 3,633 | 8,132 | 24,426 | 45,397 | 39,070 | 11,448 | 10,979 | 6,498 | 163,118 |
| 1956 | 4,688 | 2,977 | 2,558 | 2,167 | 3,328 | 9,515 | 16,703 | 41,838 | 30,682 | 11,969 | 5,808 | 4,207 | 136,440 |
| 1957 | 3,671 | 2,953 | 2,884 | 2,533 | 3,215 | 6,784 | 16,474 | 15,939 | 17,557 | 16,678 | 5,785 | 3,801 | 98,274 |
| 1958 | 2,903 | 2,304 | 2,277 | 2,272 | 3,058 | 7,202 | 20,951 | 30,955 | 25,442 | 11,716 | 7,939 | 4,970 | 121,989 |
| 1959 | 3,707 | 3,257 | 3,433 | 3,187 | 4,311 | 10,419 | 19,454 | 35,542 | 36,648 | 20,701 | 11,145 | 6,385 | 158,169 |
| 1960 | 4,659 | 3,841 | 2,976 | 2,343 | 3,196 | 6,878 | 17,380 | 39,916 | 36,191 | 18,395 | 9,415 | 6,880 | 152,072 |
| 1961 | 4,455 | 3,389 | 3,070 | 3,587 | 4,773 | 12,969 | 18,112 | 32,540 | 42,528 | 28,050 | 11,948 | 8,075 | 173,496 |
| 1962 | 5,473 | 3,809 | 3,460 | 3,260 | 4,972 | 13,232 | 19,885 | 35,142 | 27,216 | 17,700 | 9,131 | 5,781 | 149,061 |
| 1963 | 4,188 | 3,109 | 3,072 | 2,673 | 3,271 | 7,670 | 24,447 | 42,731 | 30,990 | 18,742 | 20,086 | 8,718 | 169,697 |
| 1964 | 5,532 | 3,938 | 3,684 | 3,669 | 6,115 | 10,306 | 29,215 | 34,152 | 36,569 | 24,337 | 12,046 | 8,256 | 177,819 |
| 1965 | 5,692 | 4,082 | 3,617 | 3,151 | 3,861 | 13,671 | 25,352 | 50,278 | 28,147 | 19,004 | 20,629 | 10,133 | 167,647 |
| 1966 | 6,593 | 4,451 | 3,740 | 3,424 | 5,112 | 13,602 | 28,398 | 50,172 | 53,461 | 25,019 | 14,218 | 9,358 | 217,748 |
| 1967 | [illegible] | 4,153 | 3,673 | 3,922 | 4,833 | 8,338 | 15,463 | 24,732 | 26,139 | 18,346 | 9,937 | 6,880 | 132,765 |
| 1968 | [illegible] | 4,119 | [illegible] | 3,414 | 6,341 | 8,974 | 16,777 | 26,230 | 28,134 | 15,534 | 12,468 | 6,500 | 142,547 |
| 1969 | 4,256 | 2,908 | [illegible] | 2,417 | [illegible] | 10,387 | 21,246 | 42,552 | 22,435 | 13,069 | 8,861 | 5,359 | 159,586 |
| TOTAL | 231,134 | 141,992 | [illegible] | 130,297 | [illegible] | 457,604 | 915,128 | 1,194,937 | 1,416,435 | 817,394 | 439,201 | 278,260 | 6,713,407 |
| AVER. | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 22,379 | 28,604 | 34,547 | [illegible] | [illegible] | [illegible] | 163,742 |

Surface water

TABLE [illegible]

MONTHLY AND ANNUAL RUNOFF, MEKONG RIVER AT PAKSE, LAOS

(From Reference 19)

Units in Million Cubic Meters

Drainage Area 545,000 sq.km.

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 7,200 | 5,690 | 4,390 | 3,9[illegible] | 5,830 | 37,500 | 51,100 | 84,000 | 74,700 | 48,400 | 27,300 | 13,700 | 363,420 |
| 52 | 7,660 | 5,110 | 4,630 | 4,150 | 6,200 | 15,700 | 45,400 | 88,900 | 93,900 | 56,500 | 26,800 | 9,620 | 364,370 |
| 53 | 4,580 | 3,970 | 3,590 | 3,580 | 11,600 | 30,100 | 45,400 | 63,100 | 64,200 | 37,800 | 22,800 | 11,600 | 302,320 |
| 54 | 6,270 | 3,510 | 3,370 | 3,730 | 6,960 | 19,800 | 25,500 | 51,800 | 82,100 | 53,200 | 23,100 | 10,800 | 290,140 |
| 1955 | 6,490 | 4,370 | 3,920 | 4,630 | 5,760 | 16,300 | 42,700 | 59,000 | 80,800 | 31,300 | 20,000 | 11,900 | 266,170 |
| 56 | 6,850 | 4,820 | 3,440 | 3,480 | 10,400 | 27,200 | 41,900 | 89,300 | 82,200 | 36,000 | 17,800 | 9,650 | 333,440 |
| 57 | 6,810 | 4,830 | 4,320 | 4,310 | 5,720 | 20,100 | 51,100 | 49,400 | 61,100 | 47,400 | 20,300 | 8,460 | 283,850 |
| 58 | 5,690 | 43320 | 3,960 | 3,260 | 4,360 | 17,400 | 37,900 | 52,600 | 77,400 | 37,100 | 17,500 | 9,520 | 271,010 |
| 59 | 5,370 | 4,070 | 3,860 | 3,970 | 5,510 | 13,300 | 27,800 | 57,900 | 79,800 | 46,000 | 23,300 | 10,600 | 283,420 |
| 1960 | 6,710 | 4,780 | 4,030 | 2,870 | 3,520 | 13,000 | 27,300 | 80,500 | 73,100 | 50,500 | 20,300 | 10,300 | 296,610 |
| 61 | 6,350 | 4,480 | 4,180 | 4,420 | 6,980 | 34,600 | 46,700 | 69,200 | 99,900 | 73,400 | 23,100 | 10,900 | 384,210 |
| 62 | 7,790 | 5,328 | 4,745 | 4,016 | 7,601 | 28,166 | 48,851 | 71,833 | 64,869 | 46,716 | 19,119 | 8,452 | 317,486 |
| 63 | 5,950 | 4,220 | 3,800 | 3,320 | 3,950 | 25,500 | 49,500 | 85,600 | 65,600 | 37,800 | 28,500 | 13,800 | 325,540 |
| 64 | 7,610 | 5,400 | 4,860 | 4,650 | 8,800 | 22,700 | 45,800 | 55,900 | 75,500 | 60,300 | 25,300 | 13,200 | 330,020 |
| 1965 | 7,900 | 5,630 | 5,090 | 4,430 | 5,720 | 40,200 | 53,000 | 58,500 | 55,400 | 30,300 | 26,300 | 12,500 | 304,970 |
| 66 | 11,030 | 6,896 | 5,155 | 4,176 | 10,656 | 25,534 | 51,400 | 82,426 | 103,740 | 41,600 | 19,945 | 11,930 | 374,488 |
| 67 | 5,368 | 5,726 | 5,264 | 4,420 | 6,710 | 17,600 | 27,800 | 49,200 | 62,700 | 46,200 | 15,100 | 10,800 | 259,888 |
| 68 | 6,870 | 5,270 | 4,680 | 4,040 | 8,800 | 15,800 | 31,200 | 53,400 | 67,500 | 32,600 | 17,800 | 9,550 | 257,510 |
| 69 | 6,350 | 4,460 | 3,980 | 3,530 | 4,410 | 26,100 | 56,800 | 76,800 | 51,000 | 27,900 | 16,400 | 8,570 | 286,300 |
| Avg. | 6,940 | 4,890 | 4,298 | 3,938 | 6,815 | 23,400 | 42,482 | 67,282 | 73,437 | 44,353 | 21,603 | 10,834 | 310,272 |
| Max. | 11,030 | 6,896 | 5,264 | 4,650 | 11,600 | 40,200 | 56,800 | 89,300 | 103,740 | 73,400 | 28,500 | 13,800 | 384,210 |
| Min. | 4,580 | 3,110 | 3,370 | 2,870 | 3,520 | 13,000 | 25,500 | 49,200 | 51,000 | 27,900 | 15,100 | 8,452 | 257,510 |

TABLE 7

MONTHLY AND ANNUAL RUNOFF, MEKONG RIVER AT KRATIE, CAMBODIA

(From Reference 15)

Units in Million Cubic Meters

Drainage Area 646,500 sq.km.

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 10,829 | 7,498 | 5,576 | 5,251 | 9,910 | 37,525 | 61,102 | 97,502 | 89,277 | 63,521 | 32,293 | 16,628 | 436,912 |
| 52 | 8,223 | 4,914 | 4,719 | 4,452 | 8,576 | 18,691 | 50,380 | 119,042 | 121,038 | 82,529 | 35,303 | 13,472 | 471,341 |
| 53 | 7,418 | 5,330 | 4,895 | 4,750 | 12,259 | 37,921 | 54,492 | 88,655 | 87,316 | 55,633 | 27,195 | 13,656 | 399,528 |
| 54 | 8,482 | 5,105 | 4,523 | 5,098 | 10,319 | 25,952 | 35,407 | 68,075 | 108,570 | 71,669 | 28,435 | 13,444 | 386,059 |
| 1955 | 8,563 | 5,412 | 5,006 | 5,282 | 6,935 | 21,131 | 54,532 | 67,972 | 78,365 | 45,775 | 20,631 | 30,590 | 348,799 |
| 56 | 10,807 | 6,280 | 5,180 | 5,159 | 14,869 | 31,053 | 56,224 | 105,370 | 107,179 | 49,365 | 23,410 | 12,263 | 427,159 |
| 57 | 9,159 | 6,290 | 5,606 | 5,452 | 8,186 | 25,955 | 60,758 | 86,244 | 90,517 | 74,146 | 26,493 | 13,819 | 392,225 |
| 58 | 8,960 | 6,072 | 5,139 | 4,491 | 5,794 | 24,326 | 55,734 | 67,167 | 110,722 | 52,979 | 22,627 | 11,867 | 375,880 |
| 59 | 6,382 | 4,705 | 4,633 | 4,273 | 5,906 | 16,465 | 31,914 | 69,981 | 96,692 | 64,360 | 26,029 | 11,145 | 342,505 |
| 1960 | 7,709 | 5,753 | 4,893 | 3,518 | 4,818 | 16,376 | 36,270 | 105,900 | 93,614 | 76,049 | 29,500 | 15,608 | 400,017 |
| 61 | 8,796 | 5,778 | 5,367 | 5,112 | 10,539 | 41,945 | 75,531 | 107,240 | 129,056 | 105,451 | 34,404 | 17,262 | 546,481 |
| 62 | 11,155 | 7,589 | 6,704 | 5,615 | 9,889 | 37,875 | 67,581 | 100,949 | 94,280 | 65,969 | 29,312 | 14,037 | 450,954 |
| 63 | 8,525 | 5,737 | 5,176 | 4,553 | 4,950 | 25,294 | 58,886 | 111,430 | 95,016 | 58,242 | 35,393 | 18,147 | 431,349 |
| 64 | 9,880 | 6,310 | 5,260 | 4,810 | 11,300 | 24,300 | 51,800 | 77,000 | 98,200 | 85,300 | 40,700 | 19,900 | 431,760 |
| 1965 | 10,800 | 6,990 | 6,010 | 5,130 | 7,030 | 46,400 | 71,400 | 76,700 | 84,100 | 43,300 | 32,400 | 16,200 | 406,460 |
| 66 | 11,600 | 7,650 | 7,090 | 6,250 | 13,900 | 27,400 | 69,900 | 106,800 | 128,700 | 51,850 | 27,500 | 17,000 | 475,640 |
| 67 | 11,300 | 7,780 | 7,270 | 5,910 | 8,860 | 23,500 | 42,400 | 75,900 | 91,600 | 64,500 | 21,200 | 14,900 | 375,120 |
| 68 | 8,920 | 6,940 | 5,090 | 4,570 | 9,530 | 17,700 | 38,400 | 81,000 | 99,700 | 43,900 | 25,400 | 13,600 | 359,750 |
| 69 | 7,920 | 4,650 | 4,160 | 4,030 | 5,170 | 27,000 | 77,800 | 105,500 | 91,600 | 43,300 | 29,290 | 15,185 | 420,635 |
| Avg. | 9,222 | 6,148 | 5,384 | 4,932 | 8,881 | 27,781 | 55,280 | 89,180 | 99,755 | 63,570 | 29,290 | 15,185 | 414,608 |
| Max. | 11,600 | 7,780 | 7,270 | 6,250 | 14,869 | 46,400 | 77,800 | 119,042 | 129,056 | 105,451 | 35,393 | 20,590 | 546,481 |
| Min. | 6,382 | 4,650 | 4,160 | 3,518 | 4,818 | 16,376 | 31,914 | 66,244 | 79,365 | 41,300 | 21,500 | 11,145 | 342,505 |

TABLE 8

PA MONG PROJECT WATER UTILIZATION SUMMARY – AVERAGE ANNUAL REQUIREMENTS

(From Reference 15)

| Pa Mong Project Service Division | 1951-69 Average Annual Requirements | | | | | | |
|---|---|---|---|---|---|---|---|
| | Irrigation | | Fishery | | DM&I | Total utilization | |
| | Area ha | Diversion $m^3 \times 10^6$ | Area ha | Diversion $m^3 \times 10^6$ | Diversion $m^3 \times 10^6$ | Pa Mong $m^3 \times 10^6$ | Return flow $m^3 \times 10^6$ |
| 1. Vientiane | 10,620 | 166 | 1,350 | 20 | 12 | 198 | – |
| 3. Vientiane Extension | 14,720 | 231 | 1,840 | 26 | 12 | 269 | – |
| 4. Nam Lik | 30,720 | 483 | 3,900 | 60 | 12 | 560 | – |
| 5. Lao Pumping | 46,070 | 732 | 5,850 | 88 | 24 | – | 844 |
| Lao total | 102,130 | 1,617 | 12,940 | 194 | 60 | 1,027 | 844 |
| 2. Huai Mong | 29,370 | 466 | 3,730 | 54 | 48 | 568 | – |
| 6. Udorn | 185,720 | 3,117 | 23,630 | 357 | 276 | 3,750 | – |
| 7. Kumphawapi | 33,380 | 559 | 4,240 | 62 | 48 | 669 | – |
| 8. Nai Nah | 45,450 | 762 | 5,770 | 87 | 72 | 747 | 174 |
| 9. Lam Phaniang | 144,710 | 2,428 | 18,380 | 279 | 216 | 2,923 | – |
| 10. Huai Pong | 210,280 | 3,526 | 26,700 | 403 | 300 | 4,229 | – |
| 11. Khon Kaen | 71,330 | 1,198 | 9,060 | 135 | 108 | – | 1,441 |
| Thailand total | 720,240 | 12,056 | 91,510 | 1,377 | 1,068 | 12,886 | 1,615 |
| Pa Mong total | 822,370 | 13,673 | 104,450 | 1,571 | 1,128 | 13,913 | 2,459 |
| Service area | 926,820 hectares | | | | 16,372 $m^3 \times 10^6$ | | |

| Item | Year-50 | | With Nam Ngum | |
|---|---|---|---|---|
| | Volume $m^3 \times 10^6$ | Percent of inflow percent | Volume $m^3 \times 10^6$ | Percent of inflow percent |
| Firm power release | 93,777 | 61.8 | 106,942 | 65.6 |
| Secondary power release | 38,267 | 25.2 | 35,226 | 21.6 |
| Irrigation diversion | 11,800 | 7.8 | 11,800 | 7.2 |
| Fishery diversion | 1,361 | 0.9 | 1,361 | 0.8 |
| DM&I diversion | 1,128 | 0.7 | 1,128 | 0.7 |
| Live stream releases | 36 | 0.0 | 36 | 0.0 |
| Reservoir evaporation | 1,331 | 0.9 | 1,566 | 1.0 |
| Reservoir spills | 4,119 | 2.7 | 4,996 | 3.1 |
| Total reservoir inflow | 151,819 | 100.0 | 163,055 | 100.0 |

TABLE 9

PA MONG PROJECT YEAR-50 WATER BALANCE BY MONTHS

(From Reference 15)

| 1951-69 Average Month | Pa Mong Project Total Volume ($m^3 \times 10^6$) | | | | |
|---|---|---|---|---|---|
| | Reservoir | | Outlet Diversion | Net Return | Total Regulation[2] |
| | Storage | Evaporation | | | |
| January | -6,650 | 310 | 2,209 | -42 | -4,089 |
| February | -6,560 | 283 | 2,046 | 71 | -4,302 |
| March | -7,543 | 254 | 2,077 | 49 | -5,261 |
| April | -7,138 | 121 | 1,408 | 402 | -6,011 |
| May | -6,241 | -38 | 736 | 389 | -5,932 |
| June | -2,894 | -77 | 835 | 31 | -2,167 |
| July | 5,637 | -74 | 802 | 3 | 6,362 |
| August | 19,267 | -86 | 674 | 6 | 19,018 |
| September | 17,820 | -102 | 285 | -15 | 18,018 |
| October | 1,888 | 97 | 1,034 | 346 | 2,673 |
| November | -2,441 | 312 | 760 | 325 | -1,694 |
| December | -5,145 | 316 | 1,423 | -18 | -3,388 |
| Annual | 0 | 1,316 | 14,289 | 1,547 | 14,058 |

Pa Mong Reservoir outlet diversions are the summation of all water requirements plus regulating reservoir storage and evaporation.

Pa Mong total regulation is the sum of combined Pa Mong Reservoir change in storage plus reservoir net evaporation plus diversions minus return flow not reused.

TABLE 10

PA MONG PROJECT YEAR-50 WATER UTILIZATION BY MONTHS

(From Reference 15)

(Unit in $m^3 \times 10^6$)

| 1951-69 Average Month | Pa Mong Reservoir | | | | | Diversions | |
|---|---|---|---|---|---|---|---|
| | Inflow | Change in Storage | Power Release | Spill and River Release | Net Evaporation | Total | Net return |
| January | 4,545 | -6,650 | 8,673 | 3 | 310 | 2,209 | -42 |
| February | 3,323 | -6,560 | 7,551 | 3 | 283 | 2,046 | 71 |
| March | 3,010 | -7,543 | 8,219 | 3 | 254 | 2,077 | 49 |
| April | 2,846 | -7,138 | 8,452 | 3 | 121 | 1,408 | 402 |
| May | 3,947 | -6,241 | 9,487 | 3 | -38 | 736 | 389 |
| June | 8,902 | -2,894 | 11,035 | 3 | -77 | 835 | 31 |
| July | 18,578 | 5,637 | 12,210 | 3 | -74 | 802 | 3 |
| August | 33,048 | 19,267 | 12,866 | 327 | -86 | 674 | 6 |
| September | 30,366 | 17,820 | 11,394 | 969 | -102 | 285 | -15 |
| October | 17,409 | 1,889 | 13,390 | 1,000 | 97 | 1,034 | 346 |
| November | 10,379 | -2,441 | 11,370 | 378 | 312 | 760 | 325 |
| December | 6,338 | -5,145 | 9,741 | 3 | 316 | 1,423 | -18 |
| Annual | 142,691 | 0 | 124,388 | 2,698 | 1,316 | 14,289 | 1,547 |
| Percent of Inflow | 100.0 | 0 | 87.2 | 1.9 | 0.9 | 10.0 | 1.1 |

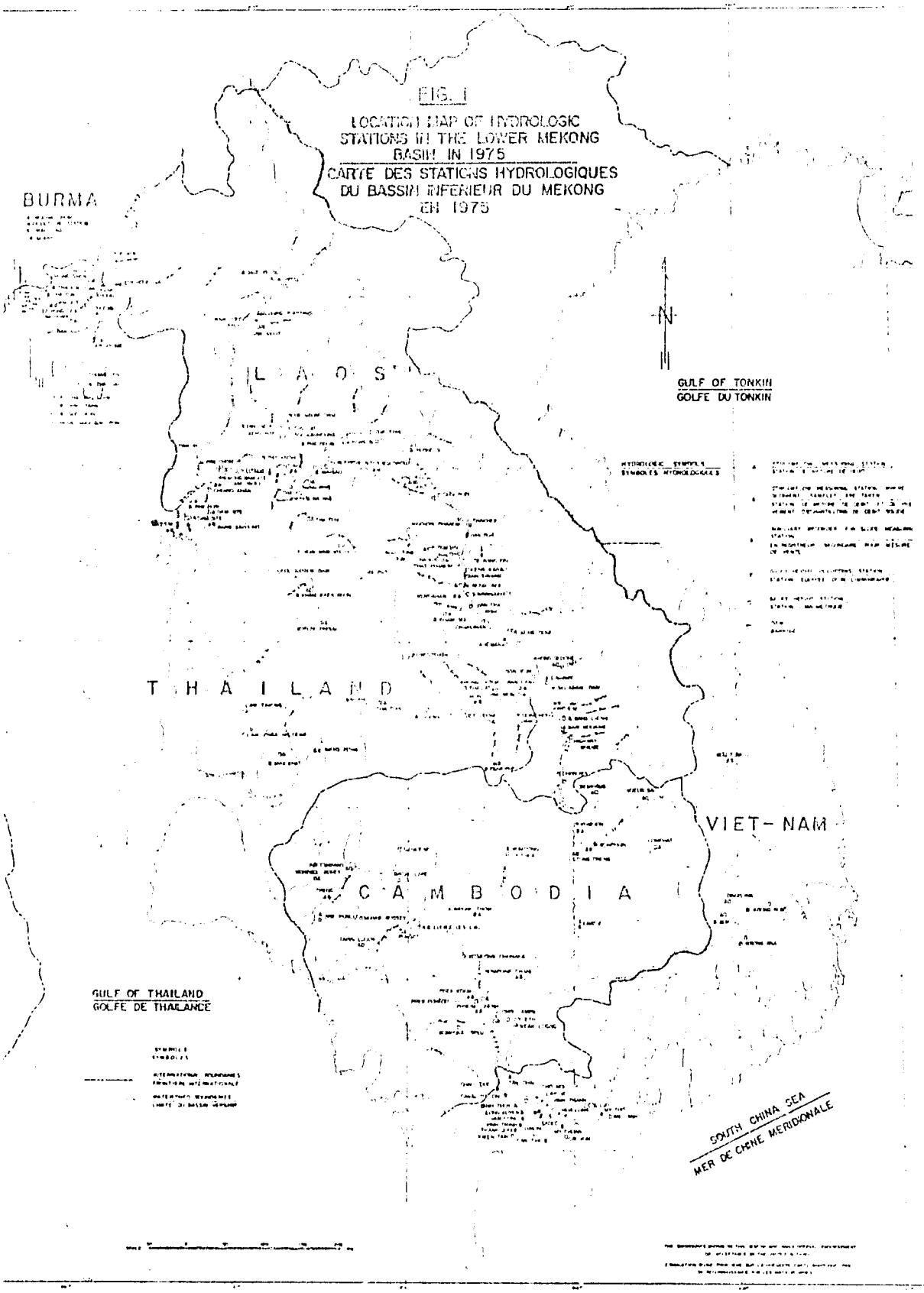


FIG. 1
LOCATION MAP OF HYDROLOGIC STATIONS IN THE LOWER MEKONG BASIN IN 1975
CARTE DES STATIONS HYDROLOGIQUES DU BASSIN INFERIEUR DU MEKONG EN 1975
BURMA
LAOS
THAILAND
CAMBODIA
VIET-NAM
GULF OF TONKIN
GOLFE DU TONKIN
GULF OF THAILAND
GOLFE DE THAILANDE
SOUTH CHINA SEA
MER DE CHINE MERIDIONALE
N

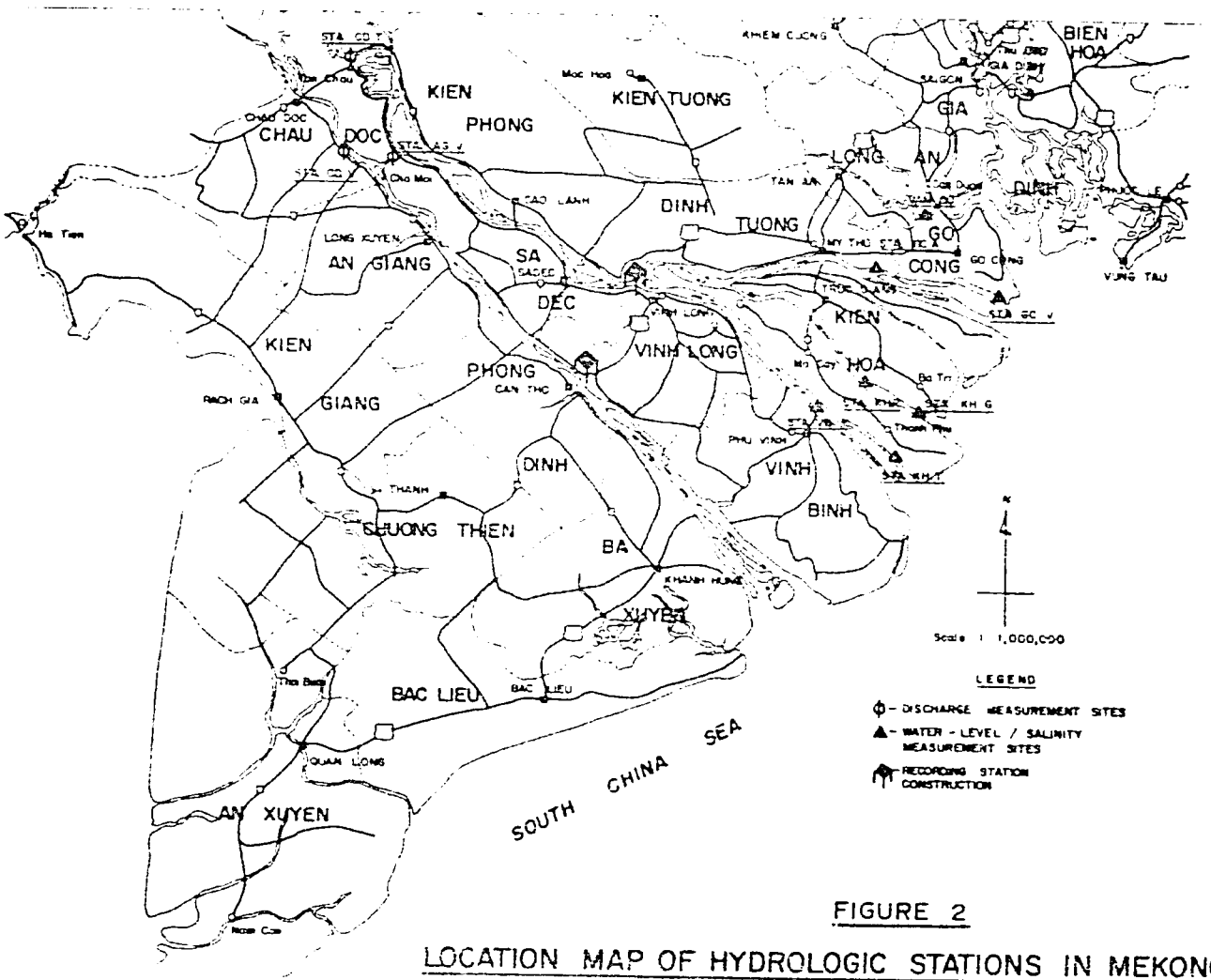



FIGURE 2

LOCATION MAP OF HYDROLOGIC STATIONS IN MEKONG DELTA

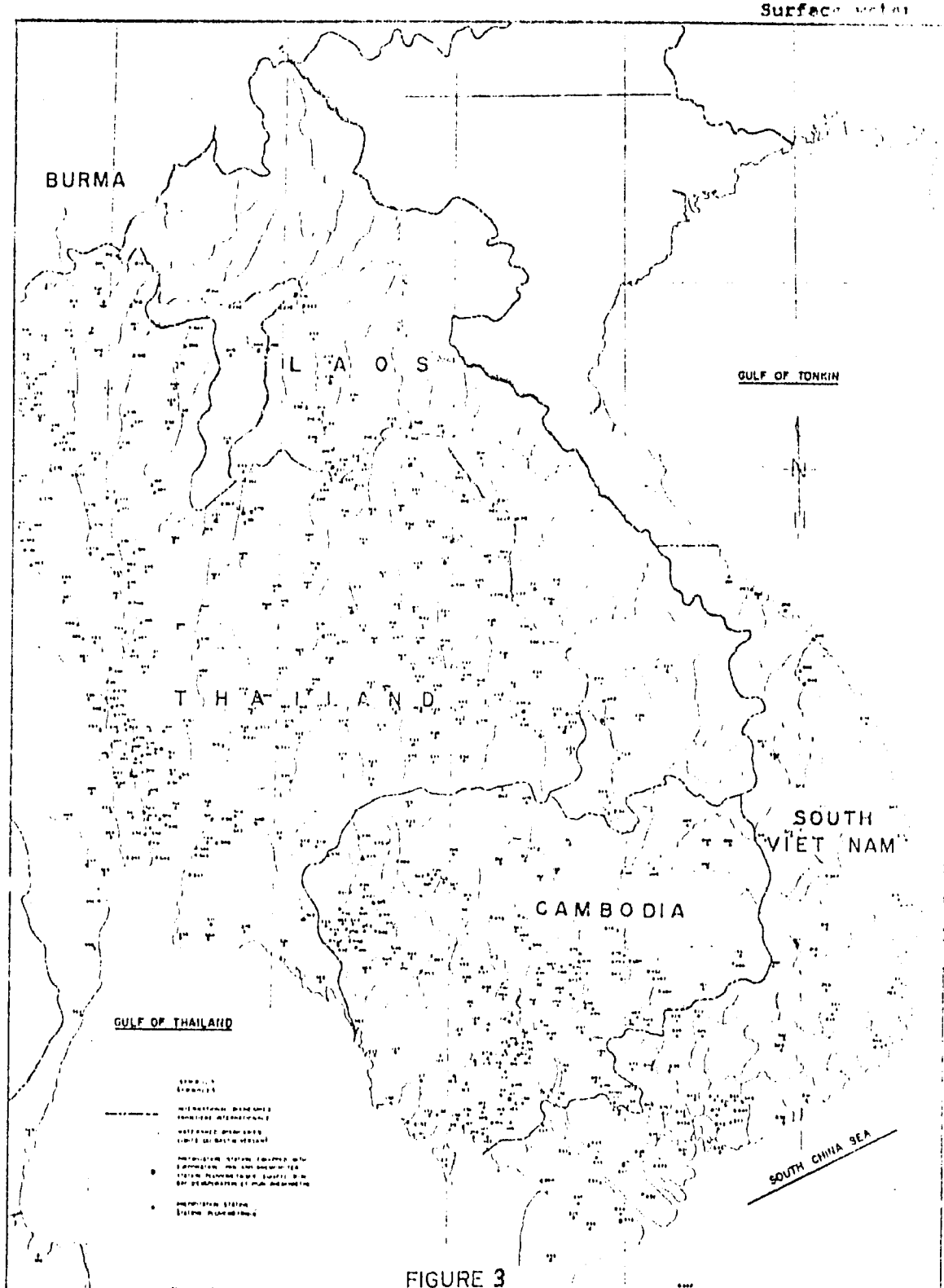



FIGURE 3

MAP OF PRECIPITATION STATIONS IN LOWER MEKONG BASIN (1975)

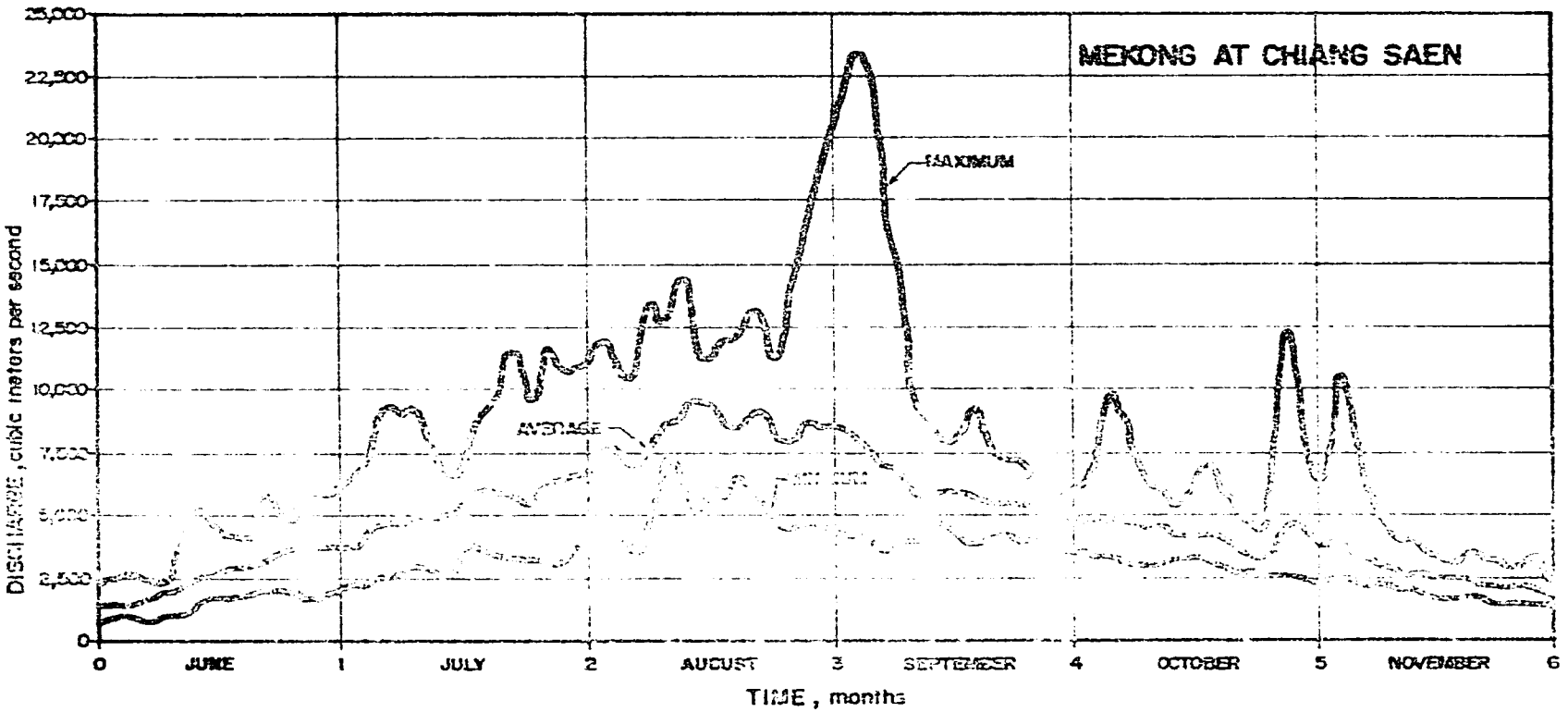



FIGURE 4A

**SUMMARY OF DISCHARGE HYDROGRAPHS OF SELECTED STATIONS**

( From Reference 9 )

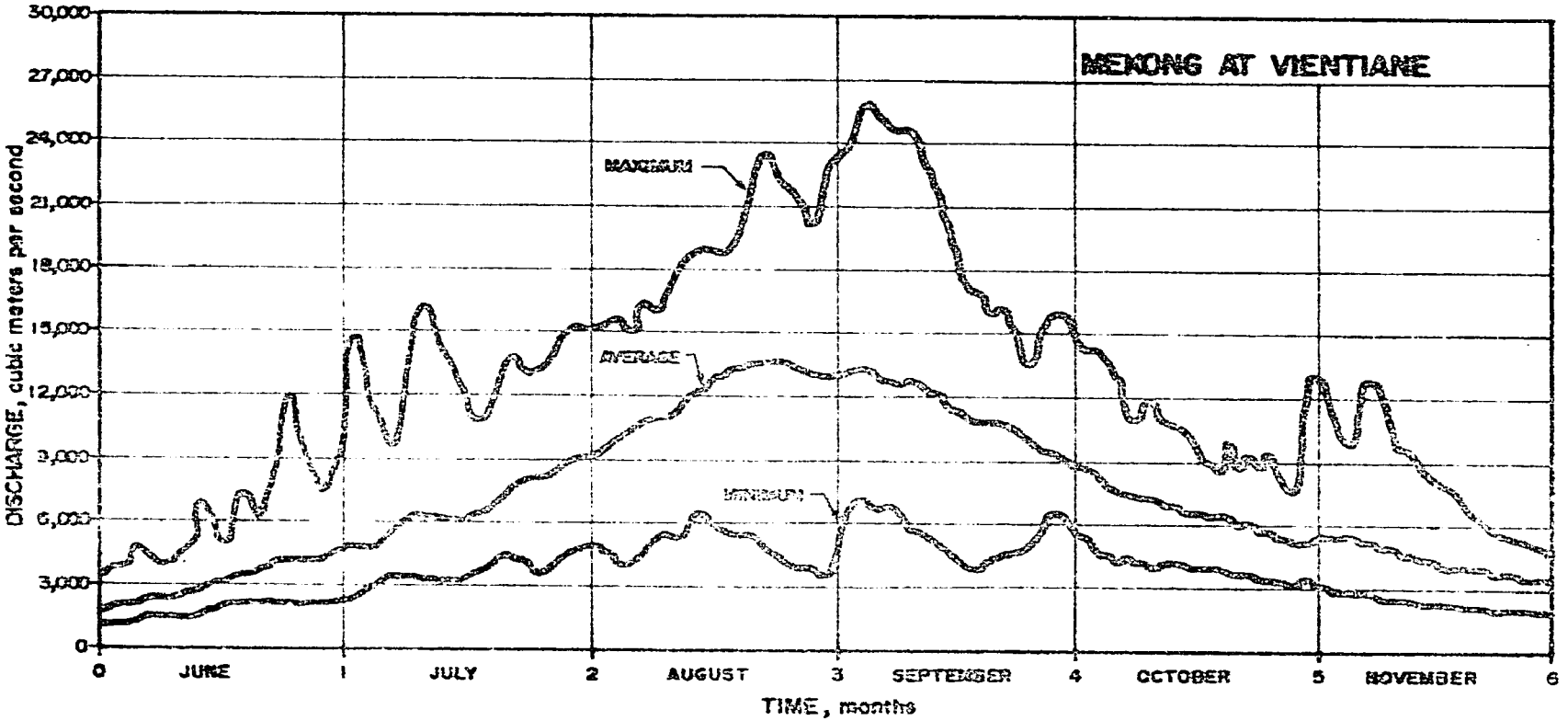



FIGURE 4B

SUMMARY OF DISCHARGE HYDROGRAPHS OF SELECTED STATIONS

( From Reference 9 )

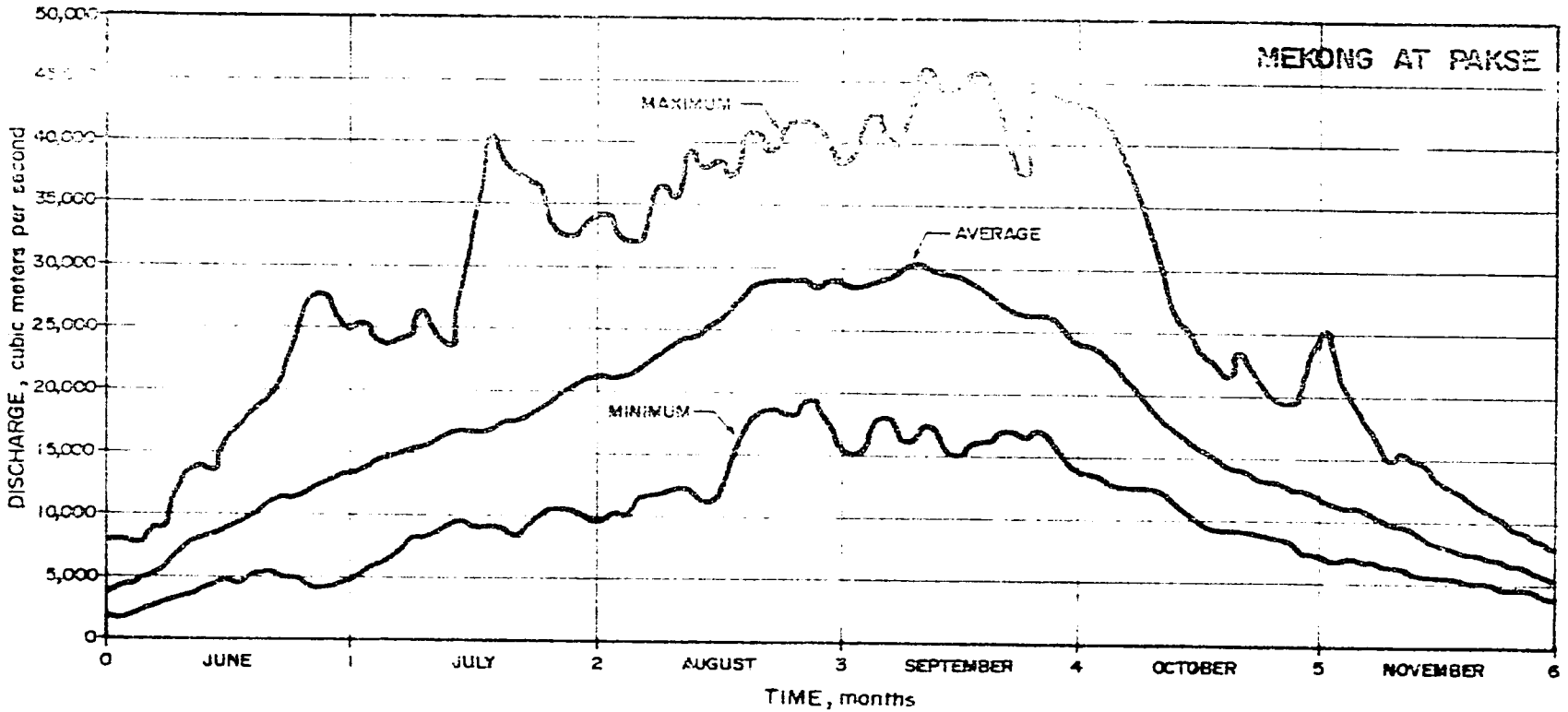



FIGURE 4C

SUMMARY OF DISCHARGE HYDROGRAPHS OF SELECTED STATIONS

(From Reference 9)

Surface w

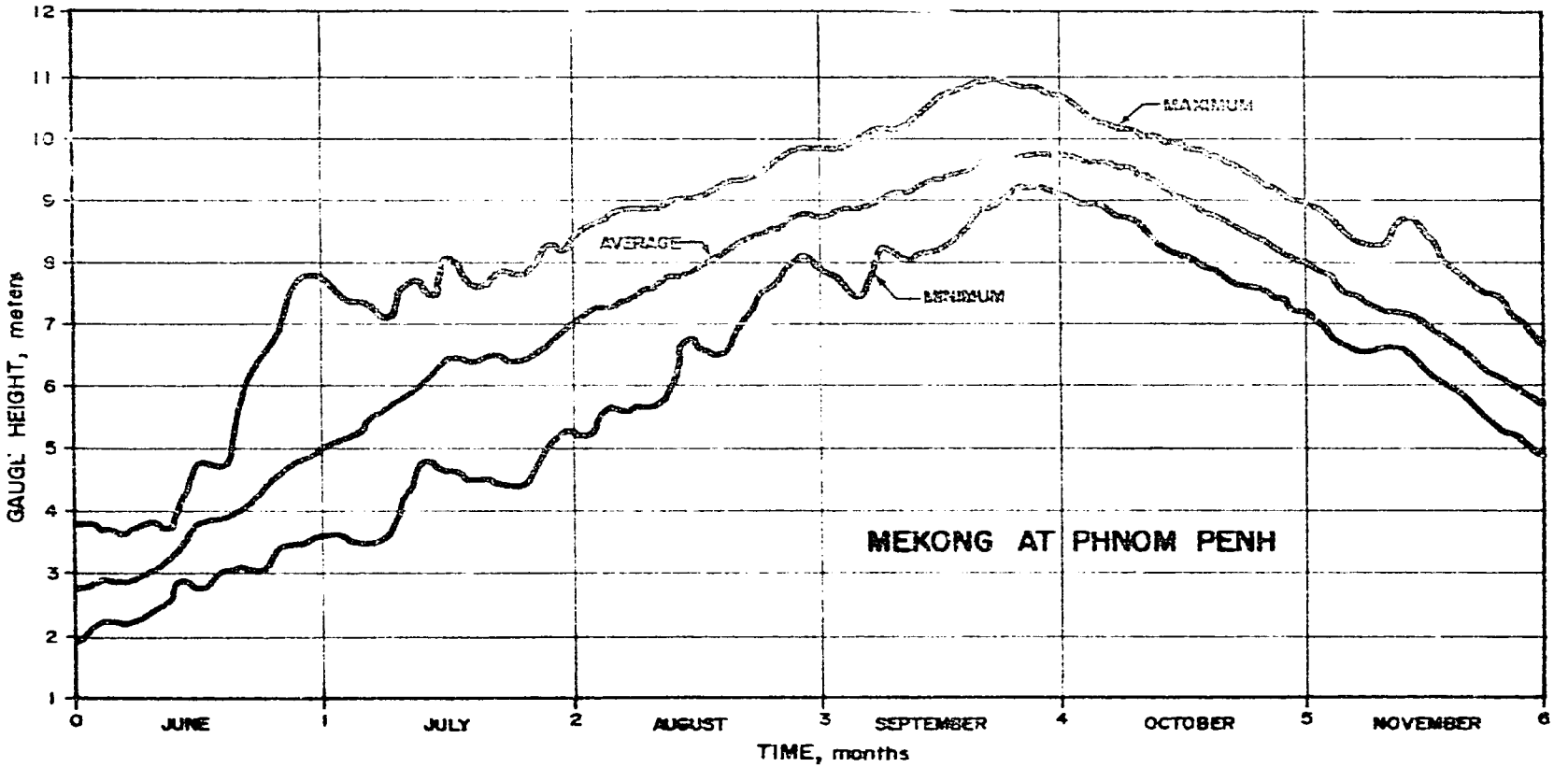
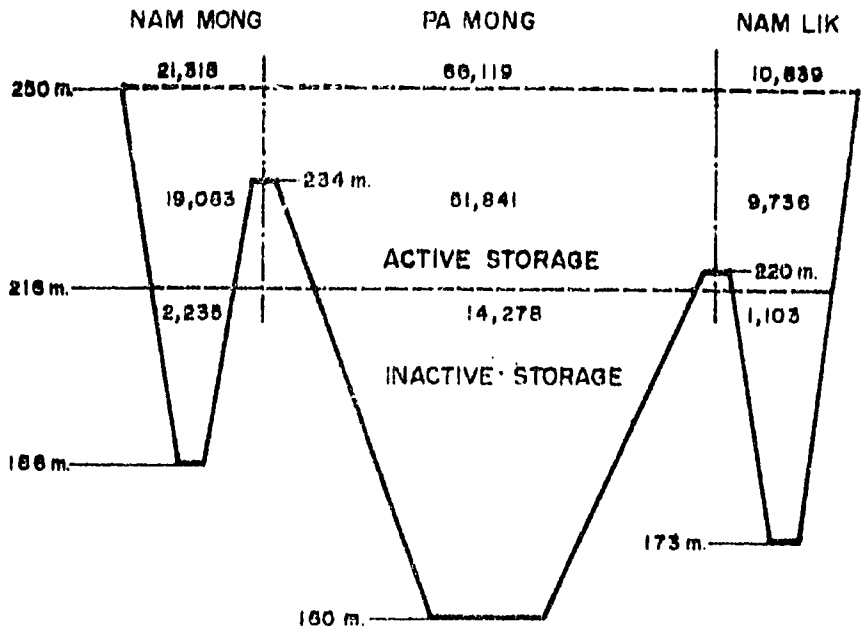



FIGURE 4D

SUMMARY OF STAGE HYDROGRAPHS OF SELECTED STATIONS

( From Reference 9 )




ELEVATION UNITS - meters
STORAGE UNITS - $m^3 \times 10^3$

| | CAPACITY (216-250) | BELOW 216 m. | TOTAL |
|---|---|---|---|
| NAM MONG | 19,083 | 2,235 | 21,318 |
| PA MONG | 51,841 | 14,278 | 66,119 |
| NAM LIK | 9,736 | 1,103 | 10,839 |
| TOTAL | 80,660 | 17,616 | 98,276 |

NOTE :

DIAGRAM REPRESENTS YEAR 1 CONDITIONS, WITH NO SEDIMENT

FIGURE 5

SCHEMATIC DIAGRAM – PA MONG RESERVOIR STORAGE PROJECT

( From Reference 6 )

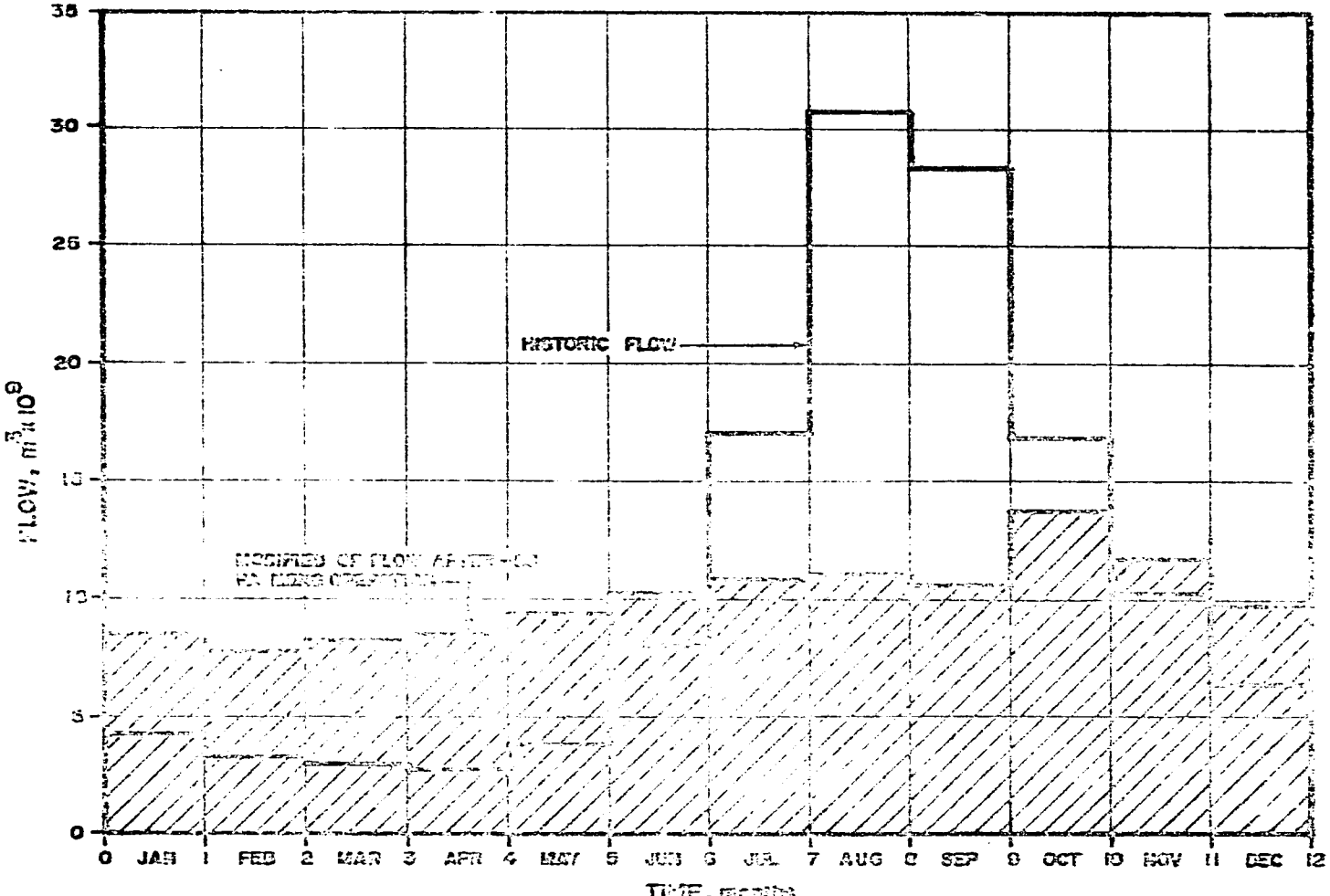



FIGURE 3

THE 1951-1958 AVERAGE MONTHLY FLOW HYDROGRAPHS MEKONG RIVER AT WAT SOR, VIENTIANE

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## WATER QUALITY

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Table 2: Summary of water quality analyses for Mekong river and tributaries for hydrologic years 1972 and 1973

Table 3: Parameters for lower Mekong basin monitoring programme

Table 4: Summarized water quality data for Mekong delta

Table 5: Summarized water quality data for Khorat plateau

Figure

Figure 1: Water quality sampling stations in lower Mekong basin in 1975

# PA MONG ENVIRONMENTAL ASSESSMENT

## WATER QUALITY

### 1. Introduction

The quality of water - its characteristics as measured by physical, chemical, and biological parameters - is important to virtually every water use including power generation, agriculture, fisheries, community water supply, and industrial uses. These characteristics are a function of the natural environment and of man-made activities, both of which cause various substances to be added to the water which alter its physical and chemical properties which in turn affect the aquatic biota.

Impoundment of the mainstream by Pa Mong will affect the water quality situation in many ways, primarily the following:

(a) A new large man-made lake will be created, which has vast potentials for fisheries production, provided a proper aquatic environment is maintained. It also offers potentials for massive growth of water weeds which can interfere seriously with many water uses including fisheries, navigation, power generation, and irrigation.

(b) Water quality changes will result from impoundment at Pa Mong, primarily in temperature, dissolved oxygen, and nutrients, which may affect downstream riverine conditions especially in the vicinity immediately below the dam.

(c) By increasing the dry season flow in the downstream river, the quality of the dry season river water will be improved.

(d) The increase in dry season flow will also help alleviate salinity problems due to saltwater intrusion in the estuarine zone. The salinity pattern in the estuarine zone (important to fisheries reproduction) will be altered and tend to become more stabilized throughout the year due to the balancing of flows.

This section of the environmental assessment report will (1) review the existing water quality basic data collecting programme and its development, and discuss how these basic data can be used for evaluating environmental impact; (2) review those aspects of other Committee programmes which involve water quality considerations; (3) discuss the probable effects on water quality of Pa Mong reservoir, and (4) indicate measures which are being or will be taken to insure proper conservation of water quality throughout the basin.

Effects of Pa Mong reservoir on sediments and erosion and on salinity in the delta are discussed separately.

2. Existing water quality in lower basin

2.1 Monitoring programme: Systematic sampling and analysis of the quality of water in the Mekong river and its major tributaries was initiated by the Mekong Committee in 1972 using some 29 stations, reaching from Chiang Saen at the Burma border to Phnom Penh in the delta, as part of the Committee's basic hydrologic data programme. Table 1 lists the 29 stations, and Figure 1 shows their locations. Table 2 presents a summary of the analyses for each of the 29 stations, which shows the analyses have been limited to dissolved mineral contituents and other parameters for assessing suitability for irrigation. Most of the data have been collected from stations in Thailand, with a sampling frequency approximately bimonthly in 1973 and monthly in 1974. The total accumulated data are considered sufficient for purposes of preliminary planning of Pa Mong.

The programme of analyses made on the water samples is now being extended to include additional parameters to permit more detailed evaluation of the suitability of the river water for community and industrial water supply, for assessing the extent of pollution (including bacteriological and biological indices as well as physical and chemical parameters), and for making better assessment of possible effects of upstream storage on altering the nutrient content of the downstream flow. Table 3 shows the list of parameters and the desired frequency of sampling considered to represent a competent programme for all preliminary planning purposes. Parts A and B of Table 3 (the physical and chemical parameters) have been or are being implemented by the Basic Hydrologic Data programme of the Mekong Secretariat, and it is intended to implement Part C (the biological parameters) when feasible.

2.2 River water quality: Review of Table 2 gives the following picture of the mineral water quality in the river:

(a) The water quality changes very little proceeding down the river from Burma to the South China Sea.

(b) The dissolved mineral quality is excellent for practically all agricultural, community, and industrial purposes. The water is low in total dissolved solids, hardness, sodium, and chloride, has a low SAR ratio, and is non-corrosive (has a slightly positive calcium carbonate saturation index). The concentration of dissolved minerals is reduced by about one-third during the wet season (July through December) as compared to the dry season (January through June).

(c) The temperature of the river appears to decrease gradually proceeding downstream, from an average of about 27°C at Chiang Saen to about 22°C in the delta.

(d) In addition to dissolved mineral constituents the Mekong river water is characterised, like most rivers in southeast Asia, by high turbidity. However, this suspended material can be readily removed by conventional rapid sand filtration methods for water to be used for community and industrial purposes.

2.3 Tributary reservoirs: Only at one tributary reservoir has it been possible to carry out limnological studies in any extensive detail, namely at Nam Ngum (Ref. 16, 17, 18). Limited observations have been made by the Mekong Committee at Nam Pong and at other Thai reservoirs by the Thai Department of Fisheries (Ref. 19) (See discussions of aquatic biology and of fisheries).

2.4 Water pollution: At this time the Mekong river is relatively unpolluted, except in the immediate vicinity of sizeable communities, because of the low level of urbanization and industrialization in the region. The water quality data being gathered by the Mekong Committee's monitoring programme, by indicating changes in water quality resulting from growth of cities and industries, should serve as a valuable base for guiding the riparian nations in developing national water pollution regulatory programmes and eventually in achieving a basinwide water quality and pollution control programme.

While water pollution from people and industries is hardly a problem now in the Mekong river and its tributaries, as urban centres and industry develop this will become a very real problem and it is important that competent regulatory measures be established as the growth proceeds. Pollution control is economical and feasible if planned and implemented so that communities and industries can arrange for proper treatment and disposal of wastes as part of the continuing expenses of growth. Correcting the problem afterwards is relatively very costly and very difficult to achieve. The Mekong Committee would alert the riparian countries if it should notice any threatening deterioration in water quality in the river or its tributaries.

3. Effects of storage at Pa Mong reservoir

An analysis of the probable effects of storage at Pa Mong (See discussion on Pa Mong reservoir ecology) indicates that storage will have negligible effect on the dissolved mineral quality, other than to tend to even out the normal variations between wet and dry season flows. The reservoir will trap or settle out most of the suspended turbidity, but the downstream river flow can be expected to resuspend similar materials and soon reach essentially the same turbidity levels (See discussion on sediments and erosion). The reservoir is expected to stratify, with respect to temperature and

dissolved oxygen, with the uppermost layers saturated with oxygen and the lower regions practically devoid of oxygen, as happens in most reservoirs in southeast Asia (including nearby Nam Ngum). The inundation of the non-removed forests and other vegetative cover will impart vast quantities of nutrients into the reservoir system, which will stimulate a high level of primary biological production and a rich fishery (see discussions on aquatic biology and fisheries).

Creation of the new reservoir at Pa Mong will justify eventual establishment of a reservoir water quality and limnological laboratory to help realize maximum benefits in using the reservoir for fisheries, power production, recreation, and other purposes, including control of aquatic weeds. The experience in other reservoirs in southeast Asia indicates no particular environmental hazards will be involved, but the physical-chemical-biological ecology of the new reservoir will be very complex scientifically, hence it is anticipated that continuing at-site study and research will be pursued to understand these relationships and to devise management measures to achieve maximum benefits.

4. Effects of irrigation from Pa Mong reservoir

The Pa Mong reservoir water will be of excellent quality for irrigation with a low salt concentration, a favorable ratio of sodium to calcium plus magnesium, toxic ions and low or negligible concentrations of potentially toxic ions. Use of this water for irrigation on the higher alluvial soils of the Stage One and Phase II irrigation service areas together with the planned system of drainage, will result in sufficient leaching, hence will maintain a satisfactory salt balance and will not involve hazards due to salinity, sodium, or toxicity. Also, assuming competent irrigation practices (good soil and water management) the water can be safely used on the low terraces (Ref. 16, 17).

Irrigation of the floodplain areas may involve salinity and sodium hazards, regardless of irrigation water quality, because of the difficult leaching conditions in these areas characterized by low soil permeability and low hydraulic gradients. However, favorable salinity and exchangeable sodium levels have been maintained in similar soils in the region under hydrologic conditions similar to those expected in the service areas, which suggests the floodplains can be successfully irrigated with Pa Mong reservoir water. Detailed field studies will be needed to determine the design requirements for suitable leaching systems.

The return flows from irrigation and their salt content will of necessity be discharged to the Mekong river or its tributaries. Assuming maintenance of salt balance in irrigation, this should have no significant effect on water quality in the Mekong river or tributaries because there will be no significant admixture of groundwater into the return

flows and the irrigated lands do not contain significant quantities of soluble salts. Also, the volumes of the return flows are very small in terms of stream flow. For Stage I all of the return flow will be discharged to the Mekong river, making up 0.2 per cent of the total river flow. For Phase II, 40 per cent of the return flow will be discharged directly to the Mekong, making up 3 per cent of the total river flow. The remaining 60 per cent will reach the Mekong via the Nam Chi and Nam Mun rivers. The effect of the return flow salt content on these tributaries should be negligible during the rainy season due to dilution, and should be beneficial during the dry season in affecting improvements both in quality and quantity.

The irrigation water for Stage One would all be fresh water from Pa Mong reservoir, but for Phase II the return flow (from both cropping and fisheries) would be reused where feasible. The extent of reuse will amount to approximately 14 per cent of the total irrigation use. All such reused water will be mixed before reuse with high proportions of fresh water. The quality of the mixed water should not be significantly lower than the reservoir water because of the high dilution and (as noted above) because there will be no significant salt pickup from groundwater nor from the irrigated soils.

In addition to use of irrigation water for agricultural cropping, considerable irrigation water will be used to supply fish farms, which will be returned to the irrigation system of streams following use. In the design and operation of the fish farms, facilities should be provided for proper treatment of the wastes contained in the return flows (See discussion on fisheries).

## 5. Irrigation in Khorat plateau

A report of a study sponsored by the Mekong Committee for evaluating effects of proposed irrigation on water quality and return flows in the Khorat plateau was completed in 1973 (Ref. 8). The Khorat plateau presents special irrigation water quality problems because of the extensive salt deposits underlying this area, both in Lao PDR and Thailand, causing apprehension about possible salt pick up when these areas are irrigated. The study evaluates the probable effects of year-around irrigation of the lands overlying the salt beds upon the salt content of the local surface and groundwaters, and the effects of the return flows from irrigation in modifying the water quality of the local streams.

5.1 Study findings: Table 5 summarizes the results of the 1973 study. The data show the surface water quality in the Khorat plateau is generally very good for virtually all purposes. Generally, the dissolved solids increase as the volume of stream flow decreases

(at low flows the streamflow is mostly from groundwater). The total dissolved solids of the Mekong river at Vientiane is in the range of 100 to 210 ppm (average about 140 ppm) which indicates the quality of irrigation water to be supplied from Pa Mong. Irrigation supplies in the Mun and Chi basins are also good, ranging from 20 to 200 ppm total dissolved solids. The total dissolved solids concentration of the dry season base flow of the Nam Mun near its mouth generally is less than 200 ppm.

Water quality analyses were available for most of the 2,500 wells drilled in the Khorat plateau as well as for many more shallow-wells. These data indicate that deeper wells produce poorer water (even brines if the wells penetrate to rock salt). However, even with the extensive area underlain by salt, 85 per cent of the drilled wells have produced water of useable quality. In shallow wells the dissolved solids usually increase during the dry season accompanied by lowering of the well water level. The source of salinity in the shallow wells is probably not from dissolving soil salts but from evaporation and transpiration (See discussion of groundwater for additional details).

5.2 Study conclusions: The conclusions of the study are summarized as follows:

5.2.1 Groundwater: In areas where irrigation will be limited to wet season crops (supplementing rainfall) there will be little change in groundwater levels, movement, or quality. Where year-around irrigation is to be practised, this will cause a rise in average groundwater levels from 1 to 2 m in low areas to as much as 3 to 5 m in uplands; hence adequate drainage must be provided to prevent waterlogging and possibly also salinization of soils. The levels of groundwater discharge (which furnishes the dry season stream flow) will increase from irrigation, with probably 10 to 15 per cent of the water used for irrigation reappearing as the groundwater discharge component of total return flows (hence many smaller streams now intermittently dry would flow permanently).

5.2.2 Salt deposits: The salt deposits should have no effect on irrigation nor will the future irrigation result in solution of salt beds. These deposits are at considerable depths and overlain by relatively impermeable strata.

5.2.3 Return flow quality: The quality of existing return flows from irrigated areas is good and not significantly different from the normal flows, even in areas underlain by salt beds as well as where brackish/saline

groundwater and salty soils are most prevalent. The tentative conclusion is there will not be harmful deterioration of water quality as a result of planned irrigation development.

Although the average dissolved salt concentration will increase slightly in all surface flows, because of the net depletion resulting from irrigation, the flow regulation to be provided (by the combination of increased return flows and reservoir regulation) will tend to reduce the present seasonal variations in water quality. The present quality of water in streams during the dry season should actually be improved by the planned irrigation.

The present quality of water leaving the Khorat plateau (represented by the Mekong river at Pakse) is not significantly different from upstream of Vientiane. The ultimate planned development for irrigation of as much as 1.4 million ha would deplete the total outflow at Pakse by less than 5 per cent. The resulting change in average quality of Mekong river water at Pakse would be slight and probably not noticeable within the typical accuracy of most methods for sampling and analysis.

6. Water quality as related to downstream environmental values

6.1 Immediate downstream effects: Immediately downstream from the reservoir there will be a short distance (estimated at about 20 km) which will be adversely affected if the reservoir releases are drawn from oxygen depleted waters at lower levels. However this problem will likely be confined to only a small reach of the river as the river water should rapidly undergo natural reaeration. In any case, if necessary, the problem can be controlled or eliminated by releasing water from higher levels or by means of artificial reaeration of the released water (for which practicable methods are available).

6.2 Eutrophication: No significant changes are envisioned. Eutrophication is hardly a problem in most surface streams of southeast Asia because of their high turbidities which inhibit light penetration and bilogical growth (Ref. 13, 14). However, discharge of massive nutrients into the Mekong delta from agricultural chemicals washed or draining into the delta waters might result in algal blooms detrimental to fisheries.

6.3 Fisheries: Trapping of nutrients at Pa Mong conceivably could have an adverse effect on fisheries in the estuarine/marine waters of the delta, but judging by experiences elsewhere a far-upstream dam like Pa Mong should have little if any significance (See discussion on fisheries for further details).

The water quality monitoring programme described in Table 3 includes parameters (e.g. volatile suspended solids and total organic carbon) which will be useful for evaluating the extent of possible nutrient reduction. Also, the estuarine salinity gradient zone should become more stabilised due to increased dry season flow which may have a favorable effect on estuarine fisheries.

6.4 Salinity intrusion: The increased dry weather flow should assist materially in reducing salinity intrusion in the delta estuarine zone and thus improve the water quality in affected coastal areas for agricultural, community, industrial, and other uses. The dry season low flows in the delta, now in the range of 1,000 $m^3$/sec, are expected to be increased to about 2,000 $m^3$/sec, a very sizeable improvement.

7. Delta water quality

The Dutch Delta Team report (Ref. 11) includes consideration of delta water quality, especially as related to irrigation needs. The collected data from all sources over the years 1933-71 are tabulated in detail in Working Paper IV of the report (Tables IV-10 through 15). Approximate averages (or ranges) of these data are presented in Table 4.

7.1 Study findings:

7.1.1 River waters: As shown in Table 4, for the river waters in the Mekong, Bassac, and Great Lake-Tonle Sap complex the mineral quality of the fresh river water is excellent, with low total dissolved solids (low conductivity), low SAR ratio, low chloride, and low hardness throughout the year. Hence these waters are quite suitable for irrigation and virtually all other purposes.

7.1.2 Fens, streams, and wells: Only limited data are available but sufficient to indicate general conditions. The Stung Prek river (as a typical stream) shows even lower dissolved mineral concentrations than the main rivers; however the fens and also wells at certain locations may have much higher mineral concentrations sometimes exceeding the limits desirable for irrigation and other uses.

7.1.3 Acidification of waters during inundation: When inundation occurs the mineral composition changes considerably due to contact with the soil and mixing with drain water, especially in the areas with catclays where the concentrations of aluminum and sulfate may become high resulting in an acid water of low pH. The acidities are highest just before onset of the rainy season. Usually the water in the branches is of good quality from September through November, but becomes salty due to seawater intrusion from December to April.

7.1.4 Groundwater: Because of the generally easy availability of surface water, groundwater has played little role in delta irrigation, and moreover such use is not anticipated except to a very limited degree. Generally good quality surface water is now lacking during the seasons of the year in areas intruded by seawater and also in areas with very acid soils, but good quality groundwater is also scarce in these same areas. Hence these areas will greatly benefit for irrigation, community water supply, and other uses, from upstream projects which augment the dry season river flow.

7.2 Planned additional studies

To gain more detailed information on delta water conditions, the Dutch Team report recommended a detailed programme of hydrologic monitoring, to extend over two to three years, which includes measurements of water quality as well as river flow quantities, tidal stages, sediment, and salinity. The recommended water quality sampling network has four stations with samples to be taken once per month. In addition an extensive programme of acidity and pH measurements would be made, including weekly samples at 13 stations, with 200 of the samples analysed for aluminum and sulfate.

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TABLE 1

WATER QUALITY SAMPLING STATIONS IN LOWER MEKONG BASIN IN 1975

| No. | Stream | Location |
|---|---|---|
| 1 | MEKONG | Chiang Saen |
| 2 | Nam Mae Fang | Ban Tha Mai Liam |
| 3 | Mae Kok | Ban Tha Ton |
| 4 | Mae Kok | Dam Site (Ban Pong Na Kham) |
| 5 | MEKONG | Sop Kok |
| 6 | Nam Mae Lao | Ban Tha Sai |
| 7 | Nam Mae Ing | Thoeng |
| 8 | Nam Man | Ban Sai |
| 9 | Nam Heung | Ban Pak Huai |
| 10 | Nam Loei | Wang Saphung |
| 11 | MEKONG | Chiang Khan |
| 12 | MEKONG | Pa Mong Dam Site (km 1601) |
| 13 | MEKONG | Nong Khai |
| 14 | Nam Songkhram | Ban Tha Kok Daeng |
| 15 | MEKONG | Nakhon Phanom |
| 16 | Nam Pung | Ban Tham Mai Bridge |
| 17 | Huai Bang Sai | Ban Nong Aek Bridge |
| 18 | MEKONG | Mukdahan |
| 19 | Huai Bang-i | Ban Kham Soi |
| 20 | MEKONG | Khong Chiam (km 1601) |
| 21 | Nam Chi | Yasothon |
| 22 | Nam Mun | Ubon |
| 23 | Nam Mun | Ban Hua Heo |
| 24 | Lam Dom Yai | Ban Fang Phe |
| 25 | Lam Dom Yai | Det Udom |
| 26 | MEKONG | Phnom Penh |
| 27 | MEKONG | Chroy Ampil |
| 28 | TONLE SAP | Russey Keo |
| 29 | BASSAC | Phnom Penh |

TABLE 2

SUMMARY OF WATER QUALITY ANALYSES FOR MEKONG RIVER AND TRIBUTARIES FOR HYDROLOGIC YEARS 1972 AND 1973

| No. | Station | Temp. | | pH | | Conductivity 1973 | | Conductivity 1974 | Ca + Mg (Hardness) (me/l) | | Sodium (me/l) | | Potassium (me/l) | | Alkalinity (me/l) | | Chloride (me/l) | | SAR | | No. of observation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 72 | 73 | 72 | 73 | Jan-June | July-Dec. | Jan-June | 72 | 73 | 72 | 73 | 72 | 73 | 72 | 73 | 72 | 73 | 72 | 73 | 72 | 73 |
| 1 | MEKONG (Chiang Saen, Th.) | 27.0 | 26.8 | 7.6 | 7.5 | 339 | 232 | 223 | 1.81 | 1.60 | 0.72 | 0.75 | 0.04 | 0.05 | 2.35 | 1.88 | 0.22 | 0.33 | 0.9 | 0.9 | 7 | 12 |
| 2 | Nam Mae Fang (Ban Tha Mai Lian, Th.) | – | – | 7.5 | 7.6 | 250 | – | – | 1.07 | 0.81 | 0.20 | 1.37 | 0.05 | 0.11 | 1.30 | 1.50 | 0.14 | – | 0.3 | 2.2 | 3 | 2 |
| 3 | Mae Kok (Ban Tha Ton, Th.) | 24.0 | – | 7.2 | 7.7 | 266 | – | 116 | 0.49 | 0.74 | 0.32 | 1.05 | 0.06 | 0.09 | 1.22 | 0.95 | 0.10 | 0.43 | 0.6 | 1.9 | 4 | 4 |
| 4 | Mae Kok (Ban Pong Ja Khan, Th.) | 26.4 | 28.7 | 7.4 | 7.7 | 233 | 161 | – | 0.81 | 0.71 | 0.52 | 0.96 | 0.07 | 0.11 | 1.32 | 1.10 | 0.50 | 0.07 | 0.8 | 1.7 | 8 | 7 |
| 5 | MEKONG (Sop Kok, Th.) | 27.0 | 26.5 | 7.7 | 7.5 | 346 | 246 | 268 | 1.83 | 1.72 | 0.62 | 0.78 | 0.05 | 0.05 | 2.21 | 1.57 | 0.18 | 0.37 | 0.6 | 0.9 | 7 | 12 |
| 6 | Nam Mae Lao (Ban Tha Sai, Th.) | 24.5 | 26.5 | 7.3 | 7.4 | 213 | 151 | 140 | 0.75 | 0.77 | 0.53 | 0.59 | 0.07 | 0.09 | 0.16 | 0.99 | 0.00 | 0.14 | 0.8 | 1.0 | 7 | 11 |
| 7 | Nam Mae Ing (Thoeng, Th.) | 25.5 | 26.1 | 7.1 | 7.4 | 181 | 147 | 163 | 0.74 | 0.89 | 0.48 | 0.45 | 0.06 | 0.07 | 1.22 | 1.09 | 0.00 | 0.19 | 0.8 | 0.8 | 7 | 12 |
| 8 | Nam Nan (Dan Sai, Th.) | – | – | 7.0 | 7.5 | 242 | 147 | 250 | 0.77 | 0.93 | 0.34 | 0.84 | 0.03 | 0.07 | 0.98 | 1.11 | 0.21 | 0.50 | 0.6 | 1.4 | 7 | 11 |
| 9 | Nam Beung (Ban Pak Huai, Th.) | – | – | 6.9 | 7.5 | 279 | 182 | 449 | 0.76 | 1.54 | 0.87 | 1.16 | 0.07 | 0.11 | 1.34 | 1.57 | 0.30 | 0.59 | 1.3 | 1.4 | 7 | 11 |
| 10 | Nam Loei (Ubang Saphung, Th. | – | – | 7.2 | 7.5 | 305 | 172 | 444 | 0.93 | 1.79 | 0.35 | 0.71 | 0.07 | 0.13 | 1.79 | 1.93 | 0.04 | 0.32 | 0.6 | 0.9 | 7 | 11 |
| 11 | MEKONG (Chiang Khan, Th.) | – | – | 7.5 | 7.6 | 313 | 240 | 259 | 1.67 | 1.69 | 0.64 | 0.88 | 0.05 | 0.05 | 2.30 | 1.93 | 0.23 | 0.42 | 0.8 | 1.0 | 8 | 11 |
| 12 | MEKONG (Pa Mong Dam site) | 24.6 | 29.5 | 7.5 | 7.6 | 306 | 218 | 255 | 1.62 | 1.22 | 0.39 | 0.80 | 0.65 | 0.06 | 1.94 | 1.94 | 0.18 | 0.29 | 0.4 | 1.0 | 4 | 8 |
| 13 | MEKONG (Nong Khai, Th.) | 25.3 | 29.9 | 7.4 | 7.6 | 324 | 215 | 269 | 1.71 | 2.36 | 0.52 | 0.75 | 0.05 | 0.05 | 2.05 | 1.86 | 0.21 | 0.38 | 0.6 | 1.0 | 5 | 11 |
| 14 | Nam Song Khram (Ban Tha Kok Daeng, Th.) | – | – | 6.6 | 7.3 | 1,160 | 216 | 1,209 | 0.56 | 1.14 | 1.24 | 4.95 | 0.08 | 0.16 | 0.65 | 0.85 | 1.94 | 5.57 | 2.2 | 5.9 | 7 | 11 |
| 15 | MEKONG (Nakhon Phanom, Th.) | 22.5 | – | 7.3 | 7.5 | 317 | 201 | 245 | 1.29 | 1.53 | 0.45 | 0.87 | 0.04 | 0.05 | 1.63 | 1.68 | 0.07 | 0.53 | 0.6 | 1.1 | 7 | 10 |
| 16 | Nam Pung (Ban Than Hai Bridge, Th.) | 26.0 | – | 7.0 | 7.5 | 173 | 130 | 210 | 0.57 | 0.70 | 0.77 | 0.57 | 0.05 | 0.08 | 0.81 | 1.01 | 0.00 | 0.29 | 0.7 | 1.3 | 7 | 11 |
| 17 | Huai Bang Sai (Ban Nong Ark Bridge, Th.) | 22.0 | – | 7.1 | 7.5 | 222 | 115 | 177 | 0.50 | 0.88 | 0.19 | 0.53 | 0.05 | 0.09 | 0.65 | 1.01 | 0.04 | 0.30 | 0.4 | 1.0 | 7 | 10 |
| 18 | MEKONG (Mukdahan, Th.) | 23.0 | – | 7.6 | 7.4 | 314 | 201 | 299 | 1.29 | 1.54 | 0.44 | 0.82 | 0.04 | 0.05 | 1.76 | 1.62 | 0.03 | 0.42 | 0.6 | 1.1 | 7 | 11 |
| 19 | Huai Bang I (Ban Khan Soi, Th.) | 22.5 | – | 7.0 | 7.4 | 152 | 142 | 130 | 0.54 | 0.66 | 0.32 | 0.45 | 0.07 | 0.09 | 0.71 | 0.80 | 0.20 | 0.26 | 1.0 | 0.9 | 7 | 11 |
| 20 | MEKONG (Khong Chiam, Th.) | – | – | 7.6 | 7.4 | 236 | 205 | 218 | 1.16 | 1.41 | 0.49 | 0.65 | 0.04 | 0.04 | 1.65 | 1.50 | 0.42 | 0.28 | 0.7 | 0.9 | 5 | 9 |
| 21 | Nam Chi (Yasothon, Th.) | – | – | 7.4 | 7.4 | 711 | 159 | 226 | 0.62 | 0.90 | 0.63 | 1.82 | 0.06 | 0.12 | 0.79 | 1.00 | 0.70 | 1.96 | 1.1 | 2.5 | 6 | 11 |
| 22 | Nam Mun (Ubon, Th.) | – | – | 7.0 | 7.4 | 561 | 175 | 279 | 0.47 | 0.80 | 0.84 | 1.81 | 0.06 | 0.12 | 0.69 | 0.92 | 0.54 | 1.66 | 1.8 | 3.1 | 6 | 9 |
| 23 | Nam Mun (Ban Hua Bao, Th.) | – | – | 7.2 | 7.3 | 306 | 183 | 276 | 0.35 | 0.69 | 0.59 | 1.42 | 0.05 | 0.11 | 0.55 | 0.76 | 0.34 | 1.07 | 1.0 | 2.6 | 3 | 11 |
| 24 | Lam Dom Yai (Ban Pang Phe, Th.) | – | – | 7.0 | 7.4 | – | 101 | – | 0.32 | 0.32 | 0.40 | 0.32 | 0.04 | 0.05 | 0.51 | 1.38 | 0.05 | 0.35 | 0.5 | 0.9 | 4 | 2 |
| 25 | Lam Dom Yai (Det Udom, Th.) | – | – | 7.3 | 7.4 | 184 | 112 | 146 | 0.29 | 0.54 | 0.33 | 0.65 | 0.04 | 0.08 | 0.37 | 0.65 | 0.13 | 0.35 | 0.9 | 1.4 | 6 | 11 |
| 26 | MEKONG (Phnom Penh, KR) | – | – | 7.8 | – | – | – | – | 1.02 | – | 0.44 | – | 0.04 | – | 1.83 | – | 0.41 | – | 0.6 | – | 1 | – |
| 27 | MEKONG (Chrui Aspli, KR) | – | – | 7.8 | – | – | – | – | 0.78 | – | 0.42 | – | 0.04 | – | 1.37 | – | 0.21 | – | 0.7 | – | 1 | – |
| 28 | Tonle Sap (Russey Keo, KR) | – | – | 7.4 | – | – | – | – | 0.42 | – | 0.24 | – | 0.04 | – | 0.75 | – | 0.00 | – | 0.5 | – | 1 | – |
| 29 | Bassac River (Phnom Penh, KR) | – | – | 7.4 | – | – | – | – | 0.48 | – | 0.04 | – | 0.04 | – | 0.83 | – | 0.21 | – | 0.08 | – | 1 | – |

TABLE 3

PROPOSED PARAMETERS FOR LOWER MEKONG BASIN WATER QUALITY MONITORING PROGRAM

A. For immediate application for all stations (primary parameters)

(1) Monthly determinations

- * Gavge Height
- * Flow
- * Temperature
- pH
- Dissolved oxygen
- Color
- * Specific conductance
- Suspended solids
- Volatile suspended solids
- * Calcium (Ca)
- Turbidity
- * Magnesium (Mg)
- * Sodium (Na)
- * Potassium (K)
- * Alkalinity (as $CaCO_3$)
- * Chloride (Cl)
- Sulfate ($SO_4$)
- * Nitrate ($NO_3$)
- BOD
- Coliforms

(2) Twice per year (wet and dry seasons)

- Toal dissolved solids
- Iron (Fe)
- Manganese (Mn)
- Fluoride (F)
- Total Phosphorus (P)
- Total Nitrogen (N)
- Silica ($SiO_2$)
- Total organic carbon in filtrate

(1a) Computed values (from 1 above)

- Hardness (as $CaCO_3$)
- Bicarbonate (as $HCO_3$)
- SAR

Note: * Denotes included in program for 1972-74

TABLE 3 (Continued)

B. For immediate application at selected stations
Twice per year (wet and dry seasons)

(1) Metals

(a) Arsenic
(b) Cadmium
(c) Chromium (total)
(d) Copper
(e) Lead
(f) Mercury
(g) Nickel
(h) Silver
(i) Zinc

(2) Cyanide and Phenols

(3) Chlorinated Hydrocarbons

C. For application when feasible at selected stations

(1) Biota (including total biomass and numbers and weights of key species):

(a) Pelagic biota

(1) Planktonic algae (using membrane filter concentration technique)

(2) Macroorganisms

(b) Benthic biota (invertebrates)

(2) Benthos physical/chemical parameters

(a) Sediment sulfides
(b) Sediment BOD
(c) Particle size distribution

TABLE 4

SUMMARIZED WATER QUALITY DATA FOR MEKONG DELTA
(from Working Paper IV of Dutch Delta Team Report)

| | pH | Ca (ppm) | Mg (ppm) | K (ppm) | Na (ppm) | SAR | EC (mmhos/cm) | Cl (ppm) | $SO_4$ (ppm) | $HCO_3$ (ppm) | Al (ppm) | Fe (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mekong and Bassac | | | | | | | | | | | | |
| January through May | 7.5 | 23.3 | 5.2 | 2.0 | 8.2 | 0.4 | 0.25 | 6-37 | 12-17 | - | 0.1-6 | 0.2-0.9 |
| June through December | 7.1 | 17.5 | 3.6 | 3.9 | 6.2 | 0.4 | 0.25 | 1-10 | 0.1-7 | 59-64 | 1-6 | 0.1-4 |
| Great Lake - Tonle Sap | | | | | | | | | | | | |
| November through March | 7.4 | 9.6 | 2.7 | 2.3 | 3.1 | 0.2 | 0.25 | - | - | - | - | - |
| June through October | 7.5 | 14.7 | 3.3 | 2.4 | 4.6 | 0.3 | 0.25 | - | - | - | - | - |
| Range for year | - | - | - | - | - | - | - | 8-17 | 1-8 | 42-102 | 0.1-1.8 | 0.4-1.5 |
| Prek Thnot River | | | | | | | | | | | | |
| Range for year | 5.2-7.1 | 1-9 | 2-4 | 0.1-3.3 | 1-22 | - | - | 5-32 | 1-25 | 2-38 | - | - |
| Fens and Small Streams | | | | | | | | | | | | |
| Range for year | 3.5-8.6 | 6-103 | 1-27 | 1-24 | 1-180 | - | - | 3-98 | - | 46-555 | - | - |
| Wells (Range for year) | | | | | | | | | | | | |
| Depth 0-20 m | 6.5-7.6 | - | - | - | - | - | - | 35-1,240 | - | - | - | - |
| Depth 20-40 m | 6.0-7.8 | - | - | - | - | - | - | 23-409 | - | - | - | - |
| Depth 40 m | 7.2-7.6 | - | - | - | - | - | - | 5-6,727 | - | - | - | - |
| Acidification/Plain of Reeds | | | | | | | | | | | | |
| Field drains | 3.5-3.8 | - | - | - | - | - | - | 100 | 90-2,167 | - | 2-608 | 1-560 |
| Canals/Streams | 2.7-7.0 | - | - | - | - | - | - | 1-1,555 | 79-678 | - | 3-55 | 0.1-4 |
| My Phuoc Canals/Streams | | | | | | | | | | | | |
| Range for year | 3.6-7.5 | 34-150 | 31-340 | - | - | - | - | 6-4296 | 34-2244 | - | 6-91 | 1-8 |

TABLE 5

SUMMARIZED WATER QUALITY DATA FOR KHORAT PLATEAU
(from report of Anderson & Kelly, Reference 7)

| Category Designation | Location of Sampling | TDS | EC x $10^6$ | Cl | Ca | Mg | Na | K | $HCO_3$ | $SO_4$ | $SiO_2$ | $PO_4$ | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Mekong River | | | | | | | | | | | | |
| | Near Vientiane (1967-69) | 151 | 242 | | | | | | | | | | |
| 2 | Nam Mun | | | | | | | | | | | | |
| | Station M-49 (1967-69) | 45 | - | | | | | | | | | | |
| 3 | Lam Sae | | | | | | | | | | | | |
| | Station M-81 (1967-69) | 24 | 39 | | | | | | | | | | |
| 4 | Nam Chi (1967-69) | | | | | | | | | | | | |
| | Station E-5 | 101 | 142 | | | | | | | | | | |
| | Station E-21 | 211 | 321 | | | | | | | | | | |
| | Station E-23 | 101 | 162 | | | | | | | | | | |
| 5 | Nam Chi and Nam Mun Basins | | | | | | | | | | | | |
| | Lam Don Yai (M-80)(68-69) | - | 88 | | | | | | | | | | |
| | Lam Don Noi (M-79)(68-69) | - | 62 | | | | | | | | | | |
| | Lam Pao (E-34)(64-65) | 155 | 245 | | | | | | | | | | |
| | Lam Pao Project (68) | - | 363 | | | | | | | | | | |
| | Nam Mun (M-38C)(64) | 158 | 160 | | | | | | | | | | |
| | Nam Mun (M-33)(64-65) | 172 | 153 | | | | | | | | | | |
| | Nam Chi (E-16A)(67-69) | 44 | 163 | | | | | | | | | | |
| 6 | Nam Mun Basin (1956-57) | | | | | | | | | | | | |
| | Lam Pao | 119 | | 36 | 9.0 | 2.1 | 24 | 4.2 | 46 | 0.3 | 16 | 0 | 0.3 |
| | Nam Chi at Chaiyaphum | 121 | - | 17 | 22 | 2.9 | 14 | 3.0 | 77 | 6.3 | 11 | 0.6 | 0.4 |
| | Nam Chi at Khon Kaen | 245 | - | 95 | 21 | 4.0 | 57 | 3.9 | 70 | 5.2 | 10 | 0 | 0.2 |
| | Nam Mun at Surin | 149 | - | 57 | 11 | 1.2 | 29 | 3.0 | 22 | 1.3 | 13 | 0.01 | 0.9 |
| | Nam Mun at Ubon Ratchathani | 165 | - | 62 | 11 | 2.3 | 40 | 2.8 | 43 | 2.0 | 11 | 0 | 0.3 |
| 7 | Ground Water (Wells) | | | | | | | | | | | | |
| | Ban Lup Pao (58m)(67)("A") | 696 | 1,034 | 76 | | | | | | | | | |
| | Dug Well (1.2m)(67-68)("B") | 881 | 1,329 | 105 | | | | | | | | | |
| | Seed Center Well (46m)(67)("C") | 244 | 478 | 11 | | | | | | | | | |
| | Village dug well (7.1m)(67-68)("D") | 229 | 341 | 70 | | | | | | | | | |
| | Village dug well(5.0m)(67-68)("E") | 4,914 | 6,048 | 2,186 | | | | | | | | | |
| | Ban Kut Tum (30m)(67)("F") | 610 | 1,224 | 117 | | | | | | | | | |
| | Village dug well (4.0m)(67-68)("G") | 88 | 101 | 24 | | | | | | | | | |
| | Wat Ban Lao (4.9m)(67)("H") | 2,628 | 3,347 | 777 | | | | | | | | | |
| | Village dug well (4.4m)(67-69)("J") | 124 | 171 | 8 | | | | | | | | | |

Notes :

All waters are surface waters except for Category 7 (wells). All values are in ppm excepting electrical conductivity (EC). Sampling station locations are shown in Figure 5-1 and 7-3 of the Anderson & Kelly report.

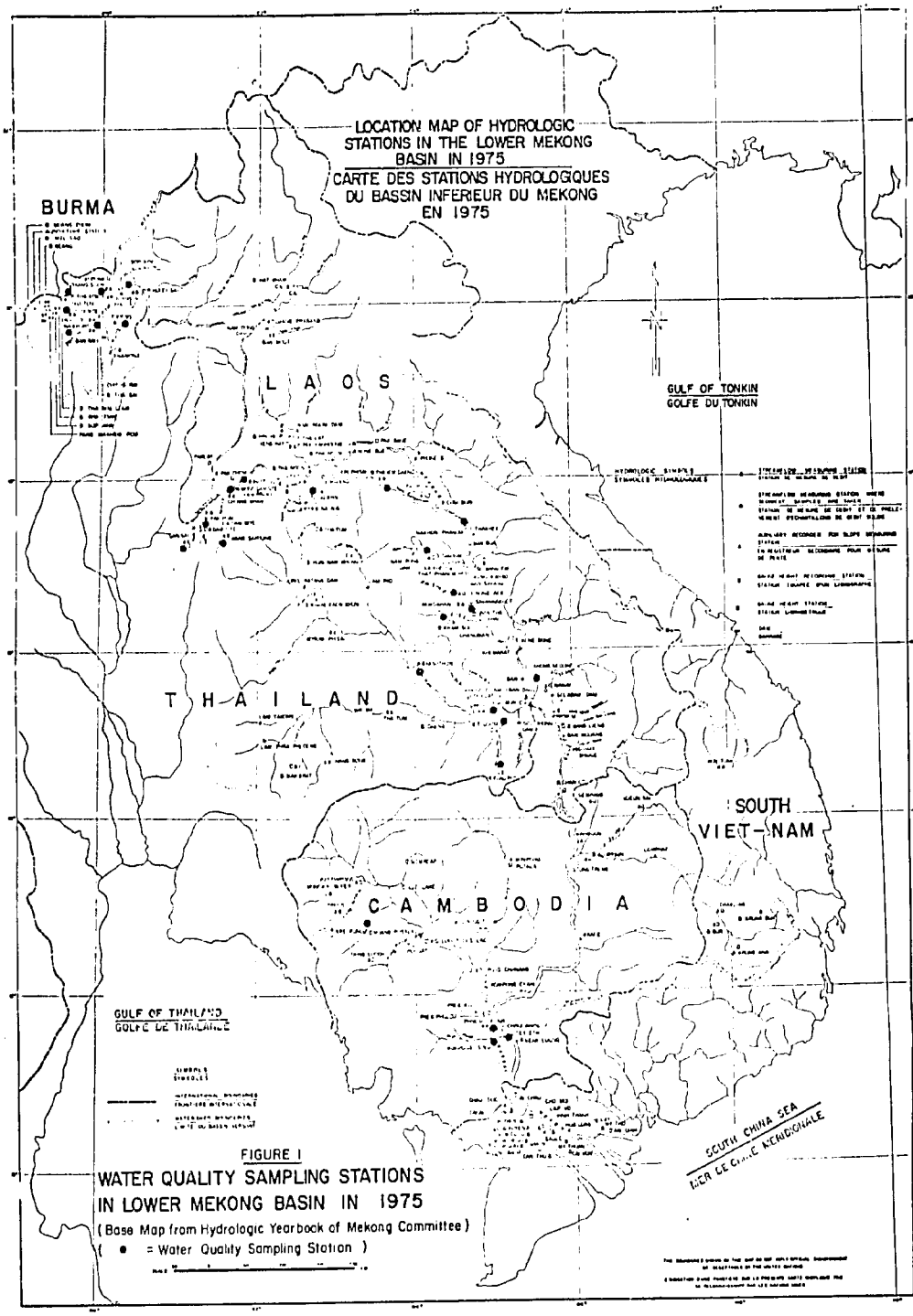


FIGURE I

WATER QUALITY SAMPLING STATIONS IN LOWER MEKONG BASIN IN 1975

(Base Map from Hydrologic Yearbook of Mekong Committee)

( ● = Water Quality Sampling Station )

# CHAPTER III

## PA MONG ENVIRONMENTAL ASSESSMENT

## WATERSHED MANAGEMENT

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Table 1: Extent of forests in riparian countries compared to other land uses

Table 2: Composition of forests in Thai portion of lower Mekong basin (1961)

# PA MONG ENVIRONMENTAL ASSESSMENT

## WATERSHED MANAGEMENT

### 1. Introduction

The Mekong Committee's studies in watershed management, together with assistance from the FAO, have provided a general overview of watershed and forest conditions in the riparian countries (Ref. 1-16). This includes preparation of a land use map based on satellite imagery which distinguishes forest from other land uses and gives general information on forest characteristics. These studies show unprecedented damage to the forests over the past two decades, due primarily to uncontrolled cultivation and associated fires resulting from population growth. This trend can only be expected to continue and accelerate and virtually ruin the forests unless competent watershed control measures are established. One of the possible serious consequences of the damage to forests is the adverse effects on reservoir storage projects including increased soil erosion and loss of water due to loss of protective cover which can hold back surface flows for infiltration into the groundwater or evapotranspiration.

### 2. Extent of watershed and of damage to forests

The Pa Mong watershed comprises approximately 302,000 $km^2$ (at a 250 m pool level), of which only about 38 per cent is located in northeast Thailand and Lao PDR and the remaining 62 per cent in Burma and China to the north. According to the Stage One Pa Mong report, about 189,000 $km^2$ of watershed are located above Chiang Saen (at the Burma border), called Subbasin I. The remaining 113,000 $km^2$ in the lower basin is distributed between Subbasin II, the area below Chiang Saen and above Luang Prabang; Subbasin III, the Mekong river drainage area below Luang Prabang and above Pa Mong; and Subbasin IV, the watershed area above the Nam Lik damsite.

Of the Pa Mong watershed lands in the lower Mekong basin, approximately 50 per cent is classified as forested. Tables 1 and 2 show the approximate extent of the forest areas in the riparian countries compared to other land uses, and the approximate composition of the forests in the Thai portion of the lower basin, as reported in 1972 (Ref. 2). These forests comprise mostly tropical evergreens, hill evergreens, coniferous forests, mixed deciduous forests, dry deciduous forests, and bamboo (Ref. 2, 4). While these forests have been fairly stable for hundreds of years, rapid population growth over the past two decades has led to unprecedented destruction of the forests, primarily because of shifting cultivation and uncontrolled fires. It is estimated more than half the forests in the Pa Mong watershed may have been destroyed or severely damaged. The annual losses of timber and other forest produce due to shifting cultivation and fires, in the lower Mekong basin, are estimated at US$40 million, and possibly even greater losses are attributed to soil deterioration and other damages to forest environment.

3. Importance of forest cover

The Pa Mong watershed forests are important to the Pa Mong project primarily because the forests cover the soil in a manner which efficiently regulates the disposition of rainfall. Although few field observations have been made in the lower basin, experience elsewhere has shown the presence of the forests and associated ground cover tends to hold back runoff. This not only serves to reduce floods and erosion but to increase infiltration into the ground water and thus stabilize the flow in surface streams by furnishing a steady input from the groundwater during the dry season. The forests thus serve to increase the proportion of the total rainfall available for use when needed, and in this sense the forests act as a type of storage alternative to dam and reservoir systems. The forests are also useful for furnishing timber and other forest products, furnishing homes for wildlife, and for enhancing the aesthetics of the environment.

While it is generally believed that the forest cover is essential to maintaining the integrity of watershed systems, this relationship is complex and varies from region to region (Ref. 17). As noted below (see 5), the precise role of forest cover is the lower Mekong basin is largely unknown and needs to be confirmed through field testing.

4. Effects of Pa Mong

The unprecedented rate of destruction of forests over the past two decades has resulted primarily from rapid population growth, i.e., encroachment upon forest lands to use them for agricultural purposes, usually involving shifting cultivation and uncontrolled fires. This has not only destroyed the forests but has probably accelerated erosion and loss of valuable topsoil. This trend is likely to continue as population pressures become increasingly severe, and the construction of Pa Mong, by creating a vast lake will further compound this problem by attracting a greater density of settlement around the lake and in the associated uplands. The opening up of navigation transportation should be a significant factor in stimulating settlement. The advent of Pa Mong will not, of course, be responsible for the overall trend in the basin of population growth and resulting increase in forest encroachment. The effect of Pa Mong will be more in inducing higher densities of population in those watershed areas in the reservoir vicinity.

At this time it is not possible to predict the effect of such changes on the net deposition of sediments in Pa Mong reservoir. The estimates of deposition included in the Stage One and Phase II reports were based on sediment measurements made in the stream flow or stream bed. There is insufficient information to permit any estimation of sediment inflow to the river as a function of watershed erosion, not even in the portion of the watershed located in the lower basin. However, it seems unlikely that the advent of Pa Mong will result in any overall increase in soil erosion discharges to the river above Pa Mong

compared to without project conditions, assuming that the total increases in erosion will be more or less proportional to total population pressure rather than to distribution of population and pressures.

5. Progress in watershed management planning

The first step in developing an effective watershed management plan for Pa Mong is preparation of a competent inventory of forest resources and of damages to these resources (Ref. 7). This work is being undertaken by the Mekong Committee, based primarily on use of ERTS satellite imagery. Results thus far indicate this methodology is valuable for general delineation of forest areas and types (but not for furnishing detailed information on types of cover) including rough assessment of damage to forests, and for periodic examination of forest areas to detect changes or disturbances.

Two additional steps are being considered for strengthening the Mekong Committee's programme in watershed management. The first is to establish one or more pilot watershed management projects at sites especially suited for study and management trials, such as Lam Takong or Nam Pong in northeast Thailand. Such projects would serve (a) to quantify the relationship between forest cover and soil erosion and surface runoff conservation, and hence quantify the losses of soil and water due to loss of forest cover, and (b) to demonstrate the feasibility of stabilizing shifting cultivation, controlling fires, soil conservation, reforestration and other rehabilitation measures, and land use planning in forest areas. The second step is to obtain additional watershed management expertise for supervising and coordinating the Committee's watershed management activities and for assisting the riparian governments in establishing or strengthening their programmes. One of the most pressing needs is for analysis of the existing maps and other information to develop quantified pictures of the changes in land use which take place as a watershed becomes progressively more populated and developed, and to assess the benefits and adverse effects of these changes on watershed resources, thus furnishing guidelines for formulation of government policies on future needs for protecting forests and other watershed resources.

A description of the Lam Takong pilot project as originally proposed in 1972 is described in detail in Reference 16. The project would require a period of five years and cost approximately $1.7 million. The Lam Takong basin total 1,430 $km^2$ of which approximately 28 per cent is still mountain forest (half of which is in Khao Yai National Park). The remainder comprises lands under cultivation, abandoned cultivation, and lowland forest.

It is recognized that the knowledge about the importance of forest cover is not at all conclusive in the lower Mekong basin. The forests certainly are valuable for timber and other forest products, and as a habitat for forest wildlife, but their role in water resource development has not been clearly

demonstrated. When the forests are removed they are replaced by bush and grass type of cover, which may or may not serve effectively for soil and water conservation. Gully erosion, the first tell-tale sign that soils are eroding rapidly when forest cover deteriorates, is not commonly observed in the lower Mekong basin. The proposed pilot project is the only means for quantifying and establishing the importance of the role of the forest cover in the particular region of concern.

Another important justification for one or more pilot projects is to demonstrate the feasibility of government programmes for controlling and conserving the forests. It is recognized that the forests, being mostly in the hilly areas, have traditionally been outside the land zones of interest to the governments in the rice-paddy oriented countries in the lower basin. A positive demonstration is needed to convince the riparian governments of the value of watershed management.

When the necessary basic data have been made available, it is anticipated the Mekong Committee, as an instrument of the riparian governments, will be in a position to assist in formulating specific policies for watershed management at Pa Mong and realistic control measures to implement them (Ref. 1).

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TABLE 1

EXTENT OF FORESTS IN RIPARIAN COUNTRIES

COMPARED TO OTHER LAND USES

(From Reference 2)

| Areas in Thousand Hectares | Total Area | Land Area | Arable Land and Land Under Permanent Crops | Permanent Meadows and Pastures | Forest Land | Other Areas |
|---|---|---|---|---|---|---|
| Democratic Kampuchea (1967) | 18,104 | 17,660 | 2,984 | 580 | 13,372 a/ | 1,168 |
| Lao PDR (1964) | 23,680 | - | 800 | 800 | 14,050 | 8,030 |
| Thailand (1965) | 51,400 | 51,177 | 11,415 | - | 27,354 | - |
| Republic of Viet-Nam (1968) | 17,326 | - | 2,837 | 2,870 b/ | 5,600 | 6,074 b/ |

a/ including rough grazing

b/ 1962

TABLE 2

COMPOSITION OF FORESTS IN THAI

PORTION OF LOWER MEKONG BASIN (1961)

(From Reference 2)

| Class of Land | Area in $km^2$ | | Total |
|---|---|---|---|
| | N.E. Thailand | Chiengrai Province | |
| Total area: | 170,226 | 18,803 | 189,029 |
| Forest area | 78,153 | 9,493 | 87,646 |
| Forest percentage | 45.9% | 50.5% | 46.3% |
| Evergreen forests | 26,127 | 1,087 | 27,214 |
| Mixed deciduous | 11,713 | 4,900 | 16,613 |
| Dry dipterocarps | 40,236 | 3,048 | 43,284 |
| Pine forests | 12 | 26 | 38 |
| Scrub forests | - | 414 | 414 |
| Plantations | 65.3 | 17.59 | 82.89 |
| Shifting cultivation | 18,081 | 4,294 | 22,375 |
| Agricultural lands | 58,204 | 4,184 | 62,388 |
| Others | 15,787 | 832 | 16,619 |

CHAPTER III

# PA MONG ENVIRONMENTAL ASSESSMENT

## WILDLIFE

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Figure


Figure 1: Wildlife habitat zones and existing and proposed national reserve areas

# PA MONG ENVIRONMENTAL ASSESSMENT

## WILDLIFE

### 1. Introduction

The lower basin has been and still is, rich in a great diversity of terrestrial fauna, especially in the forested hilly areas including the Pa Mong watershed area (Ref. 1, 2, 3, 5, 9). Little attention has been paid to this resource in the development of the riparian countries thus far. The primary attention of the governments has been oriented to the pressing needs of the human population which has traditionally lived in the lower rice paddy producing zones. Over the past 100 years or so there has been a continuing influx of humans from the hills to the north, mostly for shifting cultivation including local hunting, but until recently these incursions were modest in extent. Over the past two or three decades, however, due to accelerating population growth, plus the results of continuing military action (including increased local hunting because of easy availability of guns), the extent of the inroads made by humans has already reached alarming levels threatening the extinction of many wildlife species. All this has been without the "assistance" of water resource development projects. It is obvious that, unless action is taken by the governments concerned to pay serious attention to wildlife preservation, the present trend will not only continue but be accelerated until the remaining wildlife will be only a fraction of the traditional resource.

### 1.1 Nam Ngum study

A preliminary study of wildlife in the Nam Ngum region, as affected by the dam and reservoir, made in 1974 (Ref. 7 ), includes tabulations of the important mammals in the Nam Ngum region with information on their distribution and pre-impoundment and post-impoundment incidence, together with tabulations of key reptiles and waterfowl found in the reservoir. The report concludes that the primary hazard to wildlife is from accelerated hunting pressures due both to the population influx stemming from construction of the dam and reservoir and to the easy access to previously remote areas made possible by the lake. The study recommended that a wildlife reserve of 1,000 $km^2$ be established, as remote as possible from the dam and reservoir, with hunting limited to local residents (who would thus tend to cooperate with the authorities in keeping out hunters from the outside).

### 1.2 Draft Report on wildlife in lower basin

The first attempt to evaluate the wildlife problem in a comprehensive manner for the entire lower Mekong basin is the "Draft Report on Wildlife and National Parks in the Lower Mekong Basin". released by Mekong Committee on 7 November 1975 (Ref. 9 ). A summary of this study is as follows:

(a) The lower Mekong basin comprises five distinct wildlife habitat regions, namely the northern highlands, the Khorat plateau, the Annamite chain, the Mekong plain, and the southern uplands, each with its own unique wildlife environment fixed by vegetative types, human uses, geology, weather, and other factors (see Figure 1). Of the five regions the northern highlands (representing roughly the Mekong watershed area above Pa Mong) and the Khorat plateau are of special significance for the Pa Mong project.

(b) The lower basin includes some 1,116 species of mammals, birds, reptiles, and amphibians (which are listed in the appendices to the draft report). While the activities of man have encroached on wildlife for many hundreds of years, only in recent decades has this impact been serious, due both to increasing populations and accelerating technological developments as noted above.

(c) The effects of dams on wildlife include inundation and downstream effects (usually not serious because most of the low-lying and downstream areas have already been defaunated and the species involved can usually adjust to living in higher zones), and effects from resettlement (usually serious due to encroachment upon forests and increased hunting).

(d) The only practicable means for conserving wildlife in the lower basin is in establishing a series of some 29 national parks or wildlife reserves, shown in Figure 1. This system of national reserves, which will incorporate the existing national reserves, will serve not only to perpetuate all valuable species but also for restocking of forested areas throughout the basin, and for using selected species for augmenting and improving domestic animal productivity. Of the proposed 29 national parks or reserves, five (Nos. 16 through 20) would be located in the northern highlands, and nine (Nos. 21 through 29) would be in the Khorat plateau. Each reserve area is suited to a particular group of species, and the combination of all 29 is believed to be the minimum system needed for protecting and perpetuating lower basin wildlife.

(e) A series of additional recommendations for conserving wildlife is presented including controlled hunting, captive breeding, control of commercial trade in wild animals, and especially for continuing study of the wildlife resources of the lower basin to furnish basic information needed for detailed planning and assessment of wildlife conservation measures.

## 2. Significance of Pa Mong

2.1 Watershed: The area to be inundated by Pa Mong (approximately 3,700 ha at 250 m pool level) is a very small portion

about 3.3 per cent) of the total lower basin watershed above Pa Mong, hence inundation per se should have a relatively minor effect on the regional wildlife in the watershed area as a whole. Also, because the lower areas are more heavily populated they tend to have limited wildlife; most of the wildlife species seek their habitats in the hills. The main hazard will result, as for Nam Ngum, from accelerated hunting pressures due to population influxes and ready access on the lake to remote areas. However, although the advent of Pa Mong will result in a population concentration in the vicinity of the dam and reservoir, the total population increase in the tributary basin will probably be little affected. By tending to concentrate population around the lake, especially along the access roads, the net effect of the creation of the new lake on the total indigenous wildlife in the tributary basin might actually be beneficial, in the long run, to without project conditions. In any case the effect of Pa Mong on the overall population increase in the region should be small compared to the inroads bound to occur, sooner or later, with or without the project.

Another result of the Pa Mong project which could be beneficial to wildlife is that the increased supply of protein (fish) may tend to reduce pressures on wild game protein, and the agricultural development may also reduce pressures on wild game. At present most hunting takes place in the dry season, but with double cropping there will be far less opportunity for hunting.

2.2 Reservoir area: Terrestrial wildlife in the reservoir area will be forced to relocate, hence may be considered as essentially lost. However, because the reservoir area is a small portion of the watershed as noted above, this loss can hardly be expected to endanger any species. Also, this loss should be more than compensated for (Ref. 1, 2, 3) by the new aquatic wildlife expected to develop in the lake vicinity, especially birds. These will be primarily ducks and other birds appealing to hunters both for food and for sport (Ref. 1).

2.3 Downstream: As pointed out by Talbot (Ref. 4,5), construction of a reservoir such as Pa Mong can cause signi icant adverse effects on downstream wildlife living in proximity to the river whose life cycles are synchronized with seasonal inundation phenomena including both flooding and silt deposition. Alterations in the flooding patterns could affect the habitats of such species and even threaten the existence of inflexible species. However, it is believed such changes due to Pa Mong will be small compared to the normal variations in hydrology from season to season and year to year (Ref. 8). Also, it seems probable that all surviving species along the Mekong below Pa Mong are flexible species (the inflexible ones are already extinct). Hence the

adverse effects by Pa Mong should be small, and probably insignificant compared to the adverse effects of existing and increasing human activity along the river all the way to the sea.

With respect to design of the Pa Mong project, the design of the irrigation canals should incorporate means for protection of wildlife. Experience elsewhere has shown it is feasible to provide wildlife overpasses and also facilities to enable animals entering the canals to get out (Ref. 6).

3. Proposed conservation measures

Everyone agrees it is important that serious efforts be made to preserve the indigenous wildlife, especially that remaining in the hilly areas not yet occupied by people. This remaining fauna is still very rich and diversified, and has great potentials for important economic returns similar to that already realized in Eastern Africa and India. Unfortunately little is known about the specific ecology of the hilly areas to be affected by Pa Mong. The next step, following the preliminary study already made (Section 1.2 above), is for field surveys for obtaining more definitive information. This should include information on the specific species and their numbers, on their habitats and life cycles, and their relationships in the basin ecosystem.

With this basic information in hand, it will then be possible to proceed with the next step, including better delineation of the specific areas best suited for setting aside as national parks and scientific study reserves. Hopefully, then, a number of such parks and reserves could become established, including measures for establishing legal and physical protection, programmes for their management including continuing studies and research, and access routes and accommodations for tourists in selected limited areas.

The specific objects of the parks and reserves would be (1) to preserve outstanding or irreplaceable scenic, scientific, biotic, or historical resources, and to use these for restocking of forests throughout the basin and through selective breeding for improving domestic animal productivity, and (2) to enable continuing studies and research with the parks and reserves serving as reference areas for monitoring the effects of human activity on the terrestrial biota of the developing areas. The continuing studies and research would be designed to develop guidelines for assisting national planning on how best to utilise the terrestrial biotic resources in programmes of continuing economic and social development. Examples include utilizing local biota for control of pests and diseases in agriculture, and, as noted above, using selected animal species for developing improved strains for domestic meat production.

4. Summary

Because of human encroachment there are few undisturbed areas remaining in the lower basin, not even in the mountains of the Lao PDR. Until recently the rate of such encroachment was relatively modest, but current population growth and associated technology make it urgent to take positive measures to reverse this trend. The only practicable approach is believed to be in the establishment of a series of national parks or reserves with competent legal and physical protection and management programmes including research, in order to preserve representative samples of existing ecosystem while they still exist. Such programmes would serve not only to conserve wildlife but to develop basic scientific data and guidelines on how best to utilize wildlife resources for contributing to the national welfare and economy. These contributions include promotion of tourism, enhancement of agricultural productivity through control of crop pests and diseases and by increased production of animal protein, and continuing restocking of forested areas throughout the basin.

The Mekong Committee has recognized the need for a wildlife protection programme as described above, especially in connection with the proposed mainstream project at Pa Mong. An important first step has been taken in the preliminary identification of a series of 29 national reserve areas, which is believed to represent the minimum system which will ensure protection and conservation of the important wildlife of the lower basin. Continuing efforts will be needed for more specific delineation of the reserve areas, for detailed planning of their individual programmes, and for implementation of such programmes. It is believed the advent of Pa Mong could furnish an important impetus for establishing a number of these reserves, namely those to be carried out within the Pa Mong watershed, thus contributing to establishing a comprehensive system of wildlife preservation in the lower basin.

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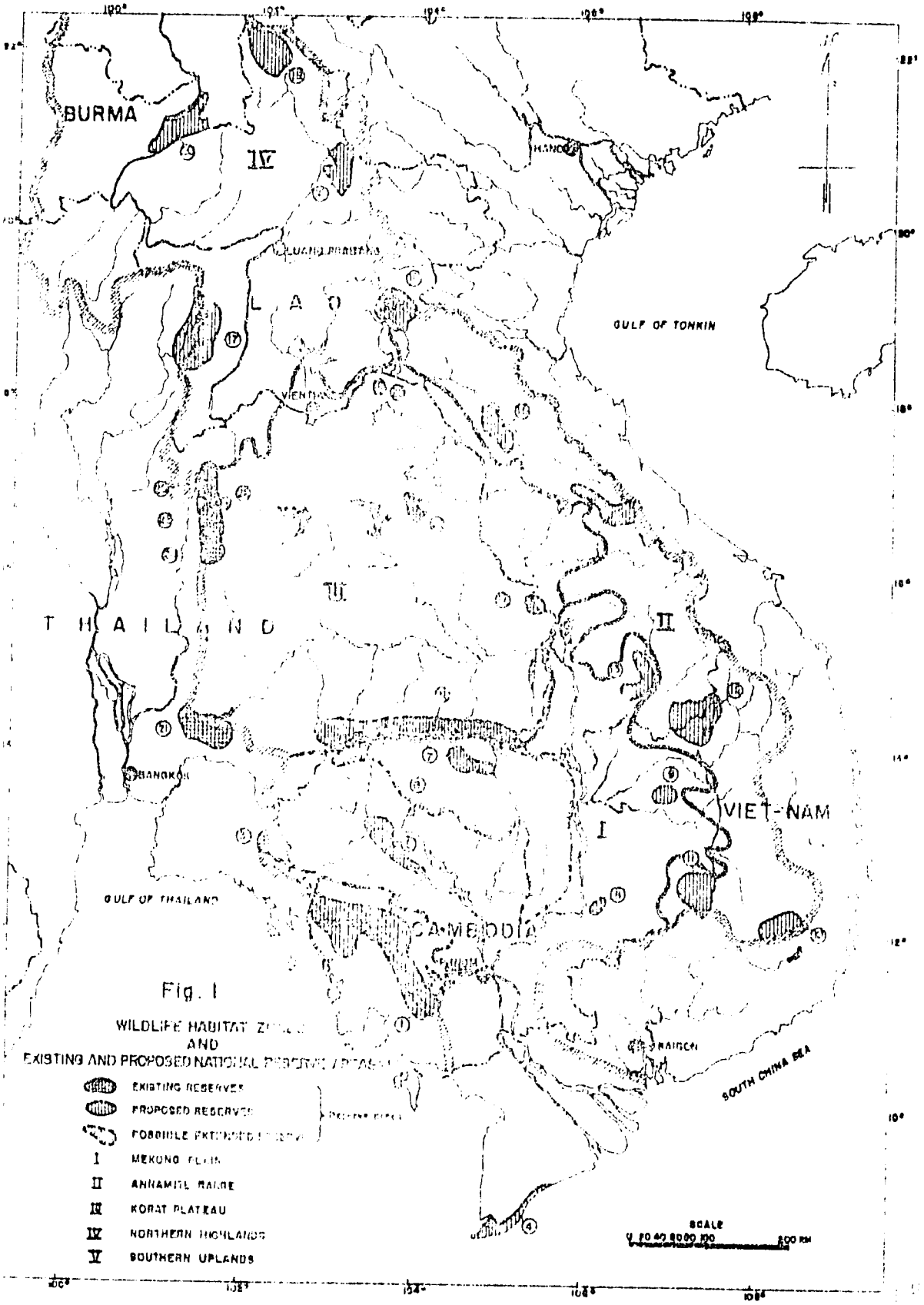


Fig. I

WILDLIFE HABITAT ZONES
AND
EXISTING AND PROPOSED NATIONAL RESERVE AREAS

# CHAPTER IV

## SUMMARY OF ENVIRONMENTAL EFFECTS OF PA MONG

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Table

Table 1: Summary of environmental effects of Pa Mong

# SUMMARY OF ENVIRONMENTAL EFFECTS OF PA MONG

## 1. Introduction

### 1.1 Pa Mong in the changing environmental picture

This chapter attempts to summarize the detailed findings of Chapter III, and to represent them in a collated and consolidated manner so as to indicate an overall picture of the probable effects of Pa Mong on environmental resources of the lower Mekong basin. Because of the vast size of the lower basin, only a generalized picture can be presented.

The key factor involved in any attempt to evaluate the effects of the Pa Mong project on environmental resources of the lower basin is that a great deal of deterioration of these resources has been taking place and will almost certainly continue to take place, under without project conditions, due to the inevitable effects of continuing rapid population growth, accelerating urbanization, and accelerating technology which can be expected to continue to take place in much if not most of the lower basin region.

Prior to World War II the impact of this combination of factors was still small, almost negligible compared to their dramatic impact since then, due to the rapid increase in the rate of growth of these three influences - a rate which can be expected to continue to increase, exponentially, at least for several more decades. Hence the impact of these influences, dramatic as they may seem compared to the past, are really only beginning to be of major significance.

These factors of change will not only bring about very significant alterations in physical and biological resources but will also result in profound socio-economic alterations, with all the stresses and strains that characterize such changes, all regardless of whether mainstream water control projects are built on and along the Mekong. The Pa Mong project will of course have some significant effects in impairment of physical and biological resources and on human uses of the Mekong water and on associated human cultural and aesthetic values, but these will, in most instances, be relatively minor compared to impacts of factors not associated with water resources control.

To take one example, terrestrial wildlife resources downstream from Pa Mong have already been essentially lost except for those species able to coexist with human community development, and the impact of technology. The ready availability of powerful guns, the advent of roads, and new methods of transportation including motorized vehicles and air craft, together with increasing human encroachment and rapid destruction of the forests, already indicate a similar fate for

most species above the site of Pa Mong. Construction of Pa Mong will in some ways tend to speed up the process primarily by providing easy access to hill areas now relatively remote, and in other ways to slow it down, but it appears doubtful that Pa Mong will have any significant influence on the end result. The only salvation for these species appears to be in the establishment of national parks and reserves, and the advent of Pa Mong could actually improve the situation in that the implementation of a dam/reservoir project of such very large magnitude, involving international collaboration, could set the stage for much more rapid action by the participating governments in establishing such national parks and reserves. The international agency, which will presumably be established to manage construction and operation of the dam/reservoir project, will be in an excellent position to sponsor and stimulate cooperative action with the riparian governments to give more rapid and more forceful attention to action programmes critically needed to preserve precious environmental resources.

Another example, already underway, is in the problem of resettlement of population living in areas to be inundated by Pa Mong - a problem hardly well managed yet for any major dam and reservoir project in any developing country. The efforts of the Mekong Committee, in sponsoring "grass roots" studies of this problem, including evaluation of resettlement activities thus far undertaken in the lower Mekong basin, are already meeting the problem head-on by recognizing that the answer must be in furnishing the funds needed for proper resettlement costs, including reestablishment costs as well as compensation for flooded property, as an integral part of the cost of implementing the project, along with construction costs. Again, this is possible because of the sheer magnitude of the project and its international nature, which require an objective assessment. Also, the findings and policy evaluation achieved by the Mekong Committee are bound to have significant impact in improving resettlement practices on in-country projects and elsewhere in developing nations throughout the world, even if Pa Mong is not built, and especially so if it is built.

The approach used in this chapter will be, first to review the anticipated future situation on population growth, and its distribution into urban and rural sectors, and the needs of this population for food and power, the two main commodities to be produced by Pa Mong, and probably the two most important key needs to be met in the future. The next step will be evaluation of the Pa Mong project's potentials for meeting these needs and other human uses of the Mekong water resources, i.e., evaluation of Pa Mong with respect to the "Tier 3" hierachy of environmental values described in Chapter II. Next will be evaluation of the impacts on Tier 4, the human values, then Tier 2, the biological values; ther Tier 1, the physical values.

## 1.2 Human ecology

As indicated above, by far the most important single factor affecting environmental and ecological resources of the lower basin is the explosive population growth. Recognizing the importance of the population factor, and its key relationship to impact on environment in the future development of the lower basin, the Mekong Committee sponsored a preliminary evaluation of the population problem in the basin, completed in 1974. The significant findings are as follows:

(a) The desirability of achieving a balance in human population in the lower basin and the consumption of renewable resources in the long run is self-evident. The only alternative is a series of unprecedented catastrophes along with a partial destruction of the overall carrying capacity of the environment. A major watershed area such as the lower Mekong basin appears to be a more suitable region for carrying out such planning than any other available.

(b) The carrying capacity of the lower Mekong basin is crudely estimated to be 125 million persons as compared to about 33 million population in 1974. The assumptions were that intensified methods of cultivation and ensuing yields would be raised to the highest levels obtainable today on all land presently cultivated, and extended to almost all the land in low-lying areas that can be irrigated. A several-fold increase in the cultivation of plateaus and hilly lands that are more lightly yielding was also assumed.

(c) Irrespective of carrying capacity limitations, the estimated lowest population at which steady state could be reached is from 130 to 170 million, depending upon conditions in neighbouring basins, and assuming the acceptance of fertility controls proceeding as rapidly as any rates that have been experienced in recent Asian history. The higher side of the range allows for use of Mekong water by growing metropolitan areas just outside the basin that are accommodating settlers from the Mekong and more densely settled basins nearby.

(d) The likelihood of population exceeding carrying capacity noted above suggests that unprecedented measures must be taken both to enhance carrying capacity and to accelerate acceptance of fertility limitation. In both instances it means depending upon knowledge that already exists and has already been reduced to practice in Asia, but only on a very small scale. Thus twenty years or more would

probably be required to fit such controls to the needs of the lower basin peoples after the studies and experiments were undertaken. A dietary plan needs to be prepared which would identify the periods and the dimensions of the prospective shortages; the appropriate region must be larger than the Mekong basin. Also, more imaginative efforts must be addressed to hold down the growth of population. One feature neglected everywhere in the world should be looked into more fully, namely, using the social changes resulting from technological development to reinforce the acceptance of family planning and fertility control.

(e) The structural characteristics that can be deduced for the steady state at a minimum adequate level of living, maintaining a rural-urban equilibrium, suggests that the labour force must raise productivity several times over current levels. For the rural areas this means a labour force roughly equal to the present (with a total population somewhat less) but getting more crops from a larger area per worker. It also means that all added population henceforth can only find productive employment in urban areas. At steady state the population is expected to be 80-90 per cent urban.

(f) On the whole, perhaps because the Mekong has had a head start, the possibility of achieving a steady state without intervening massive catastrophe seems to exist, but there is likely to be either a close squeeze or an "overshoot" about three generations from now.

## 2. Human uses

By human uses is meant the tangible benefits that people derive from project development. In the case of Pa Mong, these will be primarily power production, irrigation and flood control, but there will also be many other beneficial uses. Pa Mong is a multipurpose project in every respect.

### 2.1 Food/irrigation and agriculture

#### 2.1.1 Need for irrigation

The most compelling reason for building Pa Mong is the need for storing the mainstream water for use for irrigation, over and above the levels possible with tributary projects. In attempting to meet this need, the four riparian countries could choose one of the three options: (a) continue to utilize present agricultural practices on the existing land resources; (b) improve technology and cultivation

methods, but without introducing water control; or (c) supplement such technological improvements with full control and development of the water and related resources of the Mekong and its tributaries. Analyses indicate that if either the first or second of these choices is taken, agricultural production will fail to keep pace with the rising demand. Over the 30-year study period (1970-2000) production measured in tons of paddy equivalent would have to be expanded from about 12.7 million tons in 1970 to about 37 million tons by the year 2000. Calculations of alternative methods for meeting this production target indicate that the maximum possible increase obtainable without irrigation, but with a 50 per cent increase in the cultivated area, would not raise production to the required levels.

Assuming that the lower Mekong basin should meet its own food requirements (at an improved nutritional level), that it should be self sufficient in agricultural raw materials for domestic industry, and that it should continue to export food and non-food produce, then the estimated total area under irrigation will have to increase to between two and three million hectares during the 30-year period. This will require many inputs in addition to irrigation, namely a much improved agricultural technology including the expansion of agricultural research, improvement of livestock, expansion of fish production, and a general diversification of farming systems away from the monoculture of rice. Together with these changes, there will be a need for improved institutional arrangements, particularly in the fields of land tenure, marketing, training and extension, credit, communication, and farmers' organizations.

### 2.1.2 Indicative basin plan

The overall plan under development by the Mekong Committee for meeting the irrigation requirements of the lower basin relies upon a complex of several mainstream as well as tributary projects. Considering all such projects, the increase in irrigated area required to meet the increasing need for agricultural production in the lower basin over the period up to the year 2000 was estimated to be 1,868,000 ha for full double cropping. Tributary projects within the basin could service an area about 1,212,100 ha, only 65 per cent of this requirement.

In Viet-Nam, thirteen tributary projects, all located in the plateau area, have an aggregate capacity of 97,000 ha and represent no more than 21 per cent of the demand. These would satisfy the national development up to 1983 if the plateau alone were chosen for development. However, in planning for expansion of irrigation in Viet-Nam emphasis is being placed on the development of the delta including the coastal areas, and this is dependent on an adequate supply of fresh water during the dry season, as well as the

regulation of flood flows by mainstream projects in association with the establishment of a system of dikes and control works to prevent flooding from the river and sea water intrusion. In northeast Thailand the situation is similar in that the capacity of tributary projects is far less than the requirement to be met by increased irrigation. In Lao PDR the potential tributary projects can easily satisfy the needs to the year 2000. The situation in Democratic Kampuchea is also favourable, i.e., the potential tributary projects could service 576,000 ha which is more than sufficient.

To achieve the desired levels of irrigation will necessitate considerable regulation and storage of flood water in reservoirs during the wet season to conform with the principle adopted by the joint meeting of the lower Mekong riparian countries in 1957, that (a) the existing low water discharge of the Mekong would not be reduced in any way at any site; and (b) the supplies to be diverted for irrigation purposes would be obtained by storage of flow during the high stages of the river. In formulating the mainstream projects for the long-range plan of development, the Pa Mong, Stung Treng, and delta development projects were selected as the key projects for irrigation development in the integrated plan. The Sambor project is included mainly for hydropower.

The three major multipurpose projects, Pa Mong, Stung Treng, and Sambor, have been estimated to have a capacity for full double-cropping of about 5 million ha. Pa Mong, with an estimated potential of 1,630,000 ha, can satisfy the requirements of northeast Thailand and Lao PDR. Stung Treng and Sambor, with potentials of 1,287,000 and 34,000 ha respectively, could satisfy the requirements of Democratic Kampuchea, and Pa Mong and Stung Treng together would furnish sufficient dry season water to permit farmers to harvest a second crop on at least 2,050,000 ha in Viet-Nam.

The critical need for the Pa Mong project may be illustrated by the evolving situation in northeast Thailand. In the past 25 years the population of northeast Thailand has doubled, and the area of cultivated lands has correspondingly doubled, inasmuch as an extensive type of farming is practiced. The population is expected to double again during the next 25 years; however, of the total area of 17 million ha, eliminating deeply flooded areas, stream beds, communities, and topographically unsuitable lands, the total land suitable for cultivation is 6 million ha. Of this 5 million ha were already under cultivation in 1970. Also, a review of the distribution of paddy and upland fields shows that present paddy fields are located not only on alluvial soils suitable for paddy (recent and semi-recent alluvial soils) but that more than half are located on more coarse-textured soils less suitable for rice than for upland crops. Also the extent of upland fields is spreading into forest zones as

public roads are opened, hence increasing the extent of the total cropping on soils less suited to agriculture (because of their greater erosion potentials). Assuming this trend will continue, the total cultivated areas should use up all the potentially arable lands by 1980.

Notwithstanding the problem of land shortage in northeast Thailand, water will probably prove to be a limiting factor more serious than land. Rainfed paddies are erractic in performance and for sustained yields need supplemental water amounting to 280 mm in an average year and 800 mm in drought years occurring every 10 years. The total demand for supplemental water in irrigable paddies in drought years is about 14 billion $m^3$, almost equal to the total watershed runoff in such years. The maximum water supply potential is about 15 billion $m^3$, assuming it is feasible to store and distribute this amount. Of this 15 billion $m^3$, some 4.5 billion $m^3$ was being stored in 1970, enough for use on about 380,000 ha in the rainy season and 250,000 ha in the dry season. Moreover, for diversified or double cropping, the total demand could be as high as 42 billion $m^3$ including 14 billion $m^3$ for rainy season paddy. The deficit of 28 billion $m^3$ will have to come from another source, namely the Mekong river.

2.1.3 Pa Mong irrigation system

Figure 3, Irrigation-Drainage Section of Chapter III, shows the location of the Pa Mong Irrigation service areas (for both Stage One and Phase II). Details describing the land areas involved their present land use, extent of arable lands in the service areas (divisions), water allocations, and related information are shown in Tables 6 to 11 (Irrigation-Drainage Chapter III). The entire plan is based on the concept of service units, the service unit being the basic irrigation area (about 50 hectares) considered to be suited to management by the resident farmer organizations.

In addition to the system of canals, laterals, and ditches used for distribution, drainage facilities will be needed, especially during the rainy season when drainage requirements are more critical.

(a) Irrigation water requirements: The average annual diversion water requirements for irrigation of the Stage One area (initial development) and for the total area considered in the Phase II studies, are 632 and 13,673 million $m^3$ respectively. Return flows will be utilized to the extent practicable, averaging about 4,000 million $m^3$ annually. These average annual irrigation diversions are estimated at 0.4 and 7.8 per cent of the average annual inflow into Pa Mong reservoir for Stage One and Phase II respectively.

(b) Development period: Factors limiting irrigation development appear to be the rate at which project works can be constructed, the rate at which farmers can develop the ability to fully utilize the expanded facilities, the ability of local and export markets to absorb increased production, and the availability of capital required to finance construction. The irrigation development of the Pa Mong project is planned to begin at a relatively slow rate and increase as more experience, resources, and technology become available. The effectiveness with which the first "blocks" of irrigation are developed will affect the rate of farmer acceptance in subsequent blocks, hence the initial development should be planned so that available resources can be concentrated in a relatively small area. This will increase the probability of an orderly and efficient land development programme. The Stage One irrigation development programme will require an estimated 5 years for completion of the planned irrigation facilities. It is also estimated that 5 years under wet season irrigation and 10 years under dry season irrigation, following initial delivery of water, will be required to realize full irrigation benefits.

(c) Related irrigation projects. Areas to be irrigated from Pa Mong reservoir, in addition to the Pa Mong project service areas, include areas along the river banks downstream to be irrigated by pumping, the Mekong delta, and perhaps at some future time the central plain of Thailand by transbasin diversion. The agricultural benefits from these additional irrigation uses of Pa Mong water should be very substantial and while not yet precisely quantified can be roughly estimated. Pa Mong will make it possible (1) virtually to eliminate flooding along the middle course of the Mekong river from Pa Mong to Khone Falls, which are densely populated rivering lands, and to develop these lands by low lift pump irrigation on both sides of the river, particularly on the Lao side of the Vientiane and Savannakhet plains, (2) to reclaim sizeable areas in Democratic Kampuchea through flood control (studies indicate up to 200,000 ha theoretically possible), thus utilizing lands not now useable, and to convert other areas of equivalent size from floating rice culture to other rice varieties of higher yields and quality, (3) to make available for use in the dry season in the Mekong delta about 30,000 million $m^3$ of fresh water, (4) to engage in fish farming in many parts of the lower basin below Pa Mong, and (5) to transfer 5,000 million $m^3$ of surplus water in the dry season to the central plain of Thailand.

### 2.1.4 Agricultural research and development

The irrigation programme anticipated by the Mekong Committee is expected to have a profound impact on the existing farming practices throughout much of the lower basin, in requiring fundamental changes in traditional practices both in the technology of farming and in the related socio-economic environment in the farming village. Experience in existing tributary irrigation projects in northeast Thailand has shown that the farmer will generally be willing to try to adjust to irrigated agriculture but that he must be furnished with assistance from government if he can be expected to succeed. This assistance must include training in the technology of irrigated agriculture and assistance in establishing and operating farmers cooperatives for collective handling of problems of financing, storage, transportation, and marketing and for solving other socio-economic problems.

In response to this challenge the Mekong Committee has organized and has underway a sizeable agricultural research and development programme designed and operated to bring about the desired transition in farming methods as needed to keep pace with the availability of new irrigation areas, beginning with the existing irrigation service areas associated with tributary projects and progressively moving ahead to meet the needs of proposed mainstream projects especially Pa Mong.

The agricultural research and development programme embodies several approaches, namely:

(a) A programme of research and experimentation for producing the new technological information needed to suit Mekong basin conditions, including a group of eight experimental farms and a number of research projects on specific problem areas, and including publications and other provisions for dissemination of the research findings. Table 1 (Agr Sec Ch III) presents summarized information on the experimental farms and Table 2 on past and current specific research programmes. Also, Figure 1 shows the locations of the experimental farms (and of the pioneer agricultural projects).

(b) A programme for introducing and proving out new farming methodologies on a full-scale demonstration basis, through a series of pioneer agricultural projects, each of which will take into account all factors involved in successful farming including both (1) farming technology, and (2) socio-economic institutions for assuring availability of equipment and credit, marketing, establishment of necessary farmers' cooperative mechanics, and development of attractive communities and community facilities and

protection of public health. There will be continuing monitoring of each project to assure maximum benefits including maximum returns from each project, dissemination of information among the various projects, and coordination of and cooperation between the projects. Table 3 (Agr Sec Ch III) presents summarized information on the pioneer agricultural project.

(c) A programme for developing master plans for agricultural development in anticipated major areas to be irrigated, especially the Mekong delta and the Vientiane plain, and also assistance in planning for a number of additional zones including northeast Thailand. A brief summary of this work is presented in Table 4 (Agr Sec Ch III).

(d) An evaluation of the effects of flood control at Pa Mong on downstream agriculture, especially in Democratic Kampuchea where there have been serious apprehensions on possible adverse effects on productivity of chamkar dry-foot farming areas due to reduced colmatage silt deposition. This study has investigated various possible effects on downstream agricultural productivity including effects on present rice cultivation practices in the Democratic Kampuchea lowlands, middle elevation zones, and uplands, and has developed findings which can be utilized to realize the maximum agricultural benefits taking advantage of the new lands made available by flood control and to minimize adverse effects through positive water control measures.

It is believed that this effort by the Mekong Committee represents the most intense programme of preparation for irrigated agriculture yet attempted or accomplished for any water resource development programme elsewhere in developing countries. Also, it appears the agricultural programme is at a stage of progress in keeping with the Mekong Committee's overall programme for basin development, especially with respect to Pa Mong. Assuming continuation and progressive development of the agricultural programme, as planned, it is anticipated the transitions in farming practices to the desired new methods can be realized on schedule despite the innumerable difficulties sure to be involved.

### 2.1.5 Overall food impact of Pa Mong

The Pa Mong project is critically needed for food production in the lower basin, as the logical first mainstream project to furnish the essential water which cannot be obtained from tributary projects alone. In the irrigation service areas the benefits will be mostly in increased yields of rice and of upland crops and in fish farming. Using the general rule of thumb that a cubic metre of irrigation water

will yield about 0.5 kg of rice (and even more of upland crops), the potential extra rice yields from the improvements noted above could support at least 20 million people in northeast Thailand and Lao PDR alone.

The additional benefits in extra food supply further downstream would also be very considerable because of the very large land areas which would become subject to cropping or extra cropping either through irrigation or flood control. The potential increased rice production in the Mekong delta alone, made possible by the increased dry season flow, could support an additional 30 million people.

An additional very important potential which may be realized from Pa Mong will be the opportunity to demonstrate on a mass scale, especially in the irrigation service areas in northeast Thailand and Lao PDR, how to transform existing agricultural practices into new concepts and methodologies which take full advantage not only of continuing improvements in agricultural technology but of the unique combination of the year-around sunshine, year-around water available through water control, and a highly competent people. This combination is believed to be unique to Southeast Asia, and if these resources can be mobilized in the lower Mekong basin to take advantage of continuing technological improvements in agriculture, which in themselves can be expected to increase exponentially, it is realistic to believe that the lower basin can both meet its own food needs and also realize major export revenues. This would mean the lower basin would have a far greater carrying capacity than present circumstances might seem to indicate.

## 2.2 Power

### 2.2.1 Need for power

Of the multipurpose benefits expected from the Pa Mong project, power is one of the main bases of its economic and financial justification. The hydrologic characteristics of the lower basin indicate that the Mekong river is by far the principal indigenous source of energy available to the four riparian countries, and that Pa Mong is the logical first mainstream project for reaping this benefit. Without Pa Mong and other mainstream and tributary hydroelectric power projects, most of the region's future energy needs might have to be met by fuel imports.

To the extent and at the rate feasible, the countries of the lower basin must industrialize for their prosperity, and to accelerate industrialization, they must use power. It is an accepted fact that the wealth of nations and their people is closely related to the per capita use of electricity, particularly that portion of the per capita use allocated for industrialization. However, before any decision is made to

develop Pa Mong's tremendous power potential, it must be shown that the demand for power within a reasonable period will at least equal the quantity to be made available, that power production at Pa Mong will be less costly than alternative sources, and also that power production at Pa Mong will not result in serious losses of environmental resources which would be avoided if alternative sources of power were used.

All of the factors noted above have been the subject of many studies sponsored by the Mekong Committee in collaboration with the four riparian countries since 1963. These confirm that (a) power generation at Pa Mong will be by far the most economical source of power, and with the recent increases in costs of oil and of other fuel sources including nuclear fuels, the Pa Mong power alternative commands an even higher priority than before; (b) the market for use of the power will be more than ample; and (c) the net effects on environmental values should be positive and the impairments to particular environmental values will be less than for any other method of power generation.

2.2.2 Load forecasts

Using modern high-tension transmission technology, large quantities of power can be transmitted at high voltage and low cost to major load centres up to 1,000 km distant. Hence the entire national areas of the four lower basin riparian countries lie within the feasible market area.

A review of the many forecasts of power and energy requirements made since 1963 shows the actual increases to be greater than predicted in the earlier studies. The installed capacity of the four riparian countries in 1965 was 870.5 MW, of which 527.3 MW was in Thailand and 10.2, 33, and 300 MW in Lao PDR, Democratic Kampuchea, and Viet-Nam (South part only). Corresponding annual energy consumption in 1965 was 1,087.4, 11.2, 61.2 and 433.3 GWh for Thailand, Lao PDR, Democratic Kampuchea and Viet-Nam respectively. The installed capacities of Thailand and Southern Viet-Nam in 1973 were 1,583 and 813 MW respectively, while Democratic Kampuchea and Lao PDR in 1972 had 68.5 and 77 MW respectively. The annual consumption of energy in 1973 in Thailand, Lao PDR and Viet-Nam was 6,207, 62.2, and 1.150 GWh respectively, while Democratic Kampuchea consumed 115.2 GWh in 1972. The average annual increases in power and energy consumption, during 1965 and 1973 (during 1965 and 1972 for Democratic Kampuchea), were 21.4, 21.0, 8.2 and 11.5 per cent for Thailand, Lao PDR, Democratic Kampuchea and Southern Viet-Nam respectively.

It has been estimated that the market ability in Thailand alone can absorb the large blocks of power to be produced at Pa Mong. Fig. 1 (Power Chapter III) shows the comparison of the load forecast of the four riparian countries with and without the loads of central, northern,

and southern Thailand. This figure clearly shows that Thailand, especially the Bangkok metropolitan area, will be the major consumer of the electricity that Pa Mong project will be able to produce. Fig. 2 (Lower Chapter III) shows the proposed regional distribution of power from Pa Mong project as a result of load flow studies.

The forecasts noted above include allowances for industrial consumption at attractive rates to prompt the development of electro-processing industries in general and of mineral processing and agro-industries in particular. The anticipated rate levels for such use would be in the range of 6 to 10 mills/KWh.

2.2.3 Pa Mong power generation

Power regulation studies include Pa Mong in both isolated operation and in a system with downstream projects with four different maximum pool elevations, 230, 240, 250 and 260 m MSL, with each of these associated with three different minimum pool elevations. The installed capacity of the Pa Mong powerplant would vary from 3,200 MW to 5,600 MW while the firm power and energy would vary from 990 to 2,700 MW and 8,650 to 22,500 GWh/year respectively. In any case eight generating units would be installed, and the power distributed by a network of 500 KV transmission lines.

2.3 Flood control

Pa Mong reservoir at FSL 250 m MSL would have a total effective storage of about 80,600 million $m^3$, of which 21,000 million $m^3$ would be available for flood control, without reducing the firm power output. This provision for flood control is equivalent to about 70 mm of runoff for the total drainage area above Pa Mong damsite. The control exercised by Pa Mong would reduce the highest flood peak of record (1939-1970) at Vientiane from 25,900 $m^3$/sec down to 13,000 $m^3$/sec, enough to keep the flow of Mekong within its banks from below Pa Mong damsite to Pakse and at the same time materially reduce the flood flow in Democratic Kampuchea and Viet-Nam.

For the 100-year flood, Pa Mong reservoir regulation would reduce the flood peak at Vientiane from 26,600 to 15,600 $m^3$/sec. There would possibly be some residual damage in the middle reache from floods of magnitudes occurring at frequencies of about or larger than 100 years, due to the effects of uncontrolled flows into the Mekong from tributaries.

The probable adverse environmental effects stemming from use of Pa Mong for flood control include (a) a significant decrease in colmatage silt deposition occurring under natural conditions on chamcars (levee banks) in Democratic Kampuchea (but this can be offset by controlled or designed colmatage systems), and (b) reduction in inundation fisheries, especially in Democratic Kampuchea and Viet-Nam (but this is offset by cropping of the same lands which are no longer inundated).

While it has not yet been possible to quantify the total benefits versus adverse effects from flood control, it appears certain that the benefits will far outweigh the losses.

## 2.4 Urban water supplies

Domestic, municipal and industrial (DM & I) water supplies in the Pa Mong project area are generally obtained from a variety of sources including rivers, streams, ponds, reservoirs, irrigation systems and wells. The present supply of DM & I water is generally adequate during the wet season, but very inadequate during the dry season. Water quality also becomes a serious problem during the dry season as the limited available surface water is often ponded hence becomes increasingly contaminated from human and animal wastes. In rural areas, there are only a few communities with water treatment plants and distribution systems. Most rural water supplies come from polluted ponds, lakes, and streams with water hauled great distances during the dry season at considerable effort and cost. A dependable supply of clear water for DM & I uses is very much needed throughout most parts of the lower basin.

An important additional benefit to be realized from the investment in the extensive Pa Mong irrigation distribution system will be in the use of this same system to supply water for DM & I uses. An estimate of the amount of water required to meet this demand was made assuming an average rate of 50 liters per capita per day for the initial needs and 400 liters per capita per day ultimately, assuming progressive urbanization and industrialization. The average annual DM & I requirement for the initial needs (200,000 people, Stage One) represents only a small portion of the available irrigation water supply. For the 50-year study, the average annual DM & I requirement (for 7.7 million people) is estimated to be 60 and 1,068 million $m^3$ in Lao PDR and Thailand, respectively. Although this represents only a small fraction of the total annual river discharge, this contribution to the development of the region, as a base for urban and industrial growth, will be of the first priority.

A fortunate fact is the excellent mineral quality of Mekong river water, which suits it admirably for virtually all urban uses both for domestic purposes and for industry. The water is low in total dissolved solids, low in hardness (yet it is in calcium carbonate balance hence not corrosive), low in chlorides, and has no significant concentration of any deleterious constituents. The only treatment generally required will be rapid sand filtration together with final chlorination.

## 2.5 Agro-industries

In keeping with the Mekong Committee's basic policy that water resource project development must contribute effectively to advancement of human welfare in the lower basin, the Committee has carried out a programme for promoting industrial development throughout the region wherever the project products (plentiful

water, improved navigation, etc.) might favor the establishment of such industries. Numerous investigations have been made to explore the feasibility of such ventures, which may be organized into two general categories, namely (a) agro-industries, (b) mineral resources development and related power oriented industries.

Present trends in industrial development in the riparian countries indicate most industries, including agro-related industries, tend to concentrate in a few major cities, in particular in and around metropolitan centers such as Bangkok, Saigon, and Phnom Penh. Industry is attracted to these centres because of their large and rapidly growing markets, their well developed infrastructure, and facility for contacts with interested government agencies. Such highly centralized industrial development progressively reinforces itself as industry expands and develops, thus tending to contribute to an ever-widening income gap between the urban and rural sectors.

The Mekong Committee's programme for agro-industrial development has two main objectives, first, to identify and describe promising agro-industrial investment opportunities, and second, cooperation with the riparian governments in formulating and implementing plans and policies for establishing such industries, together with provisions for training in technical specialties and in management. The various studies may be classified as project studies (evaluations of specific industry potentials), regional reviews for identifying input and output potentials for specific agro-industries, and master planning for agro-industrial complexes. Most of the studies have been carried out since 1970.

A summary of the agro-industrial feasibility studies completed is presented in Table 1 (Agro-Ind Ch III). These include studies of potentials for both (a) agro-input industries, namely nitrogen fertilizer, phosphoric acid, and calcium carbide, and (b) agro-output industries, namely processing of pipeapples, poultry, cane sugar, vegetable oils, and various fruits and vegetables (especially by dehydration or quick-freezing), manufacture of pulp and paper utilizing a variety of local materials including kenaf, and sericulture.

The programme thus far has served to identify and characterize many of the numerous complexities involved in establishing agro-industries in agricultural areas traditionally oriented to rainfed paddy. These include the problems of motivating and training the participating farmers, of adapting local and imported fruit and vegetable species so their cultivation will suit processing needs (considering matters of protection against spoiling, storage, and transportation), of scheduling cropping to coordinate with and not interfere with rice cultivation, of making arrangements by which the farmer can receive a guaranteed fair price for his crops and likewise the buyer be protected on matters of delivery and of repayment for advances to the farmers for fertilizer, etc., and many other related problems.

The impact of Mekong Committee's programme, being essentially limited to assisting the responsible government agencies, is difficult to assess. However, there has been an encouraging growth of decentralized agro-industries in north Thailand over the past several years, which is providing experience in solving the numerous problems involved in establishing successful new ventures located in agricultural zones. It is believed the total experience being gradually accumulated, including the contributions from the Mekong Committee represents a significant achievement and a essential first step in preparing for the major impact of a mainstream project like Pa Mong.

2.6 Mineral development

An integral part of the Mekong Committee's programme for industrial development in the riparian countries, taking advantage of the benefits made available from water resource project development (plentiful power and improved river transportation), has been in the field of mineral resources. The programme activities include (a) field explorations for locating and evaluating the extent of mineral resources, (b) evaluations of specific industry potentials, including the possibilities for carrying out metal refining operations with imported ores where the availability of plentiful power might be a sufficient incentive, and (c) training to assist the riparian countries in strengthening their professional and technological capabilities for developing mineral resources. The programme has been basinwide, but has given primary attention to the areas of northeast Thailand and northern Lao PDR, which could be readily furnished with power from Pa Mong as well as from existing tributary power projects. An impressive number of surveys and studies have been completed since start up of these activities in 1963.

Table 1 (Min Dev ChIII) presents a tabulation with brief description of the various field surveys and explorations, studies, and compilations carried out under the Mekong Committee's programme relating to development of mineral resources in the lower basin. The main results and contributions of the programme may be summarized as follows:

(a) For the area of northern Lao PDR, and to a lesser extent, for northeast Thailand (both areas in proximity to Pa Mong) development of a substantial base of information on the geology of this region, which will greatly assist in planning of future mineral exploration surveys, including a completed set of photogeological maps for northern Lao PDR. Also, a beginning effort toward preparing a geologic/mineral resources map of the entire lower basin.

(b) For the region of northern Lao PDR and northeast Thailand, completion of preliminary mineral surveys in selected areas with the objective of locating valuable mineral deposits, especially certain key industrial minerals including iron

ore, base metals, coal, and fertilizer raw materials. In all of these categories mineral resources with economic potentials are known to exist but they all require further exploration and evaluation.

(c) Very rich deposits of potash have been confirmed in the northeast Thailand/northern Lao PDR region, which appear to be so vast and adapted to ready mining that exploitation of this resource can be expected to capture a sizeable share of the market for potash throughout southeast Asia. The deposits in Lao PDR especially appear to be among the world's richest containing more than 25 per cent $K_2O$, and moreover the impurities in this ore are rich in boron which can be recovered in the processing operations as a valuable by-product. Exploitation of this resource could have a major impact on the economy of northeast Thailand and northern Lao PDR. While the drilling programme is only preliminary, it is sufficient to merit the conclusions stated.

(d) Because of conditions of insecurity in key areas, field surveys for locating bauxite mostly remain to be done. The preliminary indications are that the lower basin, in both Democratic Kampuchea and Viet-Nam, possesses some bauxite but at present there are no indications of bauxite in exportable quantities. The prospects for aluminum smelting appear promising, however, even if bauxite has to be imported, on the basis that electrical power will be in plentiful and cheap supply. A typical plant could produce 120,000 tons of aluminum ingot per year, consuming 250,000 kW power.

(e) The availability of plentiful power will justify establishment of small steel rolling mills in each riparian country and of specialized steel mills serving regional needs to be located in Thailand and perhaps one additional country. It is possible that local iron ore deposits, for example, from Loei province in Thailand and from Krey Khoung in Lao PDR, can meet these needs. Also, a ferro-alloy industry may be feasible in the basin, using local manganese and quartzite ores, for meeting regional needs for ferro-manganese and ferro silicon.

(f) Another promising power using potential is use of rock salt mines from the northeast of Thailand for manufacture of caustic soda and chlorine. Plans are underway for a major facility of this type to be built in the near future with private financing. In addition to potash, the rock salts contain large reserves of gypsum and possibly magnesia.

Thus far interest in mineral development has focused on explorations and studies. When actual mining and ore processing operations are contemplated, then it will be important for the

regulatory agencies of the riparian governments to exercise proper controls as needed for preservation of environmental values, to prevent strip-mining which devastates the landscape, and to prevent wholesale pollution of ground and surface water supplies which inevitably result when mining operations are permitted to take place without regard to environmental impact. As has been amply demonstrated elsewhere, proper controls are available and are readily affordable for virtually all mining and ore processing operations provided these controls are incorporated into the planning of the operations from the outset. Also, if not so incorporated at the outset, the costs for remedial measures will usually be relatively very high, and often so high as to be difficult if not virtually impossible to accept.

## 2.7 Navigation

Navigation along the Mekong river system, except in the delta region, has not been developed over the decades since World War II to the extent it could and should be as an important element in the transportation network for the upper portion of the lower basin. This is especially true for landlocked Lao PDR. As part of its planning for comprehensive development of the water resources of the lower Mekong basin, the Mekong Committee has since 1960 sponsored a programme of studies and projects for improving navigation throughout the Mekong river system. This programme includes both long-run and short-run phases.

In the long-run, as noted in the Indicative basin plan, many major improvements would come from the construction of several mainstream dams including Pa Mong. Each of these projects will include provision for locks and other navigation facilities, and will ultimately provide many hundred kilometers of navigation improvements upstream of the dams through creation of reservoirs or deepening the streams which will submerge rapids or former non-navigable or dangerous spots in the river reaches. In addition, the increase of the low-water discharge during the dry season will augment the depths in the channels downstream of the reservoir. Construction of Pa Mong would have major effects on navigation in the Mekong river. The new reservoir itself will furnish the basis for a vast system of navigation upstream of Pa Mong, and provision of trans-shipment facilities at the dam would serve to extend the range of river-borne traffic far downstream.

The short-run navigation improvement programme includes improvements which can be implemented prior to construction of Pa Mong and other mainstream projects, including hydrographic surveys, channel marking, bank protection, construction or improvements to ports, harbors, and shipyards, and training of riparian personnel. These activities carried out or coordinated by the Mekong Committee are a summarized in Tables 1 to 3 (Navig Ch III).

The primary benefits to result from Pa Mong will be improved year-around navigation along the Mekong river from Luang Prabang to Vientiane and from Vientiane to Savannakhet, the latter

case due to the increased dry season depths to be made available. The estimated total savings in each reach is in the order of $ 600,000 to $ 700,000 per year. In the event of extensive mineral development in the upper portion of the lower basin, which seems likely sooner or later, the improved navigation system could contribute much more to the regional economy.

Possible adverse effects from navigation improvement activities are of minor importance and readily manageable. These include provision for proper disposal of dredged materials and control of spills from ships and docks of petroleum products, toxic chemicals, and other materials especially damaging to ecology.

## 2.8 Recreation

The huge new lake to be created at Pa Mong should be an aesthetic "gem" and, because lakes are not plentiful in the region, this will certainly add to its overall aesthetic and recreational values. In areas where lakes are scarce, for example in Southern California, the creation of sizeable reservoirs has usually led, sooner or later, to their massive use by the public for recreational purposes including aesthetic enjoyment, boating, fishing, swimming, skin-diving, and other water contact sports. While it is recognized that the aesthetic value of waterways have not generally enjoyed any significant priorities nor much public attention in the past in the lower basin (except to a limited extent in Thailand), it is also true that there is growing recognition of the recreational and sports potentials of outdoor environment.

By the time Pa Mong has been completed it should be a recreational attraction for many residents in the lower basin as well as visitors from outside. Traditionally the Thai and Lao peoples in the Pa Mong region, when visiting the outdoors for recreation, have been mostly interested in picnicking and camping. The new lake will create inumerable choice sites for such activities as well as for various types of water contact sports likely to become popular in the future. Studies sponsored by the Mekong Committee indicate the annual number of visitors to the reservoir area is expected to increase from approximately 31,000 persons/year initially to about 369,000/year in 50 years.

Experience elsewhere has provided the guidelines to be used in formulating a recreational programme for Pa Mong reservoir. Recreation development planning should start when project design is begun. Natural beauty spots should be left intact wherever possible, and recreational facilities developed around them. Boat ramps and boat-docking facilities are beneficial to most reservoir areas and should be constructed at the same time as the dam. Camping facilities for truck campers, tents, and picnicking areas can often be provided at reasonably low costs. Sanitation facilities should be provided at convenient locations, and it may be desirable to provide bicycle paths, equestrian paths, and foot paths for public use. At the damsite or nearby, a reservoir viewing location and possibly a visitors center should be built. Where possible, sand swimming beaches should be constructed and maintained to provide maximum usage. These and many other detailed guidelines, developed in other "lake-scarce" regions, should permit proper attention to recreational planning at Pa Mong.

In addition to recreational development at Pa Mong reservoir, as noted in the discussion on wildlife, a number of national parks together with scientific reserves need to be established in the lower basin, especially in the hilly areas, if representative samples of the terrestrial biota are to be preserved. One key aspect of a national park is its tourist potentials which can furnish the financing for the entire park plan. In Eastern Africa and India this type of venture has already been successfully demonstrated. The rich and varied wildlife of the Pa Mong watershed and its scenic beauty should offer the same potentials for Thailand and Lao PDR.

2.9 Reservoir uses

Construction of Pa Mong will create a vast new reservoir which should be immensely valuable for numerous purposes including navigation, fisheries, waterfowl and other wildlife, water supply, recreation, aesthetics, and also as a nucleus for establishment of a new series of communities along its shoreline including a major city at the damsite, and probably also for limited cropping in the drawdown zone. Details of these added values are discussed in the other sections of this summary, including specific environmental effects.

The losses offsetting the gains noted ab[illegible] will be inundation of the area to be flooded, thus creating a la[illegible]-scale resettlement problem (but which should be properly manageable as an intergral part of the project costs), eliminating the riverine fishery and much of the wildlife and all of the forests in the inundated area (but the forest can be harvested and the fishery and wildlife replaced with even more valuable fishery and wildlife), increasing accessibility to the hinterland hence imposing hazards to wildlife (but also providing local protein sources and year-around employment which may reduce hunting), and impairment of much of the riverine fishery downstream of the dam for some 20 km due to wide flow fluctuations (which is taken into consideration as one of the project costs).

Development of communities, industries, navigation facilities, recreational facilities, roads, and other urban amenities will pose some special problems, including protection of works and buildings against landslide hazards created by the extensive vertical drawdown range (from 20 to 40 m depending upon the selected maximum/minimum pool levels); however, these problems should be reasonably manageable considering the relatively slow rate of surface level fluctuation (maximum of about 2 to 4 m per month depending on selected pool levels). Also, studies and experimentation are needed to develop practicable vegetative covers which are adapted to the drawdown zone, and to develop cropping methods suited to these conditions.

Another special problem will be control of fishing activities in the reservoir for various purposes including prevention of overfishing and use of injurious fishing methods, development of lakeside fishing communities with sound socio-economic structures and community facilities needed for sanitation, public health, and control of water pollution.

## 3. Human values

By "human values" is meant benefits derived by people from project development of a somewhat less tangible nature than "human uses", although it is sometimes difficult to distinguish between these two categories. The elements of aesthetics and "quality of life" (as distinguished from the "quality of living" associated with human uses) are iherent in the concept of human values.

### 3.1 Resettlement

Resettlement is regarded by many as the most important environmental issue of the Pa Mong project. As previously noted, to ensure proper resettlement requires that provision be made for all of the real costs of resettlement, including reestablishment and rehabilitation as well as property compensation costs, as an integral part of the capital costs of the project. This policy adopted by the Mekong Committee in 1968 is believed to be an unprecedented decision which simply faces up to the reality of the problem.

Based on preliminary studies of resettlement experiences in the lower basin and in Africa, the Mekong Committee in 1973 formulated and established two fundemental and pioneering projects, plus several supplementary studies, designed to furnish the facts and findings to serve as the basis for developing an effective meaningful resettlement programme for Pa Mong. One of these major studies, the Pa Mong Resettlement Costing Project, finalized in 1976, analyzed and estimated resettlement costs specifically for the Pa Mong project. The second, the Resettlement Study and Planning Project, completed in 1976, developed methodologies for resettlement applicable throughout the lower basin. A brief summary of the major findings of the Mekong Committee studies is as follows:

#### 3.1.1 Pa Mong resettlement costing project (PMRCP)

The PMRCP is designed to set a true and fair value for the amount to include in the Pa Mong project budget for both property compensation and reestablishment costs. This includes a variety of feasible reestablishment alternatives, so the evacuees will have a reasonable number of choices in selecting their new home locations and occupations. These include, in addition to moving to resettlements in vacant rural uplands, use of the reservoir fringe areas, reservoir fisheries, purchase of privately owned land, cattle raising, and urban employment.

The total population to be resettled and land inundated by Pa Mong will depend on the high pool level for the dam, the extent of protection works to be built, and date of closure. Eight alternatives are considered in the study, including protection schemes both for the Loei valley in Thailand and the Vang Vieng valley in the Lao PDR. Taking one alternative as an example, assuming Pa Mong would be closed by 1990, with

a high pool level of 250 m MSL with no protection schemes, the land and population to be inundated/resettled is estimated to be 462,150, comprised as follows:

| Sector | Thailand | The Lao PDR | Total |
|---|---|---|---|
| Rural | 289,856 (63%) | 88,237 (19%) | 378,093 (82%) |
| Urban | 61,789 (13%) | 22,270 ( 5%) | 84,059 (18%) |
| Total | 351,645 (76%) | 110,507 (24%) | 462,152 (100%) |

The land areas to be flooded, and the present uses of these lands, are as follows:

| Use | Thailand (Rai) | The Lao PDR (Rai) | Total (Rai) |
|---|---|---|---|
| Paddy | 357,652 (32%) | 109,280 (10%) | 466,932 (41%) |
| Upland | 525,868 (46%) | 68,846 (6%) | 594,714 (52%) |
| Residences | 59,345 (5%) | 12,471 (1%) | 71,816 (6%) |
| Total | 942,865 (83%) | 190,597 (17%) | 1,133,462 (100%) |

Resettlement costs are estimated for each for the alternatives considered, for various times of closure. These costs include allowances for (a) compensation costs (including costs for farmland, urban land, perennial tree crops, private property), (b) communication replacement, (c) dislocation allowance, (d) moving allowance, (e) early moving allowance, (f) land development, (g) social overhead, (h) title verification, (i) downtime allowance, (j) administration, and (k) replacement of roads and towns. For the 250 m/no protection alternative, the total resettlement costs will be close to US$626 million, equivalent to a unit total resettlement cost of US$1,355 per person (in 1974-75 dollar values).

Regarding distribution of the resettlers among the various resettlement alternatives, of the total 462,152 persons to be resettled, it is estimated that (a) planned upland settlements can accommodate only 51,714 persons or 11 per cent (due to the limited lands available), (b) the bulk of the population or 273,094 persons (59 per cent) will seek self-settlement by purchasing agricultural lands in other parts of the country, (c) the portion of the population to be resettled as urbanites, or 80,821 (say 18 per cent), would be essentially those already living in the urban sector of the reservoir area and (d) 56,523 (12 per cent) would be relocated on the reservoir margin.

### 3.1.2 Resettlement study and planning project (RSPP)

The two main accomplishments of the RSPP were (1) establishment of sound methodology for planning resettlement based on analysis of physical and socio-economic opportunities and constraints, and development of an actual plan for the Huey Luang resettlement project in northeast Thailand (activated in 1976) thus illustrating the usefulness of the methodology, and (b) planning and implementing a pilot project within the existing resettlement scheme at Nam Pong (activated in 1965) as an actual demonstration of how to increase farm productivity and thus the standard of living of the resettlers.

The two-year period of the pilot project limited its role to initiation of the desired new pattern of agricultural practices, as only the first step, with continuation of the project to be carried out by the Thai Department of Public Welfare. Hence it is not possible yet to make more than a preliminary assessment of the

meaningfulness of the project. For example, cooperative schemes in Thailand have generally met with little success, and the future of the cooperative agency established at Nam Pong will depend on the adequacy of its continuing service to the farmers. The data thus far available, however, indicate encouraging results in promotion of irrigated agriculture, including doubling of the average cultivated area of irrigated crops and tripling of the gross value of irrigated crops during the first year, with a corresponding increase in average gross family income from 10,000 to 14,500 baht during the first year. These increases were due to both to expansion of the cultivated area and increase in farm productivity, primarily due to better farm management (better cropping techniques and improvement of irrigation methods), all improvements achievable by the farmer through increase in labour input. There was little improvement in farm inputs nor in soil conservation measures, probably because of financing requirements, but both are expected to be realized in time with the availability of short-term credit using the crops as collateral.

### 3.1.3 Economic criteria for resettlement

As an adjunct to the RSPP and PMRCP projects, an evaluation and compilation of the economic theory and methodology for estimating resettlement costs involved in reservoir projects was completed for the Mekong Committee by the Netherlands Economic Institute in 1975. The report reviews the various methods for making economic evaluations and costing of the numerous aspects of resettlement projects, such as would be used by financing and developmental agencies, including the "financial cost", "economic cost", and "social cost" approaches.

### 3.1.4 Nam Ngum resettlement project

An additional effort of the Mekong Committee in demonstrating the feasibility of the Committee's approach to resettlement involved development of detailed plans for assisting the government of the Lao PDR in achieving satisfactory resettlement of some 579 families flooded out by construction of Nam Ngum reservoir in 1971. The resettlement plan instituted in 1975, includes provisions for reclaiming forest areas to make new agricultural lands, for small scale water control projects, for land distribution, and for provision of physical and socio-economic infrastructure to bring the existing facilities up to the desired minimum levels. The total project would cost $1.17 million and require two years.

In summary, it is believed that several key steps included in the Mekong Committee's approach to resettlement should make it possible to develop a competent resettlement plan for Pa Mong namely (1) recognition by the Committee that the cost of reestablishment as well as compensation for flooded properties should be an integral part of the project budget, (2) determining the amount of a fair allowance to cover these total costs,

and (3) making available to the resettler a variety of alternative choices for his new career including urban employment. The most important factor is the decision to furnish a reasonably adequate amount of money, at the outset, to cover all real components of resettlement costs. It is realistic to expect it is possible to solve all other problems if the money and sound institutional and management arrangements are provided.

The resettlement planning programme of the Committee is admittedly in its early evolving stages, as is the case in the development of any new approach to solving difficult socio-economic problems. The current activities should lead to continuing and more advanced findings, as has been evidenced since the statement on principles and policies was adopted in 1968. Step by step, the new concepts which appear feasible can be tested and proven through demonstration in tributary project resettlements as is now being done in the first trials at Huey Luang, Nam Pong, and Nam Ngum.

### 3.2 Public health

Because water control projects elsewhere in tropical developing countries have led to major new problems with malaria and schistosomiasis, the Mekong Committee has directed primary attention to these two hazards. Attention has also been given to problems of environmental sanitation and of nutrition.

#### 3.2.1 Malaria

The malaria investigations sponsored by the Mekong Committee, dating back to 1967, have focussed on field observations at existing tributary projects where the new conditions have been in existence for a sufficient number of years to permit significant environmental changes. These studies have concerned all aspects of malaria investigations, including collection of epidemilogical data, but have focussed on the entomological aspects to determine the extent to which the creation of new reservoirs and of irrigation systems might establish habitats for malaria transmitting anophelenes, either imported species or adaptations of local species. Detailed entomological studies carried out at Nam Pong and Nam Phrom reservoirs in Thailand 1971-74 produced no evidence that Pa Mong would result in production of any such malaria hazards. However, it was also concluded that continuing surveillance of these tributary project areas or of similar areas should be carried out to detect any significant changes which might evolve over more prolonged periods.

Another aspect of the Mekong Committee's malaria investigations was formulation of economical control procedures to be excercised at the dam site during the period of construction, including DDT spraying of dwellings and other buildings, to prevent epidemic outbreaks of malaria such as occurred at Nam Ngum in the Lao PDR in 1969. Dam construction sites, being located in hilly areas, are usually in or on the fringes of malaria endemic areas; also, many of the workers may be from outside areas hence will have no local immunity, and may import new malaria strains.

### 3.2.2 Schistosomiasis

The existence of schistosomiasis in the Mekong river region between Khemmarat and Kratie prompted the Mekong Committee to sponsor detailed field investigations in this area during the period 1970-75. The programme identified the Mekong type of schistosomiasis as a distinct type, with the infectious agent (a parasitic worm) classified as *Schistosoma japonicum*, Mekong strain, and the intermediate host being the small snail, *Lithoglyphopsis aperta*. A distinct race of this snail species has also been found in the Nun river near its confluence with the Mekong. As far as is known, human schistosomiasis is transmitted only at two places along the Mekong, at Khong Island and at Kratie. The overall prevalence in these areas is believed to be about 15 per cent.

The studies concluded there was no evidence to indicate that the Pa Mong project would induce the spread of the disease beyond its present zone. It was found that the snail, which is the key link in transmission of the disease, reproduces in shallow zones along the river, and that control and perhaps eradication of the disease should be possible by a combination of measures including provision of specific access routes to the river (so that people would approach the river only at controlled locations and thus not be infested with the snails), elimination of snail habitats in the vicinity of these access places, including filling of shallow breeding places and other measures, and improved sanitation facilities in the community including water supply and water-seal type privies thus greatly reducing the chances of discharge of fecal materials containing the parasite into the river. A control project at Khong Island, employing these measures, together with continuing studies, has been formulated and approved.

### 3.2.3 Opportunity for health improvement

There are other communicable disease problems which might stem from Mekong river development, for example, increased incidence of dengue fever due to increased navigation along the river, and of liver flukes in the vicinity of the reservoir. Such possibilities appear minor, however, when assessed in terms of the general lack of adequate public health facilities and services in most of the lower basin's rural areas. The conditions of sanitation in most villages are much the same as in past eras, and so long as these conditions persist they will sustain high incidences for a prolific array of communicable diseases. The advent of Pa Mong, in particular of the pioneer farms being implemented to determine how to get the most out of systematic irrigated agriculture, including new types of communities suited to the new technological and socio-economic regimes, should enable demonstration of how to develop a new concept of sanitation of these villages which meets minimum acceptable standards within their economic means. The desired demonstration is to show how to proceed from the traditional

village setting, with its very limited facilities, in a step-by-step process evolving toward achievement of minimum international standards. The results from the pioneer farm prototypes would then tend to spread and be assimilated throughout the lower basin.

Much in the same manner, an entire new pattern of nutrition can be developed, again suited to the economic realities but nevertheless meeting minimum acceptable standards.

### 3.3 Socio-economics

One of the most sensitive environmental issues for major dam and reservoir projects, in addition to the resettlement problem (which is separately discussed), is whether the quality of life of the affected rural farming population will in fact be improved by the project as intended. A key aspect in making such an evaluation is to gain a competent picture of the existing socio-economics of the rural population, including attitudes towards the proposed Pa Mong project, to serve as a basis for project planning which is realistic in terms of the response of the affected population which can be expected when the project is built.

As a key aspect of the Mekong Committee's policy that the benefits of Pa Mong and other water resource projects in the lower basin will be used to improve the quality of life for the basin's inhabitants, the Pa Mong project plan provides for the irrigation ultimately of up to a million hectares in northeast Thailand and the Lao PDR, and also will greatly enhance irrigation potentials in the delta by maintaining an assured minimum dry season flow. This commitment will certainly have profound impacts on the socio-economics of the rural population, because irrigated agriculture, in contrast to traditional rainfed rice monocropping, requires the imposition of modern technology and related controls, including proper land preparation, choice of appropriate seed varieties, use of appropriate agricultural chemicals for fertilizer and weed and pest control, use of some mechanized equipment, storage facilities, access roads and transport, availability of adequate markets with fair prices, availability of timely and reasonable credit, and training of farmers through extension services and other means.

Assuming the irrigation system has been provided, to put this to good use will require transforming the attitudes, habits, customs, and social institutions to suit the new farming methods. This means drastic changes in the traditional socio-economic patterns including reorienting the processes of rural education to focus on rural agricultural needs, upgrading the agricultural extension services, creation of farmers cooperative organizations, provision by government of access roads and of facilities for transport, control of lending institutions to insure proper credit, management of land tenure so that the farmers will remain free owners and not become share croppers, and many other transformations.

The Mekong Committee studies show that the typical farm family in the Pa Mong service area has from 6 to 7 members, including 2 to 3 workers, has from 2 to 6 hectares of land, depends on rainfed rice monoculture, is tradition oriented in farming methods (still depends mostly on water buffalo power), consumes much of his own rice product (hence is not too concerned about the business aspects of selling the rest), depends for labour primarily on his own family (has few funds for hiring labor), realizes significant extra income from non-rice agricultural activities (gardening, fishing), seeks non-farming employment during the dry season to supplement his income, has an education level of about four years of schooling, often does not have formal legal title to the land he thinks he owns, sometimes has too little land due to fragmentation on inheritance, and has a otal income in cash and kind usually in the range of US$400-$850 per year, just enough to meet his immediate needs and can be regarded as "poor" compared to his urban compatriots.

The studies and surveys also show that the farmer in the projected irrigation areas will generally be interested in and willing to change his traditional methods and convert to irrigation and multiple cropping, primarily out of desire to increase his income. He must, however, receive assistance of the types noted above if he can be expected to do his best to be successful. In fact, the studies show that many existing irrigation projects in tributary areas have been something less than successful because the necessary guidance and assistance was not forthcoming, hence these irrigation projects as distinct from hydro-power projects, have as yet scarcely justified their costs judging from their productivity records.

Because of the admitted complexity of achieving such profound changes in socio-economic patterns on a massive basis, involving as it does the very basic philosophies of the governments in the lower basin and their social concepts, the Mekong Committee recognizes that the transformation must be achieved in progressive stages. A very key aspect of the entire programme is the planned system of pioneer agricultural farms, now being implemented, which will be a series of full-scale farming communities organized to practice and to coexist with the new irrigated agricultural methods at selected sites in the lower basin using irrigation water availabe from either tributary dam/reservoir projects or from the Mekong river. The total programme now includes 14 projects, with project populations in the 10,000 to 100,000 range. It has the objective of proving out the validity of the new concepts - to make sure they will result in higher production and in satisfaction both to the farmers and to the government concerned. The accumulated experience of these farms - which will be carefully monitored as to performance and results - should be sufficient to permit the governments to make strategy decisions on such basic questions as educational requirements, needs for community facilities, needs for new institutions, etc., and in turn to permit the Mekong Committee to prepare detailed plans for implementing the proposed wide-scale application of irrigated agriculture to be associated with Pa Mong.

To sum up, the types of irrigated farming communities contemplated will require extensive changes in the socio-economics of farmers accustomed to rainfed rice cropping, but in return the farmer will enjoy higher income and a significantly better quality of life. Moreover the farmers will tend to be drawn together into more closely-knit communities which should enhance national political stabilities. All this is a great expectation, and certainly transcends the actual results of irrigation projects in the region to date. The difference lies in the Mekong Committee's programme of studies which have carefully evaluated the key problem areas and have been working toward evolution of realistic solutions, using the pioneer farms to demonstrate, on a sizeable scale, how to proceed with progressive expansion of the programme to achieve the desired massive transformations covering large regions of the lower basin.

### 3.4 Archaeology

Pa Mong reservoir will flood several hundred kilometers of the Mekong valley containing remains from at least a half-dozen distinct regional traditions, thus obliterating evidence of cultural interaction and diffusion which almost certainly has taken place over the past ten millennia or more. However, little archological work had been done in the Pa Mong region, hence the Mekong Committee since 1969 has sponsored a series of investigations leading to a detailed field study of the Pa Mong reservoir site now underway. In addition, the Mekong Committee has been interested in archaeological findings as a means for assisting in the Committee's long-range development planning programme. This phase of archaeology, known as environmental archaeology, yields information on key environmental factors, such as changes in climate, rainfall, flooding patterns, and river courses which have influenced patterns of vegetation, soil formation, land use, settlement, and migrations of earlier civilizations, and which continue to influence human uses of the lands.

Interest in the archeological resources at Pa Mong has been stimulated by the recent startling archaeological discoveries in the adjacent regions of northeast Thailand. The site of Non Nok Tha, some 50 km south of Pa Mong reservoir, has provided evidence to indicate, as a working hypothesis, that bronze metallurgy may have existed in the area prior to 2,000 B.C., and domestic rice and animals prior to 3,500 B.C. The even more spectacular site of Ban Chiang, 10 km east of Na Klang, has yielded bronze tools and ornaments as early or earlier than those at Nong Nok Tha, as well as hundreds of the now-famous red-on-white vessels decorated with fine sophistication. These discoveries and other are replacing the view of mainland southeast Asia as a backwater of cultural development with one emphasizing its importance as a centre of progressive development.

While the final report on the current studies is not yet available, the tentative findings show the Pa Mong reservoir area appears to straddle at least one major cultural boundary, roughly

following the easternmost range of the Phetchabun mountains south from the Mekong, and roughly paralleling the present border between Loei and Udon provinces. East of this boundary there is little evidence of human habitation prior to the Fifth Century B.C., but subsequently at least three different cultural zones (defined primarily by ceramic styles) have emerged (eastern Udon, Sakon Nakhon, and Nakhon Phanom), including the very distinctive Ban Chiang pottery. The situation west of the boundary is very different, the evidence suggesting habitation by late Hoabinhian peoples. Generally the findings indicate a considerably closer tie between the reservoir area and the western Hoabinhian culture featuring an economy based on hunting perhaps supplemented by limited agriculture, with only a sparse population until early historic times when wet-rice growing people entered the valley. Although some changes in ceramic and architectural styles have since occurred, there has been little overall change in patterns of economy or settlement.

In summary, the Loei-Vientiane vicinity in which Pa Mong reservoir would lie and areas to the north exhibited an essentially nomadic Hoabinhian technology and economy until early historic times, whereas the Khorat plateau encouraged the early development of rice cultivation, cattle breeding, and sophisticated bronze technology. A promising theory to explain the difference is the contrast in vegetational cover between the dry Khorat plateau as opposed to the dense forests of the Loei-Phetchabun range. This may have encouraged a semi-sedentary type of settlement near the permanent swamps which in turn stimulated agricultural experimentation leading to reliance on rice cultivation and an economy based on rice, cattle, and bronze tools.

### 3.5 Aesthetics

As noted in the discussion on recreation (Section 2-8), lakes are relatively scarce in the lower Mekong basin and the Pa Mong reservoir should be an aesthetic "gem" which will no doubt form the basis for a new large-scale tourist activity. Proper controls will need to be exercised to maintain these aesthetic values, including waste control measures to protect the water, land, and air environment, controls on urban development (zoning, building permits), and control of tourists to protect natural beauty sites from damage due to uncontrolled access or unmanageable tourist volumes. A valuable device for helping maintain the natural environmental beauty is an Advisory Aesthetics Commission, to review all development proposals, such as are now in use in a number of countries for safeguarding environmental beauty. By the time Pa Mong is built, these goals should be readily achieveable through the experience in these types of control programmes in the riparian countries (especially Thailand).

Care must be exercised in planning the dam construction operation to avoid permanent impairment of environmental beauty. For example, borrow pits and quarries should when possible be located upstream in the area to be inundated, and if downstream sites must be used, these should be reforested to simulate natural conditions. Transmission lines should located to minimuze adverse effects on the natural scenery and to be as attractive in design as possible. Again, practicable techniques now being evolved and used to achieve these ends should be ready for application in the design of the Pa Mong system.

## 4. Ecological resources

The valuable biota of the Mekong system to be affected by Pa Mong include both aquatic animals and plants, especially fisheries, and terrestrial animals ("wildlife") and forests. The changes in ecology will generally be most evident in the immediate vicinity of the reservoir, except that there will be significant effects on fisheries all the way from Pa Mong to the ocean.

### 4.1 Fisheries

Of all the environmental biological resources of the lower basin, of important economic value to man, the fisheries will be the most profoundly affected by Pa Mong. With respect to the dam and reservoir project in itself, a very positive benefit will be the establishment of a massive new fishery in the new reservoir. The negative effects will include (a) serious impairment of the existing riverine fishery downstream from Pa Mong for an estimated 20 to 30 km, because of severe river stage fluctuations which will occur in this reach of the river, (b) reduction in the extent of annual inundation of lands due to flood overflows, hence a comparable reduction in the annual harvest of inundation fisheries, especially in Democratic Kampuchea and Viet-Nam, and (c) endangering of migratory fish species which may be blocked off from their vital behavorial patterns by Pa Mong dam.

Other possible impairments to fisheries which were considered included (d) possible reduction in marine fisheries dependent on nutrients discharged by the Mekong river system into the South China Sea, but there probably will be little significant change in this nutrient discharge; (e) possible impairment of the very valuable estuarine fisheries, including shellfish as well as finfish, due to changes in salinity patterns (or in patterns of hydrology) or in nutrients, but it was concluded that Pa Mong will not impair the existing salinity pattern and may possibly improve it (due to augmentation of dry season flows), that there will be no significant change in nutrient supply, and that the changes in hydrology will be well within the existing range of changes; (f) possible impairment of delta fisheries due to the toxic effects of greatly increased use of agricultural chemicals, including herbicides and pesticides, but it was concluded such usage will occur on a large scale regardless of Pa Mong hence the answer must lie in effective controls such as are now being developed in the industrialized nations, and (g) possible impairment of fisheries due to pollution from community wastes discharges, but again, these will be essentially independent of Pa Mong, and moreover the Mekong is still essentially unpolluted and the advent of Pa Mong could stimulate an effective regional water pollution control programme conceivably much faster than would otherwise tend to evolve.

To offset the possible adverse impact of Pa Mong on the existing fisheries, the Mekong Committee proposes a programme for systematic cultivation of fish including shellfish taking advantage of the year-around fresh water supply of good quality to be made available by Pa Mong, both in the irrigation service areas and in the delta.

Regarding the new fishery to be established in Pa Mong reservoir, the technology of managing such fisheries is only beginning to be developed hence it is difficult to estimate the maximum sustained yields of desirable species that might be expected with confidence within realistic concepts of management methods likely to be achieved. However, it appears that a level of production of at least 60 kg per year per hectare can be expected, and probably as much as twice this much as management technology steadily improves. Fish stocking will almost certainly be employed, using either native species which are capable of high growth rates and yields, or exotic species known to have these capabilities, depending upon the results of testing projects to be carried out well in advance of dam completion and reservoir filling. In addition to the fish technology involved, the reservoir management programme must include attention to socio-economic factors to prevent over-fishing and use of dangerous fishing methods, and to ensure realization of proper earnings and distribution of earnings through provision of arrangements for storage, transport, marketing, training, and credit.

Regarding inundated zone fisheries, these are an important food supply in the lower part of the lower basin (Democratic Kampuchea and Viet-Nam) where most of the inundation occurs. Due to the flood control to be achieved by Pa Mong, some reduction in inundation fisheries must be anticipated. The estimated reduction is 10 per cent, which is a sizeable loss considering the inundation fisheries are believed to make up at least half the total existing fish productivity in the lower basin, However, the same flood control which creates this loss by lessening land inundation also reclaims these lands for farming purposes, hence the total food production should be increased not lessened as a result of flood control. Also, the potentials for fish farming in both Democratic Kampuchea and Viet-Nam, either by use of fish farms or of fish growing cages floating in the river system, appear very promising.

A summary of the net change in fish production in metric tons/year for the two areas of most concern, the Pa Mong reservoir and irrigation service areas (northeast Thailand and Lao PDR) and the lowland/delta zone in Democratic Kampuchea and Viet-Nam, is roughly estimated as shown in the following tabulation.

Estimated changes in fisheries production due to Pa Mong

(tons/year)

| | Reservoir and Phase II Irrigation area | lowlands/delta | Total |
|---|---|---|---|
| Reservoir fishery | - 400 + 8,000 | | + 7,600 |
| Downstream disturbed zone | - 500 | | - 500 |
| Inundation losses | - 4,000 | - 16,000 | - 20,000 |
| Migrating fish losses | - 100 | - 100 | - 200 |
| Subtotal | + 3,000 | - 16,100 | - 13,100 |
| Fish farming | + 204,000 | + 100,000 | + 304,000 |
| Total | + 207,000 | + 83,900 | + 300,900 |

With respect to endangered species, the Mekong Committee programme, in the event Pa Mong moves ahead, will include research and development of facilities for developing practicable systems for artificial propagation of all migratory species found to be endangered and sufficiently valuable to merit saving, utilizing techniques developed in recent years which make artificial propagation both practical and economical. These same facilities can be used for testing native species for their suitability for reservoir stocking, and for use in fish farming in the delta (especially for the giant prawn, Macrobrachium rosenbergii). At this time it is believed some half-dozen valuable riverine fish species may be migratory and endangered, including the giant catfish, Pangasianodon gigas, but only by continuing studies can definitive conclusions be made and desirable control programmes formulated. The existing programme of fishery studies sponsored by the Mekong Committee is believed to be sufficient for the current feasibility stage of planning.

## 4.2 Aquatic biology

Other than for effects on fisheries, no significant deterioration in aquatic biological resources is expected to result from Pa Mong. There are questions about the role and probable fate of the extensive mangrove swamps along the delta coastal areas, but these should not be significantly affected by Pa Mong. Pa Mong will deliver a sizeable extra supply of fresh water to the delta in the dry season, and while much of this will be extracted for irrigation, a significant portion will flow to the sea, thus the present ecological patterns along the coastal swamps should be improved. However, they may be

significantly affected by the salinity intrusion control measures expected to be used as part of the eventual improved delta agricultural programme as proposed by the Dutch Delta Team. Hence effects on aquatic resources of value must be considered in the detailed design of such improvements.

A problem in aquatic biology which may be generated by the Pa Mong reservoir and irrigation complex is the explosive growth of aquatic weeds known to occur in reservoir/irrigation systems in tropical climates. However, experience in existing tributary projects in the lower basin has not shown any really serious problem. There may be explosive massive growths, but thus far this is a transitory phenomenon and the massive aspects of the growths do not persist. Nevertheless it is recognised this could be a serious factor in project operation and the programme of research proposals to be funded and carried out in the near future includes studies to try to develop practical and economical control measures suited to Southeast Asian conditions.

4.3 Wildlife

A number of significant direct impacts on wildlife are expected to result from Pa Mong. One is the drowning out of the reservoir area, hence decreasing the forested valley areas available to wildlife; however the flooded area will be only a small percentage of the total watershed area above Pa Mong (within the lower basin). Second, the drowned-out wildlife will be replaced by a very valuable waterfowl (mostly ducks) which are expected to be attracted to the reservoir and to propagate there in large numbers (especially with good management procedures). Third, the greatly increased fish production in the vicinity, from the new reservoir fishery, will lessen the need for securing protein by hunting of game animals. Also, the advent of year-around cropping will significantly decrease the available hunting time (most hunting now takes place in the dry season). However, the creation of the reservoir will facilitte access to forest areas now difficult to reach, and thus will accelerate hunting in those areas.

As noted previously, however (Section I), the wildlife picture in the lower basin is not favourable, regardless of whether water resource control projects such as Pa Mong are built. As noted previously (Section I), most of the natural wildlife has already gone from the lower basin except in the hill areas of Lao PDR and Thailand, parts of which are still rich in a great variety and diversity of wildlife, but persistent and accelerated encroachment seem destined to liquidate most of these species even in these areas unless unprecedented positive control measures are undertaken. With increasing human encroachment and destruction of the forests (Section 4.4), the only means for preserving any significant levels of the still existing wildlife will be in the establishment of national parks and reserves while this is still possible (such as Khao Yai in Thailand). A preliminary system

of some 29 reserves has been delineated by preliminary studies sponsored by the Mekong Committee, including existing reserves, which together are believed to represent the minimum system needed for the lower basin. These reserves would not only serve to preserve important species but would make these available for restocking purposes throughout the basin and for selected breeding for improving domestic animal productivity.

Assuming Pa Mong moves ahead, the Mekong Committee would undertake to assist the riparian countries to establish such a minimum system of national reserves by implementing the necessary new reserves or improving existing reserves, within the Pa Mong watershed. This could be a major step in achieving the basinwide plan. Thus the advent of Pa Mong, by speeding up action on the problem, could do much to help conserve wildlife in the lower basin.

4.4 Forests

The projected picture for the forest reserves in the Mekong watershed above Pa Mong (within the lower basin) is even more bleak than wildlife. While forest destruction was small prior to the second World War, since then, especially in the last two decades, there has been an exponential increas in the rate of forest destruction due mostly to human encroachment as manifested by slash and burn and other uncontrolled methods of cultivation and by uncontrolled fires. At this time, although precise data are lacking, it is believed that about 50 per cent of the forests in the Pa Mong watershed may already be lost. Little has been done about this, probably because the hill areas of the lower basin, being non-rice producing in a region where governments have traditionally been rice oriented, have never been brought under meaningful government control. It is difficult to see how this trend of destruction can be altered in time to save some of the forests, and the wildlife in them, except by establishment of national parks and reserves. One of the aims of the Mekong Committee is to assist in getting the facts on the extent of forest resources still remaining, to identify and evaluate them, and thus to permit delineation of forest areas which may possibly be saved by concentrated action programmes. It is hoped that the satellite imagery interpretation programme of the Mekong Secretariat may, with more study andexperimentation, be able to assist effectively in the forestry mapping programme.

In addition to their value as wildlife habitat, the forests serve as soil cover and thus contribute to conservation of both soils and surface water, and when the forests are burned or otherwise destroyed, the trees are replaced with "lesser" types of vegetative cover which may not be equally effective. In some parts of the world, removal of the forests has led to massive soil erosion (e.g., certain parts of the United States and of China), but the

evidence in the lower Mekong basin, primarily the absence of deep ravines, after removal of the forest, indicates the savannah type vegetation which tends to replace the forest may possibly serve with some effectiveness to conserve the soil and surface water. One of the planned projects of the Mekong Committee is for one or more pilot demonstrations in selected tributary watersheds where the effectiveness of forest versus savannah cover for conserving soil and water can be measured and compared. These demonstration projects would also have the objective of developing guidelines on practicable measures which might be undertaken by the riparian governments to control continuing forest destruction.

4.5 Reservoir ecology

As noted previously (Section 2.9), construction of Pa Mong will create a vast new reservoir contributing much to human uses and values, and which will also alter the ecology in the reservoir and vicinity.

In addition to problems already noted, impoundment in the reservoir will result in (a) some temporary changes in water quality, especially in the lower zones of the reservoir devoid of oxygen, but no significant problems nor alterations in water quality should result (there may be adverse effects on the immediate downstream fishery, but these will be essentially written off as part of project cost); (b) growth of water weeds, due to nutrient accumulation in the reservoir, especially the water hyacinth, which sometimes blooms profusely creating all sorts of impairments to navigation, fisheries, irrigation, etc., but such blooms are generally erratic and not a major problem (also, research is planned by the Mekong Committee to try to develop practicable measures for alleviating such problems under Southeast Asian conditions); (c) potential habitats for lake water-oriented disease vectors, including malaria anophelenes, schistosomiasis snail hosts, etc., but detailed studies thus far do not indicate Pa Mong will produce such after-effects; however, continuing monitoring will be needed, both of the vector species involved and checking of epidemiological data.

With respect to anticipated changes in water quality, it is expected Pa Mong reservoir will be thermally stratified, with a stable thermocline at depths between 6 to 15 m. Below the thermocline the water temperature will fall gradually until becoming stable at 35-40 m, where temperature will be close to that of the entering river water temperature during the coolest months. Assuming that, as planned, the reservoir releases are drawn from these lower depths, the outflow water temperature will be about the same as for without project conditions. Also, due to the anaerobic conditions in the lower layers

(hypolimnion), the withdrawn waters will have considerable concentrations of organic matter (which will be useful as food for downstream aquatic biota), and of hydrogen sulfide and also of dissolved iron and manganese (which will be dispersed in the immediate downstream riverine zone).

Because of the plentiful nutrients present in tropical riverine systems, leaching of nutrients from soils in the reservoir, and discharge of nutrients in watershed runoff into the reservoir, considerable eutrophication (algal blooms can be expected to occur in the reservoir (as well as the water weeds already noted), as has been the experience with existing tributary reservoirs. Such algal blooms can contribute as food for fisheries, and it is not believed they will be sufficiently severe to be damaging to fisheries, aesthetics, or other values except possibly to increase the costs of water treatment due to the extra processing which may be required. Nevertheless continuing monitoring will be required.

5. Physical resources

All of the changes in environmental values or uses described in Sections 2, 3 and 4 above stem from basic changes in the physical resources of the lower basin as affected by Pa Mong. The Pa Mong project is a physical system, the construction and operation of which will bring about profound changes in the hydrology of the Mekong river system and related characteristics including sedimentation and erosion, water quality and salinity, soils, and even seismic hazards and local climate.

5.1 Surface waters

The main function of Pa Mong will be to provide control of the flow of water in the Mekong mainstream, in order to achieve a variety of benefits especially power production, increased agricultural production (both in crops and fish) through provision of irrigation water throughout the year, and flood control.

The main effect of Pa Mong on utilization of the surface waters of the Mekong river will be to conserve flood waters now being wasted to the ocean for beneficial agricultural purposes including irrigation and farm fisheries plus supply of water through the irrigation system for community and industrial uses. The average beneficial use for these purposes, assuming Phase II in operation, will be approximately 13,900 million m3/year, or about 10.3 per cent of the annual inflow into Pa Mong reservoir, for without project conditions, of approximately 153,000 million m3/year. The present use of Mekong river water for these same purposes is estimated at not more than 0.6 per cent or 900 million m3/year. Hence the net gain for beneficial uses will be about 8.6 per cent of the total annual flow.

There will be additional gains from use of river water for irrigation below the Phase II service area, mainly in the delta. The increased usage of river water for irrigation made possible by Pa Mong may be of the same order of magnitude as for the Phase II service area, or of the order of 10,000 million m3/year or 6.5 per cent of the annual runoff now lost to the ocean. The precise amounts of flows to be made available to the delta during the dry season will depend on the selected Pa Mong high pool level, now being evaluated in the Pa Mong optimization and downstream effects study.

The Pa Mong project would also alter the losses of river water due to evaporation. The new reservoir of about 3,700 km2 (for 250 m MSL high pool level) will result in annual evaporation losses of about 1,600 million m3/year, but in a reduction in direct evaporation losses from areas inundated during the flood season estimated at roughly 2,400 million m3/year (from about 22,200 to about 19,800 million m3/year). Hence the net additional evaporation loss (for no useful purpose) due to Pa Mong would be about 2,200 million m3/year.

The net overall gain in beneficial uses due to Pa Mong could be roughly of the order of 20,000 million m3/year or about 13 per cent of the total annual flow now lost to the sea.

5.2 Groundwater

Groundwater is important in the lower Mekong basin because of the many uses dependent on water from wells and springs, and because discharge from groundwater aquifers comprises most of thd dry season base flow of streams. However, development of groundwater resources in the lower basin is still quite limited, amounting to only about one per cent of the total safe annual yield of the basin estimated at approximately 70 billion m3. Present use of groundwater is limited mainly to domestic and community water supply in rural and in a few urban areas. Groundwater has not been significantly used for irrigation primarily because in areas where groundwater is plentiful, surface water is also usually plentiful and of more reliable quality and usable at lower costs. For the reasons noted above groundwater exploration has been very limited in most parts of the lower basin, so that precise information is generally lacking on the extent and nature of groundwater resources in most areas. However a number of studies have been sponsored by the Mekong Committee to obtain information needed for evaluating and planning Pa Mong.

The main effects of Pa Mong on groundwater include:

(a) Increased charging of groundwater in the vicinity of the reservoir, which should generally improve the availability of water from local wells (water-logging is not expected

to any significant extent). Also, this extra storage will serve to increase the effective reservoir capacity.

(b) Change in the downstream pattern of groundwater inflow into and from the river, resulting in augmentation of the total dry season flow with significant benefit to agriculture and other beneficial river uses.

(c) Charging of groundwater in the service areas due to irrigation and seepage losses from canals. Where irrigation is for wet season crops there should be little change in present groundwater levels, but for year-around irrigation the average groundwater levels are expected to rise from 1 to 2 m in low-lying areas and floodplains to as much as 3 to 5 m in the uplands. Drainage facilities will be provided to maintain hydraulic and salt balances satisfactory for cropping.

Special works can be constructed in the saddle areas separating the Pa Mong reservoir from the Nam Lik and Nam Mong basins, to prevent excessive leakage which might occur through cavernous limestone formations in these saddle areas for pool levels of 240 m MSL or higher.

## 5.3 Water quality and salinity

As previously noted, the mineral quality of the Mekong river water (i.e. the dissolved constituents) is excellent with respect both in total salts and individual consituents, so that it is well suited to all intended uses including irrigation, fish farming, and urban and industrial uses. The total dissolved solids are low (about 140 mg/l), the chlorides low (about 9 mg/l), the hardness is low (about 75 mg/l as $CaCO_3$), the calcium carbonate balance is favourable for minimization of corrosion in urban and industrial use, the cation ratios (calcium, sodium, potassium), are favourable for irrigation without adverse effects on soils, and troublesome minor constituents such as dissolved iron and manganese are not significantly present. About the only treatment generally needed for municipal use will be rapid sand filtration to remove suspended matter, plus final effluent chlorination.

### 5.3.1 Irrigation return flows

One question on the effects of Pa Mong will be possible depreciation of river water quality by irrigation return flows. However, studies have shown, even with the total development of Phase II, the total volume of return flow discharged to the Mekong will amount to only 14 per cent of total irrigation use. For Stage I all of the return flow (0.2 per cent of total river flow) will be discharged to the Mekong, and 60 per cent for Stage II (the remainder will flow to the Nam Chi and Nam Mun rivers). The effect of these return flows on river water quality will be insignificantly during the rainy season and in the dry season will actually improve water quality.

### 5.3.2 Khorat salt formations

Another apprehension about Pa Mong is possible pickup of salt from year-around irrigation of the soils of the Khorat plateau which overlie extensive salt formations. However, studies show that the salt strata generally lie beneath the zone of groundwater affected by irrigation, hence no problem is anticipated. Also, in places where efflorescent salt films now form on the surface, in areas now used only for rain-fed crops, due to lack of good natural drainage, the drainage system to be provided will eliminate such formations.

### 5.3.3 Salinity intrusion in Mekong delta

With respect to salinity problems in the delta due to seawater intrusion, the present patterns of salinity distribution will not be affected by Pa Mong except favourably to the extent that the extra fresh water flow furnished in the dry season will be allowed to flow to the sea and thus tend to repel intrusion. It is estimated only a portion of the extra fresh water will be extracted by pumping for irrigation, hence there will be a beneficial change in the existing salinity pattern due to Pa Mong. Significant changes in this pattern could also result from construction of salinity intrusion barriers to be provided as part of the overall plan for development of agriculture in the delta, which would be implemented as a result of Pa Mong. Such works would change the existing patterns including salinity gradients, hence could affect fishery reproduction in this zone as well as other aquatic biological values including mangrove swamps. These effects will need to be evaluated in detail and taken into account as part of the evolving delta improvement plan.

### 5.3.4 Water pollution

Another apprehension about possible effects of Pa Mong is the potential for water pollution to result from intensified urban, industrial, and agricultural development. The Mekong is as yet still relatively unpolluted and it is desired to keep it that way, As previously noted, the anticipated population growth will require urban and industrial intensification, with or without Pa Mong, hence the answer will be in establishing an effective regional system of water pollution control which takes advantage of and puts into effective use the technology by which water pollution can be feasibly controlled. Such technology exists and is continually being further developed in the industrialised nations, hence the problem is how to provide the desired control mechanisms in the lower basin before the problem gets out of hand.

Experience elsewhere has shown that such controls must be implemented as part of the growth process, and paid for as part of the process, otherwise a huge backlog develops which is difficult to cure because of the large accumulation of unpaid

costs. Also, where more than one jurisdiction is involved, the problem of implementing the desired regional programme is compounded by institutional constraints. The Mekong Committee should be in a good position to assist the riparian countries to establish the necessary programme in a timely manner.

## 5.4 Sedimentation and erosion

Sedimentation and erosion, i.e. the picking up, transport, and deposition of silt, are important influences in the operation of most dam and reservoir projects. Generally, the problems of greatest concern are trapping of silt in the reservoir and erosion downstream. In the upper Mekong basin, the Mekong river generally flows through steep, rugged terrain at relatively high velocity, and as a result in capable of transporting sediment of considerable size. Proceeding into the lower basin the river enters a floodplain in the vicinity of Vientiane, and from this point to the China Sea, except for those reaches where falls and rapids occur, the slopes become flatter. Because of the resulting general decrease in velocity, the ability for transporting sediment diminishes, per unit of flow volume; however, the increased volume of flow is such that the total quantity of sediment transported downstream is increased.

With the construction of Pa Mong dam many factors comprising the natural regime of the river will be significantly changed, such as the flow discharge, sediment transport, and bed slope of the river channel. New cycles of sedimentation processes will become established in the river channel above and below the dam. Due to trapping of silt in the reservoir, the releases from the dam will be essentially sediment free and the discharge of this clarified water into the downstream river will create a powerful erosive agent which will cause scouring of the river bed. The extent of this degradation will depend primarily on the amount and pattern of the flow releases, and will have important effects on many downstream environmental values.

### 5.4.1 Downstream degradation

Completion and operation of Pa Mong will result in extensive degradation of the streambed and banks immediately downstream from the damsite, and concern about this degradation, especially in the vicinity of the city of Vientiane, has led to considerable speculation on consequences. The rate of degradation will depend on many factors but eventually a stable condition will be attained. The results of studies sponsored by the Mekong Committee indicate the existing river bed would be

scoured from 3 to 6 m for a prolonged distance below Pa Mong, up to 160 to 200 km. A comparison of the channel bed before and after degradation is shown in Figure 3 (Sedimentation Erosion Chapter III). The lateral degradation or widening has been estimated to reach ultimately about 100 m.

The degradation, both vertical and lateral, will occur slowly, over a prolonged period of time, but will be faster nearer the damsite. While precise predictions can hardly be made. perhaps one-half the anticipated total degradation will have taken place in about 100 years of time. Suitable protective measures can be devised to suit the specific needs.

5.4.2 Deposition in reservoir

With the construction of Pa Mong, sediment will be deposited at the head of each valley entering the reservoir. The total annual sediment inflow and deposition in the Mekong arm of the reservoir is estimated at 160 million tons. The accumulation of this sediment load is expected to reduce storage capacity of the reservoir from 98.3 billion $m^3$ at the beginning to about 91.9 billion $m^3$ without 50 years after closure. The sediment deposition in the reservoir is estimated to fill the reservoir from the original bed level of 155.4 m MSL to the level of about 178.3 m MSL within a 50 year period and to 185.8 m MSL in 100 years. The loss in reservoir capacity for a high pool level of 250 m MSL would be 6.7 and 13.4 per cent, respectively, for 50 and 100 years.

5.4.3 Changes in water surface profile

Lowering of the river surface profile downstream of Pa Mong, and elevation of the profile upstream, will bring additional environmental effects. Downstream the lowered profile will improve drainage of the surrounding areas but decrease the extent of areas which can be irrigated by gravity, and also lower flood inundation risks. Upstream, the backwater effects will reduce flow velocities in the river and tributaries over considerable reaches, resulting in aggregation in these reaches; there will be an increase in the extent of inundation, and less natural drainage. While these effects are minor in terms of overall project considerations, they will need to be taken into account in the detailed implementation of the project.

5.5 Soils

The soild resources of the lower Mekong basin will be significantly affected by the Pa Mong project. A primary concern is the suitability of the soils for irrigated agriculture in the proposed irrigation service areas. Other anticipated problems will result from trapping of silt and from reductions

in floods to be achieved by Pa Mong, which may affect delta soil fertility and deposition of silt on levee bank farming areas (chamkars) in the delta in Democratic Kampuchea. Also, water control made possible by Pa Mong will introduce opportunities for reclamation of soils not now suitable for agriculture.

### 5.5.1 Irrigation service areas

Detailed studies have been made of the soils in the proposed Pa Mong irrigation service areas, both for Stage One and Phase II, and geographical zones (river levees, active flood plains, old lowland surfaces, and uplands), and have established their general suitability for agricultural production under conditions of irrigation. Most of the soils are arable, and the nonarable soils, including saline soils, have been excluded from the planned development. With proper use of agricultural chemicals and water control including drainage, there should be no deterioration of soild structure and satisfactory salt balances can be maintained in the root zones. Also, availability of water control should permit reclamation of a significant portion of the saline soils.

One possible problem with paddy irrigation is the generation of toxic substances resulting from anaerobic conditions; however, it is expected, when the riceland soils are flooded, that toxic quantities of residual products will not accumulate.

The principle soils problem in irrigation of both rice and upland crops will be attaining and maintaining soil fertility. Rather high fertilizer inputs will be required for most of the project lands to attain the desired high yields. Many major and micronutrient elements will have to be applied as fertilizers or as liming materials in quantities equal to those removed by crops, plus amounts to compensate for leaching losses, fixation in non-available forms, and inefficient plant absorption.

### 5.5.2 Delta soil fertility

Because of apprehensions that trapping of silt by Pa Mong reservoir would result in lessening of silt deposition in the Mekong delta and hence in impairment in delta soil fertility, a study was made for evaluating this problem. Based on mineralogical, chemical, and physical analyses of sediments and soils in the Vietnamese delta, it was concluded that the annual deposition of sediment does not measurably increase the fertility of the delta soils and moreover that water control, not soil fertility, will be the dominant factor by which large increases in delta agricultural productivity can be realized.

Another interesting finding of the study was that soils near the river contained the same levels of mineral nutrients as soils away from the river.

5.5.3 Silt deposition on chamkars

Another apprehension in Democratic Kampuchea is concern that flood control by Pa Mong would lead to impairment of chamkar agriculture (on the back slopes of river levees) due to lessening of silt deposition by colmatage (channels carrying silt-laden flood waters to the chamkars for deposit of the silt at desired locations). A preliminary study of this problem, based on hydrographic analysis, showed there will be some reduction in the normal pattern of silt deposition, but that this can be largely overcome by use of efficient colmatage systems designed to deposit silt at desired places, rather than depending on natural creeks which are only partially effective, and also that another effect of Pa Mong flood control will be to extend the extent of usable chamkar areas by virtually doubling these areas.

5.5.4 Delta soil reclamation

The availability of water control made possible by Pa Mong should make it feasible to develop programmes for reclamation of extensive areas of nonarable soils in the Mekong delta including saline soils, heavy clay soils, and perhaps even acid sulfate soils. The techniques for accomplishing this have yet to be developed, and can best be done through experimental testing to be carried out in future phases of Pa Mong planning.

5.6 Geology and seismology

Numerous investigations were sponsored by the Mekong Committee to obtain subsurface and surface information on foundation and construction materials for use in the preparation of preliminary designs and cost estimates for engineering structures. These studies were evaluated to develop conclusions relating to the integrity of the various structural components of the project, with respect to water holding capacities, structural soundness, and construction problems, and on the probable effects of geology and seismology on design, construction, and operation of the Pa Mong project and on desirable precautionary measures.

Most of the proposed engineering structures of the Pa Mong project, excepting the Nam Lik and Nam Mong saddle structures, are in the Khorat group of formations. Fault zones have been located at the Pa Mong site; however, seismic history in the vicinity of the Pa Mong damsite indicates the proposed structures are located in an area that is relatively

free from seismic hazards. The preliminary engineering studies indicate the geological formations are suited to the proposed dam and powerhouse and related structures.

The saddles between the Pa Mong reservoir and the Nam Mong and Nam Lik basins pose special problems of leakage due to the cavernous limestone formations in those areas; however the studies indicate all such leakage can be controlled within acceptable limits using a variety of engineering methods.

There will be significant landslide hazards along the eastern and southern rims of Pa Mong reservoir. Corrective control measures should be used in the landslide-prone areas including (a) erosion control such as protective cover to protect the banks from wave action, and (b) drainage systems to maintain slope stability where channels are excavated.

Regarding earthquake hazards, there is only one major fault, referred to as the Ban Ang fault, located in the dam foundation area, which is believed to be old and inactive. The general continuity of surface outcrops shows little evidence of any significant displacement. Records or traditions of earthquakes indicate that earthquakes in the region have originated at considerable distances from the project area. However, establishment of a seismic station in the vicinity of Pa Mong is proposed for indicating rock formation behavior and response under the huge body of water to be stored. This seismic station would be integrated as part of the worldwide system and, together with the two existing stations in Thailand at Chiang Mai and Songkhla, should provide sufficient information to guide design of the Pa Mong project.

5.7 Climate

The climate of the lower Mekong basin, including the Pa Mong project area, is tropical, with minimum temperatures almost always considerably above freezing. The climate is influenced primarily by the two seasonal monsoons and the intertropical convergent zone, and to a lesser extent, by tropical cyclones and other tropical disturbances. The monsoons have been designated as the southwest monsoon according to the movement of airmasses through the basin.

The southwest monsoon season, which is the rainy season, normally occurs in the lower basin approximately from May through October. It is a period of frequent and heavy rainfall, high humidities, maximum cloudiness, and tropical temperatures. The heaviest rainfall generally occurs in the months of August and September. In contrast, the northeast monsoon or the winter season is characterized by relatively little rainfall, lower humidities, least cloudiness, and lowest temperatures over most of the basin. It normally starts from October and prevails until February.

The transition period follows the northeast monsoon when the polar Pacific airmass, modified by tropical heat, moves into the basin from the east and southeast. This results

in relatively high temperatures, low humidity, comparatively higher rainfall, and cloudiness from February to May. This period is called the summer season or the hot season.

A short period of drought on one to two weeks is normally experienced during June and July, due to the influence of anticyclonic circulation of the airmasses. After the period of dought, rainfall becomesmore frequent including heavy downpours resulting from the tropical storms which enter the basin.

With respect to the anticipated impact of Pa Mong, it is concluded that creation of the reservoir and irrigation system should have no significant effects on rainfall, sunshine, and storms in the vicinity or region. There will likely be some local effects upon evaporation and evapo-transpiration, air quality, humidity, temperatures, and wind speed at certain places in or close to the project area. However, these effects are expected to be diluted or neutralized by the wind currents, surrounding environments, and other factors common to the area.

6. Summary

Table 1 is a summarized presentation of the anticipated overall net effects of Pa Mong on the various environmental values of the lower Mekong basin, based on the previously discussed evaluations. The table uses a system for grading or rating the overall effect, from no effect to three levels of improvement or degradation (slight, significant, and large).

The table is significant in showing that Pa Mong, with little if any depreciation of the basic physical resources of the region, and also (excepting for fish) with little change in basic ecological values (biota), will nevertheless achieve large improvements in both tangible and intangible human uses and values.

7. Conclusions

The Mekong Committee's programme for evaluating environmental effects of the proposed Pa Mong project, and for providing for these in project planning, carried out mostly over the past decade, is believed to represent the most detailed evaluation yet made for a major water control project in a developing region, for the feasibility stage of planning. This has been possible because of the international and regional aspects of the project, together with its sheer magnitude, have focused attention on the need to consider all environmental values and to make provision for preserving them in planning the project, and also because worldwide activity in assessing environmental impacts, mostly in the industrialized countries, has developed valuable findings for guiding the Mekong Committee's planning for Pa Mong.

Basic to the Mekong Committee's programme of environmental assessment for the Pa Mong project (and other proposed main-stream projects) has been the establishment of a continuing and progressively expanding programme for collection and collation of sufficient basic data to permit competent preliminary planning. These include (1) a fundamental hydrologic data programme (including stream gauging, sediment loads, salinity, and water quality); (2) an equally fundamental data base for agricultural planning (land uses and soil surface cover), including utilization of satellite imagery, and (3) similarly, basic information on the fundamental socio-economics of the region. In addition, a series of mathematical models have been evolved for utilizing the accumulated data in a systematic and comprehensive manner.

The Pa Mong project represents the rare occurrence of a potential major dam and reservoir project which could be a "gold mine" for the future development of the lower Mekong basin, in that it could generate vast benefits to the people of the lower basin without significant deterioration of environmental values and with positive enhancement of many of these values. Because the project can produce huge amounts of power, and because the market for using it is assured, the power aspects alone will finance the project. As is well known, electric power availability and use on a per capita basis is a valuable parameter of economic development potential, because without sufficient electric power, urbanization and industrialization can scarcely proceed. Even so, the irrigation potentials of the project should, in the long run, make an even greater contribution to the regional economy and welfare by making it possible to produce enough food (in rice, upland crops and farm fisheries) to sustain the rapidly growing population just long enough until family planning can become effective. Also, the flood control to be achieved by Pa Mong would further enhance agricultural productivity as well as very materially reducing periodic flood damages. Moreover, there will be many other benefits in achieving valuable new potentials in recreation, navigation, water supply for urbanization and industrialization, and stimulations for development of the latent but very sizeable potentials of the lower basin in agro-industries and in mineral resources.

Against these remarkable gains there will be some negative effects which will tend to deteriorate existing environmental values but these all appear to be controllable and manageable, or else are minor, or else will occur regardless of whether Pa Mong is built. The resettlement issue is certainly formidable but it should be possible to cope with it effectively through diligent attention and especially by assigning the funds for family rehabilitation as well as for property compensation as an integral part of the project costs. No particular public health problems are envisioned, i.e., there is little if any evidence that creation of Pa Mong will result in introduction of new water-oriented diseases such as malaria and schistosomiasis, although continuing

monitoring will be needed. There are no known invaluable archaeological remains which will be lost by inundation, nor should the project in itself result in depreciation of environmental aesthetic values assuming competent attention to this factor in project design and implementation.

There will be a significant loss in inundation fisheries but this can be more than made up for by the new fisheries to result from impoundment and from wide-scale application of year-around fish farming in the lower basin below Pa Mong made possible by the availability of a steady supply of fresh water either from the irrigation distribution system or in the Mekong itself. Also, some valuable migratory fish species of the Mekong may be endangered and, if so, provision will be made to sustain their existing productivity levels or to extend them through artificial hatchery technology. In addition to fishes (including shellfish), other aquatic biota of value may be affected, e.g., the mangrove swamps and other estuarine zone values so important for aquatic life reproduction; however, studies have indicated Pa Mong will hardly affect these estuarine values and to the extent there are effects these may be more positive than negative. Similarly, no adverse impact on marine fisheries is anticipated.

Another apprehension about Pa Mong is that downstream erosion will severely interfere with existing development and facilities, especially the city of Vientiane. There will be considerable degradation, until a new equilibrium is achieved, but the processes will occur over periods of decades allowing ample time for management and control.

There is considerable apprehension also that the advent of Pa Mong will speed up the deterioration of other important ecological resources of the lower basin, namely the forests and the wildlife. On reflection, however, it is realized that the threat to these values is not from water resource control projects like Pa Mong but from the unrelenting expansion of population and technology. Together these trends appear to present a dim outlook for the future of the ecological resources unless the riparian governments can be prompted to cooperate in a positive programme for salvaging these values to the extent feasible, for example, through establishment of national parks and wildlife reserves and through reforestation. It is believed the advent of Pa Mong, far from ruining these values, could contribute much to speeding up the needed corrective measures in that the international implications of the project would be conducive to some level of regional attention and management. For the same reasons a much better region-wide programme of control of water pollution (and other types of pollution) could probably be achieved.

The salient finding of the environmental review is that the population growth bound to occur, until family planning becomes effective, will present formidable problems which can be solved only by intensified agriculture and by intensified urbanization and industrialization. Pa Mong could be a key element in helping meet the needs representing a reasonable minimum quality of life. Furthermore, with respect to pool levels, it is clear that the higher pool levels, within physical and financial constraints, tend to maximize environmental and ecological benefits.

## TABLE 1

## SUMMARY OF ENVIRONMENTAL EFFECTS OF PA MONG

| ENVIRONMENTAL RESOURCE OR VALUE | NET EFFECT | | | | | | |
|---|---|---|---|---|---|---|---|
| | LARGE LOSS | SMALL LOSS | SMALL LOSS | NO SIGNIFICANT CHANGE | SMALL GAIN | SIGNIFICANT GAIN | LARGE GAIN |
| **HUMAN USES** | | | | | | | |
| FOOD (IRRIGATION AND AGRICULTURE) | | | | | | | ● |
| RICE | | | | | | | ● |
| UPLAND CROPS | | | | | | | ● |
| FISHERIES | | | | | | ● | |
| POWER | | | | | | | ● |
| FLOOD CONTROL | | | | | | | ● |
| URBAN WATER SUPPLY | | | | | | | ● |
| AGRO - INDUSTRIES | | | | | | ● | |
| MINERAL DEVELOPMENT | | | | | | ● | |
| NAVIGATION | | | | | | ● | |
| RECREATION | | | | | | ● | |
| **HUMAN VALUES** | | | | | | | |
| RESETTLEMENT | | | | ● | | | |
| PUBLIC HEALTH | | | | | | ● | |
| SOCIO - ECONOMICS | | | | | | ● | |
| ARCHAEOLOGY | | | | ● | | | |
| AESTHETICS | | | | | ● | | |
| **ECOLOGICAL RESOURCES** | | | | | | | |
| FISHERIES | | | | | | ● | |
| RIVERINE / INUNDATION | | ● | | | | | |
| MIGRATORY | | | ● | | | | |
| ESTUARINE / MARINE | | | | ● | | | |
| LACUSTRINE (LAKES/PONDS) | | | | | | | ● |
| AQUATIC BIOLOGY | | | | ● | | | |
| WILDLIFE | | | ● | | | | |
| FORESTS | | | ● | | | | |
| **PHYSICAL RESOURCES** | | | | | | | |
| SURFACE WATER | | | | ● | | | |
| GROUND WATER | | | | ● | | | |
| SEDIMENTS / EROSION | | | ● | | | | |
| WATER QUALITY | | | | ● | | | |
| SALINITY | | | | ● | | | |
| SOILS | | | | ● | | | |
| GEOLOGY / SEISMOLOGY | | | | ● | | | |
| CLIMATE | | | | ● | | | |

ANNEX A

# REVIEW OF ENVIRONMENTAL IMPACT STATEMENTS FOR MAJOR WATER RESOURCE DEVELOPMENT PROJECTS IN THE UNITED STATES

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Tables

Table 1: Summary of proposed actions and project functions

Table 2: Summary of environmental effects of twenty representative dam/reservoir projects in United States

# REVIEW OF ENVIRONMENTAL IMPACT STATEMENTS FOR MAJOR WATER RESOURCE DEVELOPMENT PROJECTS IN THE UNITED STATES

## 1. Introduction

### 1.1 Purpose of review

This report presents a review of environmental impact statements for major water resource development projects in the United States. Most of these projects involve construction of multipurpose reservoirs.

The purpose of preparing each environmental impact statement is to maintain, as much as possible, the quality of environment, at the same time permitting compatible environmental development to meet needs of a growing population and expanding economy of each project area. One of the chief mechanisms for meeting those goals is the careful preassessment of environmental damage likely to occur from each major environmental modification project. The U.S. Environmental Protection Agency (EPA) states that the Agency's success in maintaining environmental quality rests upon the thoroughness of the impact statements which are submitted for review, the Agency's expertise in maintaining environmental quality, and the ability to require the environmental modifier to abide by the Agency's findings (Ref. 21).

The purpose of this review are to study environmental impacts considered in each statement and to identify those environmental parameters which are extensively studied and believed to cause important benefits to the project or to be severely affected by the project. This information can be used as a guideline in preparation of environmental assessments in other areas including the lower Mekong basin.

### 1.2 Summary of the selected projects

A total of 20 environmental impact statements were selected for this review. All of these projects are related to construction of dams and reservoirs as the major project features. Table 1 summarizes the proposed projects and project functions mentioned in these statements. As far as environmental effects are concerned, important parameters of a project include total area to be inundated, total storage capacity of a reservoir, and shoreline created by the impoundment. Other parameters, such as the length of the dam and embankment, material of construction, and total area acquired for the project are also important, but they are not listed in the table. Of the 20 selected projects, the reservoir areas range from as small as 56 acres (140 ha) to more than 35,000 acres (87,500 ha). The storage capacities range from 1,600 acre-feet (1.97 million cubic meters) to more than 2 million acre-feet (2,467 million cubic meters). The minimum reservoir shoreline is 13 miles and the maximum is 400 miles.

Table 1 also illustrates that most of the selected projects are multipurpose in nature. The major purposes include flood control, water supply, irrigation, power generation, recreation, and enhance fish and wildlife. Of the 20 projects, 14 are proposed for recreation, 14 for fish and wildlife enhancement, 10 for flood protection and water supply, 9 for power generation, and 5 for irrigation.

## 2. Physical environmental effects

### 2.1 Water resources

#### 2.1.1 Water quality

(a) Impacts during construction: A major source of water pollution at a project area is construction-generated sediment which is transported by water, thereby creating increased turbidity in the receiving body of water. According to this review, increased turbidity levels can be caused by construction involving earthwork, dredging of dam foundation, erosion of river banks, movement of heavy equipment in or near water, scarification of the area, and excavation and stripping of unusable materials. The extent of increased turbidity depends on construction practice and amounts of rainfall and runoff.

Major adverse effects of increased turbidity are reduced suitability of water downstream as sources of water supply, reduced capacity of stream due to sediment deposition (Ref. 15, 17, 20), and reduced photosynthetic processes in the stream (Ref. 15, 16).

To mitigate problems caused by increased turbidity due to construction, the following measures are recommended: scheduling excavation and dirt-moving phases of construction for periods when there is no flow (Ref. 20), effective erosion control measures (Ref. 4, 11, 15, 17), and provision of settling basins (Ref. 1, 20).

(b) Impact due to operation of project

(1) DO and BOD: Impoundment will have direct and indirect effects on BOD and DO of the impounded water. After several weeks of holding water in the reservoir, inundation of standing trees and other organic materials will cause a significant increase in the BOD level of the water as these materials are decomposed. Where natural aeration of water is limited, exertion of BOD will gradually lower the content of DO in the water (Ref. 5, 7, 8, 9). In cases where eutrophication occurs, dead algae will sink to the bottom where their decomposition will subsequently result in DO reduction in the lower layers or hypolimnion. Releases from this depth of water will be low in DO content.

Depressed DO content will have some adverse impacts on aquatic life downstream from the project. However, the effects are considered short-term, lasting about 4-5 years after initial filling of the reservoir (Ref. 8, 9). The recommended measure to mitigate the impact is the provision of multi-level outlet works (Ref. 1, 15).

(2) Thermal stratification: Thermal stratification occurs when there is a stable temperature gradient in different layers of water in an impoundment. This results in poor mixing of the water throughout the depth of the water, thus causing different quality of waters in various layers. The DO in the hypolimnion will be lower than for higher levels.

Of the 20 statements reviewed, only six mention the possibility of thermal stratification. For most of these cases, stratification is expected to occur in summer (Ref. 5, 7, 8, 9, 15). The thermal stratification, in one case, is expected to be induced by surface discharge of heated effluent from a power plant (Ref. 4). The effects of thermal stratification are expected to be temporary and, when turnover occurs, more uniform water quality will result. Multiple intake levels of the dam can be used to mitigate problems of stratification.

(3) Nutrients and eutrophication: Nutrients, primarily nitrogen and phosphorus, include those which are present in the reservoir area derived from the nutrients in the inflow including runoff into the reservoir, those present in the effluent of sewage treatment plants discharged to the reservoir, and those released from soil and through decomposition of inundated materials. These nutrients can be utilized by higher plants and by algae. High concentration of nutrients can cause eutrophication or extensive algal blooms. Possible impacts of eutrophication are: impairing attractiveness for recreational use of lakes, depreciating the quality of the impounded water for municipal and industrial use, and lowering DO content during summer in the reservoir bottom due to decay of algae (Ref. 1).

Of the 20 statements reviewed, four indicate little to moderate chances of eutrophication due to nutrients in the waters (Ref. 1, 5, 6, 7). Only one statement expects extensive eutrophication which may cause diurnal fluctuations of DO level in the reservoir (Ref. 15). The impact of eutrophication can also be reduced by provision of multi-level discharge system (Ref. 1, 15).

(4) Effects of impoundment on water quality: A reservoir will act as a large settling basin for silt particles. Sediment entrapment will result in clearer effluent water than the streamflow under the without-project

conditions (Ref. 5, 10, 11, 19, 20). In general, water quality will also improve as the consequence of sediment entrapment. Pesticides present in the inflow may also adhere to the trapped sediments, thus being reduced in the outflow (Ref. 11). Reduction of sediment will enhance photosynthetic activities related to production of phytoplankton; this will increase productivity of the water. However, nutrients can also be trapped in the reservoir (Ref. 20).

Changes in chemical characteristics may include a decrease of bicarbonate content through deposition and dillution of pollution concentration, especially during periods of low flows (Ref. 12).

The reservoirs are expected to be excellent barriers between upstream sources of bacteria pollution and downstream points of water use. In one case, it is expected that during recreation seasons, concentration of fecal coliform downstream will be less than 10 per cent of the present concentration in the downstream reaches (Ref. 5).

Impoundment is also believed to improve temperatures of the waters. It will stabilize extreme water fluctuations and lower the water temperature in the lake and in a short reach of the river immediately below the dam (Ref. 12, 15). Effects of tempering extremes of water temperatures will be more pronounced during the period of low flow. Tempering effects will be beneficial to most organisms (Ref. 15), while cooler water will provide favourable habitat for trout fishery in the reservoir (Ref. 12, 16).

Evaporation of water in the reservoir may cause a substantial increase in the content of total dissolved solids in the outflow. In one case the increase is as high as 25 ppm (Ref. 20). The effect of increased solids content is the decrease of suitability of water for irrigation, domestic, and industrial uses.

(c) Water quality downstream

(1) Nitrogen supersaturation: Nitrogen supersaturation is a phenomenon related to impoundment projects. The phenomenon has been known to occur both in impounded waters and in unimpounded natural streams where gas concentration is in excess of 100 per cent. The adverse effect on fish is the gas bubble diseases resulting from long exposure to water supersaturated with dissolved nitrogen exceeding the tolerable level of the fish (Ref. 22). Only two statements mention the remote possibility of nitrogen supersaturation (Ref. 10, 12).

(2) Other effects: For certain projects which involve diversion of water from the reservoir out of the project area, the diversion will have effect on the salinity and nutrient contents of water downstream. The reduced streamflow may cause higher dissolved solids in the downstream stretches of the river. The damage in the area below the damsite that would result from increased salinity would occur to irrigation, municipal and industrial uses (Ref. 13, 16).

Reduced freshwater inflow to an estuary will tend to increase the salinity content of the estuarine water. This, in turn, could result in lowered total productivity of that water (Ref. 15).

Reduction of downstream flow can cause a reduction in the amount of nutrients normally present under the without-project conditions. Some nutrients are also trapped with the sediment deposits in the reservoir (Ref. 11, 15, 20). Reduced nutrient availability will result in a lower productivity of the area. Controlled releases through multi-level outlet works can mitigate the problem, but would not help solve problems caused by water diversion (Ref. 15).

## 2.2 Land resources

### 2.2.1 Land use pattern

Acquisition of land for project purposes will result in change of the land use pattern in the affected area. The impacts can be categorized as minor (Ref. 1, 6, 7, 19), moderate (Ref. 4, 5 , 8, 9, 11, 16, 17, 20), and severe (Ref. 10, 13).

Normally, land acquisition will result in conversion of land ownership from private to public. Land uses can be changed from mostly agriculture pursuits, including cropland, woodland, vegetation, livestock, wildlife, and waterfowl habitats, to those for reservoir and project facilities, road and utility relocation public use areas, recreation, and wildlife management. Land may later be used for industrial and rural development. Possible impacts of change in land use pattern are reductions of agricultural production and losses of wildlife habitat in the area. In addition, there may be a continuing conversion of agricultural land use to urban use as population increases. These impacts can be offset by benefits derived from activities related to the project.

### 2.2.2 Erosion

During construction periods, erosion can be caused by clearing, earthmoving, relocation of facilities, scarification, landscaping, and general site clean-up operations (Ref. 8, 10, 13, 18). After construction, denuded areas such

as river banks, leftover borrow pits, and other exposed construction sites, will be subject to erosion when runoff passes the areas (Ref. 4, 6, 8, 10, 20). Release of water from the reservoir over the spillway will tend to erode the streambed. Land erosion is dependent on the characteristics of the soil, climatological conditions, and topography of the site.

Attendant effects of erosion are losses of fertile topsoil, increased turbidity in the river, and deposition of the sediment in the streambed. After the reservoir fills, erosion damage in the area below the maximum pool elevation will be much reduced since the area will be inundated (Ref. 16, 18, 20).

Several measures are recommended for mitigating soil erosion. Upon completion of construction, borrow areas and exposed cut and fill slopes should be graded, sloped to drain, and seeded with proper grass (Ref. 8, 10, 13, 18). Application of chemical adhesives to the disturbed surface is also recommended (Ref. 8, 13). Where possible, the topsoil should be removed, stored and replaced to provide good soil base for restoration of vegetative cover (Ref. 13).

## 2.3 Air pollution

The major air quality impacts associated with impoundment development occur as a result of construction operations. One of the noticeable types of air pollution at construction sites is particulate matter such as dust and smoke (Ref. 1, 3, 6, 11, 13, 18). Construction activities which may result in dust pollution include clearing and grubbing, excavation, blasting, cement production, and movement of heavy equipment.

Air-borne particulate matter can be produced during the construction stages by emissions from heavy equipment (Ref. 1, 3, 13). This type of air pollution may result from motor vehicles coming to the recreation areas after completion of construction. Another source of particulate matter and other air pollution is open burning of wood waste from clearing and grubbing operations (Ref. 1, 4, 6, 17).

In most cases, effects of air pollution are considered temporary and insignificant. Dust problems are suggested to be minimized by proper construction practice, frequent sprinkling of roads, parking lots, and construction staging areas (Ref. 4, 13). Implementation and reinforcement of Sta e and Federal laws is believed to minimize motor vehicle emissions. Open burning should be allowed only when it is properly controlled (Ref. 4, 6, 1?).

## 2.4 Noise pollution

Noise pollution generally occurs during the construction periods by on-site and on-road hauling operations and construction of project facilities (Ref. 1, 3, 4, 13).

Increased noise levels may also be caused by rock blasting. In addition, noise pollution can be created by recreational facilities (Ref. 11, 12, 15, 17). Normally, noise disturbance due to construction will be most severe during the night time. Noise pollution impacts are generally considered short-term. One adverse effect of increased noise level caused by rock blasting and heavy equipment is the disturbance to wildlife in the vicinity of construction sites. This may result in severe reductions of wildlife population in those areas (Ref. 4, 13, 18).

## 3. Ecological effects

### 3.1 Aquatic biology

#### 3.1.1 Fish

(a) Effects of inundation of upstream river section: Impoundment will result in inundation of certain stretches of rivers upstream from the damsite. This will bring about a change from free-flowing, relatively shallow, riverine conditions, which are suitable for stream fish and aquatic insects, to deeper and slower moving water, which are more appropriate for lake and deeper species of game fish, rough fish, and forage fish (Ref. 2, 4, 5, 6, 7, 8, 9, 10, 13, 14, 15, 16, 17, 19, 20). Fish that are adapted to the reservoir conditions will be substituted for some fish species that are currently adapted to stream conditions. Thus, inundation of the upstream section of river will cause a reduction in stream fish population and an increase of reservoir population.

(b) Effects of impoundment: After initial impoundment the productivity of the impounded water will increase sharply due to released food from decomposed inundated organic matter and due to increased nutrient levels in the reservoir as the consequence of decomposition or releases from inundated soil (Ref. 6, 7, 20). In addition, deeper and slower moving water of the reservoir will provide more favourable habitats for sport fish (Ref. 4, 11, 15, 19). The number and weight of these fish should greatly increase during the first year of inundation and, with proper fishery management, game species are expected to be able to sustain an adequate population, reaching a peak productivity 3 to 10 years after initial impoundment (Ref. 12, 15, 16). After initial periods of high fertility, fast growth rates, and good population, game fish species have to complete for food and cover with the native rough fish species. During this period rough species may become dominant and sport fishing in the reservoir may decline (Ref. 15, 16). However, the total harvest of fish should remain substantially higher than it was in the river before the impoundment (Ref. 4, 6, 7).

(c) Effects of drawdown: Drawdown caused by operation of a reservoir can affect standing fish crops and spawning grounds for resident and migratory fish. The effect can be adverse, neutral, or slightly beneficial (Ref. 1, 8). Occasional extreme seasonal fluctuations of water levels may have a detrimental effect on fishery by hindering fish reproduction, thus causing continued need for stocking operations (Ref. 12, 13). Extreme drawdown can curtail productivity of the trout fishery in the reservoirs by creating undesirable changes in food production and water temperatures (Ref. 16). Control or manipulation of pool levels is expected to enhance spawning and hatching during certain periods of the year and can retard undesirable species (Ref. 16, 17).

(d) Effects of blockage and physical damages: Dams usually block normal passage of fish up and down the river stretches. This could reduce or eliminate stable spawning areas of anadromous fish (those ascending rivers from the sea for breeding) (Ref. 1, 3, 7, 10, 14). These fish species would be reduced because there is no suitable spawning area or because fish spawn in unsuitable areas where eggs would not incubate (Ref. 3, 10). To mitigate the problems, fish passage facilities may be installed. Stocking programmes in the reservoir area may also be desirable (Ref. 1, 3, 7).

Physical damages of fish can be expected in the reservoir where hydroelectric power is generated. Injuries and mortality of juvenile and adult fish will be more severe when the water passes through turbines than when it passes over a spillway (Ref. 3, 16). Similar damages can be caused by the pump turbines used in pump storage projects (Ref. 4).

(e) Downstream fishery: The quality of water released from a reservoir is important to the fishery downstream from the damsite. Releases which are relatively sediment-free will enhance productivity of the stream, thus becoming beneficial to the downstream sport fishery (Ref. 12, 15, 17). Normally the quality of released water is expected to be better than the inflowing water. Tempering of extremely high temperatures can significantly lower temperatures in the released water (Ref. 10, 12, 19). In addition, controlled release will result in more uniform downstream flow, thus decreasing high flows and increasing low flows (Ref. 11, 16, 19). All of these conditions will provide an aquatic habitat more conductive to increased production of aquatic organisms, and an increase in carrying capacity of the stream for fish will result, especially during warmer periods of the year and during periods of low flows.

(f) Estuarine fishery: The estuarine fishery can be effected by operation of the project. Reduction of freshwater inflow to the estuary can increase salinity gradient levels (Ref. 13, 15, 16), reduce flushing action, and reduce nutrients to the estuarine area (Ref. 11, 15, 20). Changes in salinity level and decreased productivity due to decreased nutrient availability will result in a reduction of commercial and sport fisheries, especially during periods of severe reduction in freshwater inflows.

(g) Fishery management: Proper fishery management is essential if fishery production in an area is to be maintained. Monitoring programmes on key fish species both prior and after construction are important in evaluating effects of the project on fish and in evaluation of changes in ecological conditions compared to baseline conditions (Ref. 4, 15, 17). In cases where the project has significant adverse effects on fisheries, stocking programmes may be used to establish self-sustaining fisheries in the reservoirs (Ref. 10, 14, 15, 17, 30). Success of stocking is normally governed by the amount of available water in the reservoir at the time of stocking.

### 3.1.2 Other aquatic life

Following the construction of a reservoir, the aquatic environment is expected to undergo progressive changes until an equilibrium is reached. There would be an initial surge in biological productivity in the reservoir due to release of nutrients through decomposition of submerged vegetation. The increase in nutrient levels will be reflected by increases in growth rates and abundance of species of micro- and macro-fauna. After a period of about 10-15 years, production is expected to stabilize or decline (Ref. 11, 13, 15, 20). The biota undergoing these changes include phytoplankton, benthic animals, macroinvertebrates, and fish.

During construction periods, siltation resulting from extensive activities will have substantial impacts on benthic animals. Fine sand and silt provide the least favourable habitat for these animals, thus causing temporary but severe reduction of benthic populations (Ref. 13, 15, 18).

Entrapment of sediments in the reservoir will result in a reduction of suspended sediments downstream from the dam. This phenomenon is believed to be beneficial to estuary productivity as reduced turbidity will permit deeper penetration of sunlight, thus increasing productivity of phytoplankton (Ref. 4, 11, 14).

Increased salinity in the estuary due to reduced freshwater inflow may have adverse effects on productivity of plankton, benthos, and macro- and micro-fauna by reducing their tolerance to the new conditions (Ref. 11, 14, 15, 20).

### 3.1.3 Aquatic weeds

Of the 20 statements, only five mention the possibility of serious aquatic weed infestation in the reservoir (Ref. 1, 11, 13, 15, 20). Of these, only two expect the problem to be serious (Ref. 15, 20).

The problem weeds are found to be saltcedar, alligotor weed, and water hycinth. These water weeds, if left uncontrolled, may cause extensive infestation in the reservoir. Adverse impacts of aquatic weed infestation include excessive loss of water by transpiration, restriction of navigation, interference with flood control efforts, drainage, and wildlife programmes, prohibition of access to the shoreline, and deterioration of aesthetic values. The weeds may become competive plants to more desirable species of aquatic vegetation. The most serious effects will be imposed on fish and other aquatic animals in the reservoir, namely depleting dissolved oxygen through decomposition of dead plant materials and reduction of atmospheric contact with surface water, filtering out sunlight, and restricting movement of fish.

Recommended measures to control water weeds include controlled manipulation of water levels and mechanical, biological and chemical methods. Mechanical methods involve clearing of the weeds and cutting with mechanical devices. Biological control can be achieved by introduction of some types of fish living on water weeds, such as Tilabpia mossambia. Controlled application of herbicides such as 2, 4-dichlorophenoxyacit acid can be used as a chemical measure.

## 3.2 Terrestrial biology

### 3.2.1 Wildlife

Most of the reviewed statements mention effects of the impoundment on wildlife in the project area. The effects can be categorized as minor (Ref. 1, 7, 10, 12, 17, 18, 19), moderate (Ref. 4, 5, 6, 8, 11, 14, 15, 20), and severe (Ref. 9, 13, 16), depending on the present population density and the acreage of habitat to be affected.

The primary cause of impacts is the inundation of wildlife habitat by the impoundment. This will cause loss of land serving as habitat for a number of game species of wildlife. Most of the wildlife present in the reservoir area prior to the impoundment will experience immediate displacement and will move to other areas for available spaces, while some animals will be lost to inundation. In the new places animals will encounter habitats already occupied by others of their species as well as other species and there would be a brief period of adjustment. The overall effect is the reduction of total wildlife population. The impacts can be long-term and short-term.

Other causes of impacts are recreation activities and increased human activities associated with the operation of the project. Permanent loss of some animals will result if they cannot adapt to human activities.

Construction operations also have temporary adverse affects on wildlife in areas adjacent to construction sites due to increased mortality, noise disturbance, and presence of humans and equipment. Most of the affected animals are expected to return after construction and restoration of vegetative cover.

In order to mitigate adverse effects on wildlife, proper management programmes are needed. Land away from the project area should be purchased for wildlife relocation and management. Juridicious planning is also required to promote habitat for upland wildlife.

### 3.2.2 Waterfowl

In most cases, creation of a large body of water by the impoundment will provide suitable wildlife habitat (Ref. 4, 5, 6, 9, 11). For these areas, species present prior to reservoir filling may use the area to a greater extent. More shoreline birds will be present. Increased waterfowl populations will result because the reservoir will provide additional nesting and feeding areas. However, inundation of the shoreline present before the impoundment may result in reduced waterfowl habitat (Ref. 8).

## 3.3 Terrestrial vegetation

Construction and operation of an impoundment project will result in disturbance and losses of terrestrial vegetative cover. Most of the statements indicate minor effects of the proposed actions on vegetation as compared with the total vegetation production in the area of concern. Only a few show that the effect will be moderately severe (Ref. 9, 13, 14, 16, 17).

Construction activities will, to some extent, cause disturbance to vegetation, while inundation will result in permanent loss of vegetation in the reservoir pool. In addition, clearing procedures, vehicular traffic, future development, and misuse and abuse by visitors to recreational areas can further damage vegetation. The effects on vegetation include losses of timber production, reductions of native and cultivated vegetation, reductions of wildlife habitat, and increased erosion. These impacts can be both short- and long-term.

To mitigate the problems, disturbance of vegetation during construction should be kept to a minimum. Measures for restoring vegetation, such as transplanting and reseedling, should be carried out upon completion of construction

activities. In addition, timber management programmes should be planned and integrated with wildlife management and recreation programmes in order to develop and utilize forest potentials.

## 4. Effects on human uses

### 4.1 Water resources

#### 4.1.1 Power generation, flood control, and irrigation

Power generation, flood control and water supply for irrigation are the purposes of some proposed projects. They are normally beneficial to the project area since these activities are aimed at meeting demands of the people and can boost economic growth of the areas involved. Hydroelectric power generation is said to be the cleanest type of power production (Ref. 3, 12, 13), thus having relatively minor adverse impacts on environment. However, physical damages and injuries to fish and macro-invertebrates can occur as water passes through turbines (Ref. 3, 4, 16).

Though provision of storage for flood control, water supply, and irrigation are desirable, this may induce alteration of downstream land use patterns. Downstream impacts of flood control measures include reduction of damage from flood water and debris, prevention of loss of topsoil, and reduction of risk to public health due to damage of sanitary systems in event of flood (Ref. 10, 13, 17). Increased use of land downstream and urbanization can occur as the consequences of reduced flood risk.

Use of water on irrigated lands can lower water quality in the receiving streams. Pollutants accompanying runoff include sediments, nutrients, pesticides, and decaying vegetation. Irrigation return flows in the form of drainage water may also contain high dissolved solids. Most of the statements reviewed do not indicate significant effect of runoff from irrigated lands (Ref. 8, 15).

#### 4.1.2 Recreation

Recreation is one of major purposes of many proposed projects. Thus recreation activities and their effects on environment are described in considerable lengths in the reviewed statements. In general, recreational activities include swimming, fishing, hunting, boating, camping, and picnicking. Recreation can create problems of water supply and waste disposal. It can also cause increased stress on the area to assimulate the wastes generated and increased traffic. Degradation of vegetation and loss of topsoil can occur as the consequences of carelessness and neglect of people utilizing the area. Moreover, human activities related to recreation can disturb wildlife species in the vicinity of the reservoir.

Proper management is required in order to mitigate adverse effects associated with recreation, and waste control management is necessary to accommodate intensive recreational uses. Prevention of water and solid waste pollution can be accomplished by (a) education of people through advertisement, (b) provision of trash receptables, (c) presence of custodial patrols, and (d) provision of waste treatment facilities. Zoning of the reservoir area is also necessary to insure compatability with various recreation uses.

According to the review, extensiveness of description of recreational activities and their effects can be describe as low (Ref. 1, 2, 3, 6, 7, 12, 18), medium (Ref. 4, 9, 10, 11, 14, 15, 17, 19, 20), and high (Ref. 13, 16).

## 5. Human effects

### 5.1 Socio-economic effects

#### 5.1.1 Fishery production

Fishery production varies directly with effects of the project on fish in the reservoir and in downstream sections of the river, as previously described. Fishery production in the reservoir is normally much better than the without-project conditions. Where unfavourable conditions exist, either in the stream or reservoir, fish production can be enhanced by proper stocking programmes. In general the net effect of a project is a sizeable net gain in fishery production. The beneficial effects can be classified as minor (Ref. 1, 5, 6, 16), moderate (Ref. 8, 9, 10, 12, 15, 17), and significant (Ref. 11, 14, 20). Reduction of the freshwater inflows to estuarine areas, which results in increased salinity gradient and decreased nutrients, can severely reduce both commercial and sport fishery production (Ref. 11, 20).

#### 5.1.2 Agricultural production

Effects of the projects on agricultural production are mentioned, but not stressed, in the reviewed statements. This may be due to the major project purposes which are normally not for agricultural production. Acquisition of productive agricultural lands will result in reduced production, while increased water supply for irrigated lands will cause increase in production. In general, the effect of the project can be categorized as minor (Ref. 6, 9) and moderate (Ref. 8, 13, 19). In some cases, the effect is severe in a local sense and moderate on a regional level.

#### 5.1.3 Resettlement problems

Acquisition of land for the project will result in displacement and relocation of residents in the area. People who must relocate will face auxiety, discomfort, and readjustment. Relocation may cause direct or indirect economic growth. Land

values are expected to rise, and there may be increased work opportunities. There may be gradual changes in some areas to greater population density. Inhabitants who are used to or prefer rural settings may be adversely affected as a result of the alteration.

According to the Federal laws, people displaced by land acquisition will have available to them replacement housing meeting established standards for decent, safe, and sanitary dwellings. Other requirements include payment of property taxes.

### 5.1.4 Rural development

Rural development is the secondary impact of the project occurring as a result of population growth in the area. This will cause some changes in life style of the residents. There will be a greater need for goods and services in the vicinity of the project. Because of large number of people in the area, there will be greater variety of goods and services. Increased population will require services provided by local governments to be expanded. Demands for more recreation can increase with population. This would result in increased employment related to operation of recreational activities, and in increased numbers of businesses and industrial complexes. Social and cultural benefits may result from improved community and recreational services. Adverse social and cultural effects would result when an area become overcrowded and from heavier traffic conditions, loss of vegetation, displacements, and disturbance and pollution during and after various construction activities. However, there will be economic gains in the area due to increased income of the residents during construction periods. After construction has been completed, labour requirements will decline, but labourers will still be needed for project operation. Income of people may be enhanced by needs for services and businesses where recreational uses are intensive.

### 5.1.5 Vectors and public health problem

Only a few of the 20 statement reviewed mentioned vector problems and public health problems associated with them (Ref. 4, 14, 15, 17). All of them are related to species of mosquitoes such as Anopheles quadrimaculatus (a vector of malaria) and Anopheles trivitus (a vector of arthropod-borne encephilitis). Mosquitoes are expected to breed in leftover borrow areas and marshes within the conservation pool and drawdown, in areas of stagnant water, and in areas with dense masses of hyacinth. To minimize problems with mosquitoes, steps should be taken to eliminate pool formation caused by incomplete drainage of the reservoir during the drawdown. Swamps conductive to mosquito breeding should be cleared, filled, and graded. Controlled manipulation of water level is believed to control mosquito breeding and larval production. Mosquito control measures such as application of chemicals may be needed.

Health hazards may develop from the construction and recreational activities due to wastewater disposal. Pit-type sanitation facilities should be provided and properly maintained at these areas. In addition waste disposal should be accomplished in accordance with pollution control authority standards.

## 5.2 Cultural values

### 5.2.1 Life style

Most of the statements mention possible change of life style of residents in the project areas. The effects can be either adverse or beneficial (Ref. 4, 7, 20). They involve the disruption of existing social patterns, means of livelihood, or particular characteristics associated with work, recreation, and social traditions of the area. The major changes which will affect life style include removal of land from present use, displacement of families, and relocation of transportation and utilities. Industrial, recreational, residential, and agricultural developments may also cause changes in existing life styles. Changes in life styles can result from socio-economic effects such as change in recreational activities, out-migration, and increased unemployment.

### 5.2.2 Archaeological values

Archaeological information of the project area is an important aspect of environmental statements. Most of the statements reviewed mention plans for archaeological study and salvage. Some discribe archaeological evaluations and findings with relatively few details (Ref. 4, 5, 6, 7, 10, 14, 17) and some in moderate detail (Ref. 8, 11, 13, 15). Construction of the project will result in loss of some archaeological knowledge due to damages caused by construction equipment and due to inundation. Damages can also occur along the lakeshore where recreation activities are permitted. Adverse effects will be loss of information concerning prehistory of the project area.

In order to minimize loss of archaeological information, complete reconnaissance surveys of archaeological elements in the construction area should be conducted by qualified archaeologists. Valuable artifacts should be salvaged for identification. An appropriate timetable should be provided; otherwise surveys and salvage operations might not be completed by the time the construction begins.

## 6. Quantification of environmental effects

While it is not possible to quantify the extent of impact on environmental resources without a great deal of subjectivity, for purposes of this review a simple method was selected for evaluating the comparative importance of the environment parameters and of effects on these both during construction and operation periods. As shown in Table 2, the information presented in the environmental impact statements were rated using the letters A, B, C, and D. The letter A,

which is assigned when an effect is mentioned only, is given a weight of 0.5. The letters B, C, and D, represent respectively the adequacy of discussion of the environmental effects, adequacy of proposed mitigating measures, and adequacy of field work for supporting the evaluation. These letters (B, C, D) carry equal weights, depending on their subscripts. For example, $B_3$ and $C_3$ will have equal weight. The weights indicated by subscripts 1, 2, and 3 are 1, 2, and 3, respectively. For instance, a parameter marked $2A_1$, $2B_1$, $3C_2$, $1D_3$ (indicating this this parameter was mentioned or discussed in eight of the 20 projects) will have a total weight equal to 2(0.5) + 2(1) + 1(3) = 12. This total weight is called an "index of importance" (I). Values of indices of importance are given at the bottom of Table 2. Thus the higher the index value for a given environmental parameter carries, the more important it is indicated to be, based on the information on the selected 20 projects. It should be noted that the ratings were made based on the information given in the environmental impact statements, regardless of the stated purpose of the project.

Assuming the project purposes are not considered, the order of importance of environmental parameters, placed according to the indices of importance, were found to be as follows: water quality (I = 86), fish (83), wildlife (64), recreation (53), aquatic animals other than fish (50), land use pattern (42), etc. Ranks of importance for other environmental parameters are given in the last row of Table 2. Thus it could be said that, for the parameters which are indicated to be the most important, priority should be given to them in environment assessment activities prior to project construction.

## 7. Summary

Environmental impact statements prepared for a reservoir development project in the United States normally include almost all environmental parameters shown in this report. A careful preassessment of environmental impacts likely to be induced by a proposed project is essential for proper design and planning to help alleviate the expected problems. As a consequence, the project construction and operation can be made as economically beneficial as possible and at the same time adverse impacts on the existing environments can be kept to a minimum.

On the basis of severity of adverse effects and extensiveness of the effects being described in the reviewed statements, ranking in order of importance of environmental parameters will be water quality, fishery, wildlife, recreation, aquatic animals other than fish, and land use patterns. These parameters should also be studied and evaluated with more attention than other less important parameters.

It can be seen from this review that some parameters, which seem to be of major concern in Southeast Asia, are not much stressed in the environmental impact statements for

(11) "Final Environmental Statement, Cibolo Project, Texas." U.S. Bureau of Reclamation, Department of the Interior, Washington, D.C., August 1974.

(12) "Final Environmental Statement, Pueblo Dam and Reservoir, Fryingpan-Arkansas Project." U.S. Bureau of Reclamation, Department of the Interior, Washington, D.C., January 1972.

(13) "Final Environmental Statement, Central Arizona Project." Bureau of Reclamation, Department of the Interior, Washington D.C., September 1972.

(14) "Final Environmental Statement, Raystown Lake, Huntingdon County, Pennsylvania." U.S. Army Engineer District, Baltimore, Maryland, March 1973.

(15) "Final Environmental Impact Statement, Palmetto Bend Project, Texas." U.S. Bureau of Reclamation, Department of the Interior, Washington, D.C., September 1974.

(16) "Final Environmental Statement, Central Utah Project, Bonneville Unit. " U.S. Bureau of Reclamation, Department of the Interior, Washington, D.C., August 1973.

(17) "Gathright Lake, Jackson River, Tames River Basin, Virginia". U.S. Army Engineer District, Norfolk, Virginia, January 1973.

(18) "Bad Creek Environmental Study, Duke Power Company, Charlotte, North Carolina". B.C. Dysart, Clemson University, South Carolina, 1973.

(19) "Final Environmental Statement, Pojoaque Unit, San Juan - Chuma Project, Colorad-New Mexico." U.S. Bureau of Reclamation, Department of the Interior, January 1973.

(20) "Draft Environmental Impact Statement, Nueces River Project, Choke Canyon Dam and Reservoir Unit, Texas." U.S. Bureau of Reclamation, Department of the Interior, June 1974.

(21) "Survey of Impacts of Construction Activities in Wetland Areas." U.S. Environmental Protection Agency, Washington D.C. (Undated).

(22) "Lower Columbia and Lower Snake Rivers Nitrogen Gas Supersaturation and Related Data: Analysis and Interpretation." Corps of Engineers, Portland, Oregon, March 1974.

projects in the United States. Some examples are vector and public health problems, agricultural production, and resettlement problems. The reason for these environmental parameters not being emphasized may be that the projects reviewed are located in areas where effects on these parameters are not likely or not significant. Although all parameters should be studied, in making an environmental assessment for any project, the relative importance of these parameters will vary from region to region and from project to project within regions. Location of the project area is an important factor which must be carefully considered in environmental assessment work.

References

(1) "Final Environmental Statement, Tocks Island Lake Project, Delaware River, New Jursey, New York, Pennsylvania." Department of the Army, Philadelphia District, Corps of Engineers, Pennsylvania, October 1971.

(2) "Final Environmental Statement, Crystal Dam, Reservoir and Powerplant, Curecanti Unit, Colorado River Storage Project, Colorado," Bureau of Reclamation, Department of the Interior, December 1971.

(3) "Final Environmental Impact Statement, Rock Island Project, No. 943 - Washington". Federal Power Commission, Bureau of Power, Washington, D.C., 1974.

(4) "Final Environmental Impact Statement, Parr Hydroelectric Project, No. 1894 - South Carolina". Federal Power Commission, Bureau of Power, Washington, D.C., March 1974.

(5) "Environmental Statement, Duch River Project." Tennessee Valley Authority, April 1972.

(6) "Environmental Statement, Tellico Project". Tennessee Valley Authority, February 1972.

(7) "Final Environmental Impact Statement, Lakeview, Mountain Creek, Trinity River Project, Texas". U.S. Army of Engineer District, Fort Worth, Texas, August 1972.

(8) "Supplement to Final Environmental Statement, Sixes Bridge Dam and Lake Maryland and Pennsylvania," U.S. Army of Engineer District, Baltimore, May 1973.

(9) "Supplement to Final Environmental Statement, Verona Dam and Lake Project," Office of Chief Engineer, Department of the Army, August 1973.

(10) "Environmental Statement, Lost Creek Lake Project, Roque River, Oregon". U.S. Army Engineer District, Portland, Oregon, May 1972.

TABLE 1

SUMMARY OF PROPOSED ACTIONS AND PROJECT FUNCTIONS

| Ref. No. | Reservoir Description | | | Project Functions | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Capacity Acre - feet | Area, Acres | Shoreline Miles | Flood Control | Water Supply | Irrigation | Power * | Recreation | Fish & Wildlife |
| 1 | 845,000 | 12,425 | 20 | x | x | | x (75) | x | x |
| 2 | 24,580 | 287 | 20 | | | | x (28) | | x |
| 3 | 11,000 | - | 13 | | | | x (410) | | x |
| 4 | 400,000 | 6,800 | 400 | | | | x | x | |
| 5 | 410,000 | 15,800 | - | x | x | | | x | x |
| 6 | 126,000 | 16,500 | - | x | | | x | | x |
| 7 | 375,000 | 25,800 | 53 | x | | | | | x |
| 8 | 103,000 | 4,650 | 50 | | x | | | x | |
| 9 | 107,500 | 4,750 | 30 | | x | | | x | |
| 10 | 315,000 | 3,440 | - | x | x | x | x (49) | x | x |
| 11 | 478,000 | 18,290 | 60 | | x | | | x | x |
| 12 | 357,000 | 5,675 | - | x | | x | x | x | x |
| 13 | 2,018,000 | 35,000 | - | x | x | x | | | |
| 14 | - | 10,800 | 70 | x | | | | x | x |
| 15 | 204,000 | 12,500 | 125 | | x | x | | x | x |
| 16 | a | - | - | x | x | | x (113) | x | x |
| 17 | 203,600 | 3,160 | - | x | | | | x | |
| 18 | 34,500 | 365 | - | | | | x (1,000) | | |
| 19 | 1,600 | 56 | - | | | x | | x | x |
| 20 | 1,083,000 | 17,400 | - | | x | | | x | x |
| Total Number of Projects | | | | 10 | 10 | 5 | 9 | 14 | 14 |

Notes :

x - Proposed function

* - Values in parentheses are in megawatts

a - A project composed of 10 reservoirs which have a total storage capacity of more than 2,000,000 acre-feet

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## TABLE 2

### SUMMARY OF ENVIRONMENTAL EFFECTS OF TWENTY REPRESENTATIVE DAM/RESERVOIR PROJECTS IN UNITED STATES

| | | PROJECT NUMBER (3) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | TOTAL A | TOTAL $B_1$ | TOTAL $B_2$ | TOTAL $B_3$ | TOTAL $C_1$ | TOTAL $C_2$ | TOTAL $C_3$ | TOTAL $D_1$ | TOTAL $D_2$ | TOTAL $D_3$ | I | R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PHYSICAL ENVIRONMENTAL EFFECTS | WATER RESOURCES | GROUND WATER | $B_1$ | | A | | $B_1$ $D_2$ | $B_1$ | | $B_1$ | A | | | | $B_3$ | $B_1$ | | | A $D_2$ | $B_2$ D | A | $B_3$ | 4 | 5 | 1 | 2 | 0 | 0 | 0 | 1 | 2 | 0 | 27 | 12 |
| | | SURFACE HYDROLOGY | A | A | A | $B_1$ | $B_1$ $D_2$ | A $D_2$ | | | A | | $B_2$ | | $B_3$ | $B_2$ | $B_3$ | $B_2$ $D_1$ | | $B_2$ $C_1$ $D_2$ | $B_2$ | | 5 | 2 | 5 | 2 | 1 | 0 | 0 | 1 | 3 | 0 | 29 | 11 |
| | | WATER QUALITY | $B_2$ $C_1$ | $B_1$ | $B_1$ $C_1$ $D_1$ | $B_2$ $C_2$ | $B_3$ $C_2$ | $B_2$ $C_1$ $D_3$ | $B_2$ | $B_3$ $C_2$ $D_3$ | $B_2$ $C_1$ | $B_2$ $C_2$ | $B_3$ $C_1$ $D_2$ | $B_2$ $C_1$ | $B_2$ $C_1$ | $B_1$ | $B_3$ $C_2$ | $B_2$ $C_1$ $D_1$ | $B_2$ $C_2$ $D_3$ | $B_2$ $C_2$ $D_3$ | $B_2$ $C_1$ | $B_1$ $C_2$ $D_3$ | 0 | 3 | 12 | 5 | 9 | 8 | 0 | 2 | 1 | 5 | 86 | 1 |
| | LAND RESOURCES | GEOLOGY | $B_1$ | A | | A | $B_1$ | A $D_3$ | | A | A $B_1$ | | | A | | A | $B_2$ $C_1$ | $B_1$ | | | A | $B_1$ $C_1$ $D_3$ | 8 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 17 | 14 |
| | | LAND USE PATTERN | $B_1$ | | A $D_1$ | $B_2$ | $B_2$ $C_1$ $D_1$ | $B_1$ $D_3$ | $B_1$ $D_1$ | $B_2$ $C_1$ | $B_2$ $D_1$ | $B_3$ $C_1$ | $B_2$ $D_1$ | $B_2$ | $B_3$ | $B_2$ | $B_2$ | $B_2$ | $B_2$ | | $B_1$ | $B_2$ | 1 | 4 | 11 | 2 | 3 | 0 | 0 | 5 | 0 | 1 | 42 | 6 |
| | | EROSION | A | A | A | $B_1$ $C_1$ | A | $B_1$ $C_1$ | A | $B_2$ $C_2$ | A | $B_2$ $C_1$ | A | A | $B_2$ $C_1$ | A | $B_2$ $C_1$ | $B_2$ $C_1$ | $B_1$ | $B_3$ $C_2$ | A | $B_2$ $C_2$ | 10 | 3 | 6 | 1 | 6 | 3 | 0 | 0 | 0 | 0 | 35 | 8 |
| | OTHERS | AIR POLLUTION | $B_1$ $C_1$ | | $B_1$ $C_1$ | $B_1$ $C_1$ | A | $B_2$ $C_1$ | A | A | A | A | $B_2$ $C_1$ | A | $B_2$ $C_1$ | A | $B_1$ | $B_1$ | $B_1$ | $B_2$ $C_1$ $D_1$ | A | A | 9 | 6 | 4 | 0 | 7 | 0 | 0 | 1 | 0 | 0 | 27 | 12 |
| | | NOISE POLLUTION | A | | A | $B_1$ $C_1$ | A | | A | A | | A | $B_2$ | A | $B_2$ | A | | A | A | B | A | A | 12 | 2 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 15 | 16 |
| | | SOLID WASTE, WASTEWATER | A | | A | A | A | | A | A | | A | A | | A | A | A | A | A | A | A | A | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 18 |
| ECOLOGICAL EFFECTS | AQUATIC BIOLOGY | FISH | $B_2$ $C_1$ | $B_2$ $C_1$ | $B_2$ $C_1$ $D_3$ | $B_3$ $C_1$ $D_1$ | $B_2$ $C_1$ $D_3$ | $B_3$ $C_1$ $D_3$ | $B_3$ $C_1$ $D_1$ | $B_3$ $C_1$ $D_1$ | $B_1$ $C_1$ $D_1$ | $B_2$ | $B_3$ $D_2$ | $B_3$ $C_1$ | $B_3$ $C_2$ | $B_3$ $C_1$ | $B_3$ $C_1$ $D_3$ | $B_3$ $C_1$ $D_3$ | $B_2$ $C_2$ | $B_1$ $C_1$ $D_2$ | $B_2$ $C_1$ | $B_3$ $C_1$ $D_1$ | 0 | 2 | 13 | 5 | 14 | 4 | 0 | 5 | 3 | 4 | 83 | 2 |
| | | OTHER AQUATIC ANIMALS | A | | A $D_2$ | $B_2$ | $B_2$ $D_3$ | $B_1$ | A | $B_1$ $D_2$ | A | | $B_3$ $C_1$ $D_2$ | $B_2$ | $B_3$ $C_1$ | $B_2$ $C_1$ | $B_3$ $D_2$ | | A | $B_3$ $C_3$ $D_3$ | $B_2$ | $B_3$ $D_1$ | 3 | 2 | 5 | 5 | 3 | 0 | 1 | 1 | 4 | 2 | 50 | 5 |
| | | AQUATIC VEGETATION | $B_1$ $C_1$ | | A | | A | $B_3$ $C_1$ | $B_1$ | A | | | $B_2$ | | $B_3$ $C_2$ | | $B_3$ $C_1$ | | A | | A | $B_2$ $C_2$ | 5 | 1 | 3 | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 20 | 13 |
| | | VECTORS OF DISEASES | | | | $B_1$ $C_1$ | | A | | | | | | | | | $B_2$ $C_1$ | | | | | | 1 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 6 | 19 |
| | TERRESTRIAL BIOLOGY | WILDLIFE | $B_1$ $C_1$ | A | A $D_1$ | $B_2$ $C_2$ $D_3$ | $B_2$ $C_1$ $D_3$ | $B_3$ $C_1$ $D_1$ | $B_1$ $D_1$ | $B_2$ $C_1$ | $B_3$ $C_1$ $D_1$ | $B_1$ | $B_2$ | $B_1$ $C_1$ | $B_3$ $C_1$ | $B_2$ $C_1$ | $B_2$ $C_1$ $D_3$ | $B_3$ $C_2$ | $B_1$ $C_1$ $D_2$ | $B_1$ $C_1$ $D_3$ | $B_1$ $C_1$ $D_1$ | $B_2$ $C_1$ $D_2$ | 2 | 7 | 8 | 3 | 13 | 2 | 0 | 5 | 2 | 4 | 64 | 3 |
| | | WATERFOWL | A | | A | A | A | $B_1$ | | B | A | A | | $B_1$ | A | | $B_1$ | A | | A | A | A | 11 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 17 |
| | | VEGETATION | A | A | A | $B_1$ $C_1$ $D_3$ | $B_1$ | A | $B_1$ | A | $B_2$ $C_1$ $D_1$ | A | A | A | $B_2$ $C_2$ | $B_2$ $C_1$ | A | $B_3$ $C_1$ $D_2$ | $B_2$ | A | A | A | 12 | 3 | 4 | 1 | 4 | 1 | 0 | 1 | 1 | 1 | 32 | 9 |
| EFFECTS ON HUMAN USES | WATER RESOURCES | FLOOD CONTROL | A | | | | A $D_2$ | A | A | A $D_1$ | | $B_2$ | A | A | $B_2$ | A | B | A | $B_2$ | | | A | 9 | 1 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | N/A | |
| | | WATER SUPPLY | A | A | A | A | A $D_2$ | | A | | A | | A | $B_1$ | $B_2$ | | | A | | | | A | 9 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | N/A | |
| | | POWER GENERATION | A | | | | | A | | | | A | | A | | | | $B_2$ | | $B_2$ | | | 4 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N/A | |
| | | RECREATION | $B_1$ | $B_1$ | $D_1$ $C_1$ | $B_3$ $C_1$ | A | $B_1$ | $B_1$ $C_1$ | A $D_2$ | $B_2$ $D_2$ | $B_2$ | $B_2$ | $B_1$ $C_1$ | $B_3$ $C_1$ | $B_2$ $C_2$ | $B_2$ | $B_3$ $C_1$ | $B_2$ $C_1$ $D_3$ | $B_1$ $D_2$ | $B_2$ $C_2$ | $B_2$ $C_1$ | 2 | 7 | 9 | 3 | 8 | 2 | 0 | 0 | 4 | 0 | 53 | 4 |
| | LAND RESOURCES | AGRICULTURE | | A | | $B_1$ | | | | $B_2$ | $B_1$ | $B_2$ | | | $B_1$ $C_1$ | | | | | | | | 1 | 3 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 8 | 18 |
| | | MINERAL RESOURCES | A | | A | A | $B_1$ | | A | A | $B_1$ | | A | | $B_1$ $C_1$ | | A | A | A | $B_2$ | | B C | 9 | 4 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 12 | 16 |
| HUMAN EFFECTS | SOCIO-ECONOMIC EFFECTS | AGRICULTURAL PRODUCTION | | | A | | | $B_1$ | A | $B_2$ | $B_2$ | A | | | $B_2$ | | | | | $B_2$ $D_1$ | | | 3 | 1 | 4 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 12 | 16 |
| | | FISHERY PRODUCTION | $B_1$ $C_1$ | A | | | $B_1$ | $B_1$ | | $B_2$ | $B_2$ | $B_2$ $C_2$ | $B_3$ | $B_2$ $C_2$ | $B_2$ | $B_3$ | $B_2$ | $B_1$ | $B_2$ $C_2$ | | | $B_3$ $C_1$ | 1 | 4 | 7 | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 35 | 8 |
| | | RESETTLEMENT PROBLEMS | A | A | A | $B_1$ $C_1$ | $B_1$ $C_1$ | $B_1$ $C_1$ | A | $B_2$ $C_2$ | $B_2$ $C_1$ | $B_2$ $C_2$ | $B_2$ $C_1$ | $B_1$ $C_1$ | | $B_2$ $C_1$ | $B_1$ $C_1$ | | | | | A | 5 | 5 | 5 | 0 | 8 | 2 | 0 | 0 | 0 | 0 | 30 | 10 |
| | | RURAL DEVELOPMENT | $B_1$ | | | | | | | $B_1$ | A | $B_1$ | $B_1$ | $B_1$ | A | A | $B_2$ | $B_2$ | A | $B_1$ $D_1$ | | $B_2$ $C_1$ | 4 | 6 | 3 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 16 | 15 |
| | | EMPLOYMENT INCOME | | A | A | A | A | A | $B_1$ | A | A | A | A | A | A | A | $B_1$ | $B_2$ | A | | | $B_2$ | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 11 |
| | | PUBLIC HEALTH | | | A | $B_1$ | | | | | | | | | | $B_2$ $C_2$ | | | $B_1$ $C_1$ | | | | 1 | 2 | | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 8 | 18 |
| | CULTURAL VALUES | LIVE STYLE | A | A | A | $B_2$ | A | A | $B_1$ | A A | | A | A | | A | | A | A | A | A | | $B_2$ | 12 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 17 |
| | | ARCHEOLOGY | A | | A | $B_1$ $C_1$ | $B_1$ $C_1$ | $B_1$ | $B_1$ $C_1$ | $B_2$ $C_1$ | A | $B_1$ | $B_2$ $C_2$ | | $B_2$ $C_2$ | $B_1$ $C_1$ | $B_2$ $C_2$ | A | $B_1$ $C_1$ | A | A | A | 7 | 7 | 4 | 0 | 6 | 3 | 0 | 0 | 0 | 0 | 30 | 10 |
| | | AESTHETIC VALUES | $B_2$ $C_1$ | A | A | $B_1$ $C_1$ | A | $B_1$ $C_1$ | $B_1$ $C_1$ | $B_2$ $C_1$ | A | $B_3$ $C_2$ | $B_1$ | $B_2$ $C_2$ | $B_1$ | A | $B_1$ | $B_2$ $C_2$ | $B_2$ $C_1$ | $B_2$ | $B_2$ $C_2$ | A | 6 | 6 | 7 | 1 | 6 | 4 | 0 | 0 | 0 | 0 | 40 | 7 |

**NOTES:**

(1) **NOTATIONS**

A – When an effect is mentioned without details

B – Effect of an environmental parameter is discussed in some detail

C – Mitigating measures are discussed

D – Adequacy of field data to support discussion

I – Index of importance

N/A – Not applicable

R – Rank of importance

(2) **SUBSCRIPTS**

1 – Low level of effect

2 – Medium level of effect

3 – High level of effect

(3) See Annex A for identification of project.