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Proceedings of Regional Training Course

WATERSHED RESOURCES MANAGEMENT ENVIRONMENTAL MONITORING

CHIANGMAI THAILAND
May 25 – June 8 1981

BEST AVAILABLE DOCUMENT

REGIONAL TRAINING COURSE

ON

"WATERSHED RESOURCES MANAGEMENT AND ENVIRONMENTAL MONITORING IN HUMID AND TROPICAL ECOSYSTEMS"

May 25 - June 8, 1981

Northern Region Agricultural Development Center

Chiang Mai, Thailand

Organized by

Office of the National Environment Board (ONEB)

Department of Technical and Economic Cooperation (DTEC)

With Co-sponsorship of

The United Nations Educational, Scientific and Cultural Organization

The United States Agency for International Development

Man and the Biosphere (U.S.A.)

University of Arizona

Ministry of Agriculture

Chiang Mai University

Maejo Agricultural Institute of Technology

Man and the Biosphere (Thailand)

FOREWORD

These proceedings are a product of the training course on Watershed Resources Management and Environmental Monitoring in Humid Tropical Ecosystems held in Chiang Mai, Thailand, from May 25 to June 8, 1981.

Twenty six participants and some 30 observers attended the course. Two of the participants were from the People's Republic of China, and one each was from Nepal, Sri Lanka, Malaysia, Indonesia, and Africa; the remainder of the participants were from various Thai agencies and institutions. Participants recieved a certificate for course completion from the University of Arizona. All persons involved in the course are listed in Annex VIII - 6.

The training course was formulated by an Ad Hoc Planning Committee of which Dr. Pakit Kiravanich, Deputy Secretary-General of the National Environment Board served as chairman.

The course combined lectures and presentations with several field trips all of which are described in the Proceedings. This combination proved to enhance the awareness and interest of course attendees and solidified the rapport and information exchange among the attendees.

All that attended the course concurred that the course objectives defined in the announcement brochure and the Welcoming Statement (Section I) were met. All attendees agreed that the course was of considerable benefit to them in applying what was learned to their various jobs in the Watershed Management area.

Office of the National Environment Board and Department of Technical and Economic Cooperation acknowledge the assistance and cooperation provided by the many Thai agencies and international organizations named in the Section II Opening Address. Office of the National Environment Board is hopeful that the proceedings will serve as a reference and guide for watershed management activities in Southeast Asia and other tropical countries.

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Section I

WELCOME STATEMENT

I. WELCOME STATEMENT

by

Dr. Pakit Kiravanich

Deputy Secretary-General, National Environment Board

I'd like to extend a heartly welcome to all participants, observers and lecturers for the training course on watershed resources management in humid tropical ecosystems. My name is Pakit Kiravanich and my position is Deputy Secretary-General of the National Environment Board of Thailand and I served as chairman of the training course planning committee.

We have a full two weeks ahead of us to realize the objectives of the training course. Those objectives are to :

1. Provide a forum for the transfer of knowledge and experience to participants in the various facets of watershed resources management.

2. Make participants more capable, qualified, and motivated in the areas of watershed resources research, planning, management and regulation.

3. Instill in participants the inherant value of multi-purpose use of watershed resources and management actions and techniques that will achieve or maintain multi-purpose uses.

4. Impress upon participants the cost-effectiveness of protecting existing high quality watershed compared to renovation once a watershed is degraded.

5. Inform participants of the status and problems of watershed management in Southeast Asian countries and those structural, non-structural, institutional, legal, and regulatory techniques that have been effective in managing and protecting watershed resources.

6. Observe, first hand, techniques that are being employed in northern Thailand to protect watershed resources and maximize their values.

To provide the opening address to our group and to launch our training course, it is my pleasure to introduce Mr. Apilas Osatananda, Director General of Thailand's Department of Technical and Economic Cooperation. DTEC has expressed strong interest in watershed management and has been most helpful in planning and arranging for the conduct of the course. Mr. Osatananda.

Section II

OPENING ADDRESS

II. OPENING ADDRESS

by

Mr. Apilas Osatananda
Director - General
Department of Technical and Economic Cooperation

Thank you, Dr. Pakit. I very much appreciate the opportunity to open this training session and to welcome all the course participants and observers. I think that I speak in behalf of all the Thai agencies in recognizing that Thailand is fortunate to be able to serve as the host for this training course.

The importance of watershed resources management looms steadily larger as we developing countries enter an age of increasing competition for available resources. In looking backwards it is easy to see that we have not paid the attention that we should have to the proper management of these resources. In too many watersheds we have taken what we wanted without adding the extra effort needed to sustain these watersheds for continuing and optimum use. The signs of our short-comings are evident in soil erosion, sedimentation of waterways, loss of watershed productivity such as from forest products, and loss of valuable nutrients from the soils.

In looking forwards, it is our job to apply management techniques on our watershed lands that will stop these historical shortcomings. We need to apply techniques that will renovate watersheds that have been damaged, and, for sure, we must manage yet-undamaged watersheds on a sustained-yield and multiple-use basis. We can no longer afford to sacrifice tomorrow's overall needs for today's single-purpose objectives; the loss will be too great and there is too much to gain from using the proper resource use and management strategies. Making these management and policy changes on watershed use and protection will not be an easy task nor one that can be done "overnight". However, the difficulties and time required must not stop us from taking up the task. The lead in this should come from agencies such as are represented at this training course. I am most hopeful that in the next two weeks you are able to study and grasp management techniques that you can apply towards better watershed management in your jobs in Thailand as well as in the other regional countries represented here. As mentioned by Dr. Pakit in his statement, if the course provides (1) motivation, and (2) Transfer of knowledge, it will be a success and long-term watershed benefits will be realized by all the regional countries. I am optimistic that both motivation and knowledge transfer will result from the course.

It has been the Department of Technical and Economic Cooperation's privilege to work with the National Environment Board, Man and the Biosphere (Thailand), Chiang Mai University, the Maejo Institute of Agricultural Technology, Kasetsart University, The Royal Forest Department and The University of Arizona in planning and arranging for the course. I would

also like to give special thanks to the sponsoring agencies who have made the course possible, namely the United States Agency for International Development, Man and the Biosphere (U.S.A.) and the United Nations Educational, Scientific and Cultural Organization.

I also want to give special recognition to the Ministry of Agriculture and Cooperatives for its cooperation in providing the comfortable facilities here at the Northern Region Agricultural Development Center.

That concludes my opening remarks and you have my best wishes for a successful and rewarding training course.

Section III

COURSE ACTIVITY SCHEDULE

III. Course Activity Schedule
for
Regional Training Course
on
Watershed Resources Management and
Environmental Monitoring in Humid Tropical Ecosystems
Northern Region Agricultural Development Center, Chiang Mai, Thailand
May 25 - June 8, 1981

PROGRAM OF TOPICS

TIME	TOPIC	LECTURER
SUNDAY May 24	Travel from Bangkok to Chiang Mai	
MONDAY May 25		
9:00 - 12:00	Registration	
12:00 - 1:00	Lunch	
1:00 - 2:30	Opening Ceremonies	
2:30 - 3:00	Course Procedures Briefing	Staff
3:00 - 3:30	Break	
3:30 - 4:30	Introduction to Watershed Resources Management : Specific Emphasis on Humid Tropical Ecosystems	Dr. Kasem Chunkao
6:30	Reception hosted by DTEC	
TUESDAY May 26		
8:00 - 8:30	Statistical Methods and Procedures	Dr. Ffolliott
8:30 - 9:30	The Hydrologic Cycle	Dr. Brooks
9:30 - 9:45	Tourism Opportunities in the Chiang Mai Area	Tourism Authority of Thailand
10:00 - 11:00	The Hydrologic Cycle (cont'd)	Dr. Brooks
11:00 - 12:00	Inventory Techniques : Precipitation	Dr. Brooks
12:00 - 1:00	Lunch	
1:00 - 2:00	Inventory Techniques : Streamflow	Dr. Thames
2:00 - 3:00	Inventory Techniques : Water Quality	Dr. Rasmussen
3:00 - 3:30	Break	
3:30 - 4:30	Working Session	Staff

TIME	TOPIC	LECTURER
WEDNESDAY		
May 27		
8:00 - 8:30	Review	Staff
8:30 - 9:30	Inventory Techniques . Timber, Range and Wildlife	Dr. Ffolliott
9:30 - 10:00	Break	
10:00 - 11:00	Remote Sensing Application and Interpretations in Watershed Resources Management	Dr. Rasmussen
11:00 - 12:00	Hydrologic Methods	Dr. Brooks
12:00 - 1:00	Lunch	
1:00 - 2:00	Hydrologic Methods (cont'd)	Dr. Brooks
2:00 - 3:00	Working Session	Staff
3:00 - 3:30	Break	
3:30 - 4:30	Vegetation Management	Dr. Ffolliott
THURSDAY		
May 28		
8:00 - 8:30	Review	Staff
8:30 - 9:30	Erosion Processes and Control	Dr. Thames
9:30 - 10:00	Break	
10:00 - 11:00	Water Quality	Dr. Rasmussen
11:00 - 12:00	Water Harvesting	Dr. Thames
12:00 - 1:00	Lunch	
1:00 - 2:00	Reservoir Management	Dr. Brooks
2:00 - 3:00	Problem Sets	Staff
3:00 - 3:30	Break	
3:30 - 4:30	Working Session	Staff
FRIDAY		
May 29		
8:00 - 8:30	Introductory Remarks	Staff
8:30 - 10:00	Case Study Country Reports	Regional Participants
10:00 - 10:30	Break	
10:30 - 12:00	Case Study Country Reports	Regional Participants
12:00 - 1:00	Lunch	
1:00 - 2:30	Case Study Country Reports	Regional Participants
2:30 - 3:00	Break	
3:00 - 4:30	Case Study Country Reports	Regional Participants
4:30 - 5:00	Concluding Remarks	Staff
SATURDAY		
May 30		
All Day	Field Trip to Sankamphang Cooperatives Village Project and Review Installation of Weather Station at Kog - Ma Watershed Research Station, Doi Pui	

TIME	TOPIC	LECTURER
SUNDAY		
May 31		
All Day	Free Day	
6:30 p.m.	Reception hosted by Chiang Mai University	
MONDAY		
June 1		
8:00 - 4:30	Use of Hydrologic Monitoring Equipment and Water Sampling at Mae - Sa Integrated watershed and Forest Land Use Project and Field Trip to Royal Hill Tribe Development Project (Mae-Sa Mai Village)	Staff and ONEB
TUESDAY		
June 2		
8:00 8:30	Review	Staff
8:30 - 12:00	Lab. Session to Analyse Sample from June 1	Regional Participants in teams of five
12:00 - 1:00	Lunch	
1:00 - 4:00	Prepare Report Summarizing Field and Lab. Data	Regional Participants in teams of five
4:00 - 4:30	Discussion of Reports	Staff and Participants
WEDNESDAY		
June 3		
8:00 - 8:30	Review	Staff
8:30 - 9:30	Economic Aspects of Watershed Resources Management	Dr. Ffolliott
9:30 - 10:00	Break	
10:00 - 11:00	Legal Aspects of Watershed Resources Management	Mr. Judha Krishnamra
11:00 -12:00	Institutional Considerations in Watershed Resources Management	Dr. Ffolliott
12:00 - 1:00	Lunch	
1:00 - 2:00	Introduction to Modeling and Simulation Techniques	Dr. Rasmussen
2:00 - 3:00	Application of Modeling and Simulation Techniques in Watershed Resources Management	Dr. Rasmussen
3:00 - 3:30	Break	
3:30 - 4:30	Exercise in Interactive Modeling and Simulation Techniques in Watershed Resources Management	Staff
6:30	Reception hosted by Maejo Agricultural Institute of Technology	

TIME	TOPIC	LECTURER
THURSDAY		
June 4		
8:00 - 9:00	Environmental Monitoring	Dr. Ffolliott
9:00 - 10:30	Ecological Aspects of Watershed Resources Management in Humid Tropical Ecosystems	Dr. Nipon Tangtham Mr. James W. Evans
10:30 - 11:00	Break	
11:00 - 12:00	Integrated Upland Watershed Management : A Case Analysis	Dr. Pisit Voraurai Dr. Suradej Puranapun
12:00 - 1:00	Lunch	
1:00 - 2:00	Integration of Watershed Resources Management with Multiple Use Concept	Dr. Ffolliott
2:00 - 3:00	General Discussion	Staff
3:00 - 3:30	Break	
3:30 - 4:30	Working Session	Staff
FRIDAY		
June 5		
All Day	Field Trip to Royal Project of Watershed Development (Khun Khong)	
SATURDAY		
June 6		
All Day	Field Trip to Inthanon National Park and Watershed Rehabilitation Project (Lower Mae Ping Basin)	
SUNDAY		
June 7		
All Day	Free Day	
6:30 p.m.	Reception hosted by ONEB	
MONDAY		
June 8		
8:00 - 8:30	Review	Staff
8:30 - 9:30	Course Evaluation	Participants
9:30 - 10:00	Break	
10:00 - 12:00	Final Examination	Participants
12:00 - 1:00	Lunch	
1:00 - 2:00	Closing Ceremony	
TUESDAY		
June 9	Depart Chiang Mai to Bangkok	

Section IV

COURSE SYLLABUS

CHAPTER I

CONCEPTS OF WATERSHED RESOURCES MANAGEMENT

INTRODUCTION

In addition to well-defined agricultural lands and urban areas is a major portion of the earth's habitable land surface which is forest or rangeland, wild lands, marginal lands or undeveloped lands. For lack of a more specific term, these residual lands will be called watershed lands. They include more than 80 percent of the land on earth. It is to these watershed lands that we must look for increased productivity of food, fiber, energy, and living space for our growing population, and it is these lands that currently stand in great danger all over the world.

This course is directed toward the understanding, planning, development and management of the land and water resources of watershed lands. It is aimed particularly at some of the major problems that concern the use of these lands in the developing countries.

PROBLEMS OF WATERSHED LANDS

The problems of watershed lands in the developing countries are often connected to social and economic patterns which endanger the environment. At present, three billion human beings inhabit the earth. Each day, 200,000 more individuals are added to our planet's population. By the year 2000, the population could increase to 6 billion. As the population increases pressure upon natural resources, our planet will need careful management if mankind is to survive. However, human survival alone is not enough. The developing nations are aspiring to equal economic and social standards that will require a more fair share of these resources.

Worldwide, the ratio of land to population is dwindling: in a number of countries, the amount of cultivated land per person is less

than half a hectare. Only a few decades ago, food production was increased in most countries by cultivating additional hectares or by extending grazing areas. Now that option is disappearing in many regions.

At present, between 50 and 60 percent of the population of the developing nations live on watershed lands. For these millions of people, it is a fact of life that the harder they work, the poorer they get. Their land is either too steep or too dry or the soil is too poor to support more than an average level of existence for a few people. Because of increasing population and current land uses, fragile environments are being subjected to mistreatment.

As populations increase, peoples migrate into fragile areas. In the more humid regions, forested slopes are cleared for fuel, fodder and primitive cultivation. Fires are allowed to escape from fields and burn indiscriminately; forests are grazed to an extent that prevents their reproduction; networks of trails are established with no concern for the erosion hazard they create. The consequences are accelerated soil loss and land deterioration, environmental degradation, and further impoverishment of the rural inhabitants themselves. In more arid areas where cultivation or wood harvesting is not possible, overgrazing is practiced to the extent that more than 4 million square kilometers of the earth have been converted to unproductive deserts during the past fifty years.

Another problem in both humid and arid areas is the loss of the protective cover of the soil and the reduction of the soil reservoir--the principal means by which water and erosion are controlled on watershed lands. The results have been increased flooding of valleys and shifting of stream beds resulting in water and silt invading prime agricultural land, irrigation structures, reservoirs, settlements, and communications. Stream flow during dry periods becomes unreliable and insufficient for the prevention of disease, the maintenance of irrigation works, and for urban and industrial needs. Ground water levels decline, resulting in the failure of springs and wells.

EXAMPLES OF WATERSHED LANDS AND THEIR PROBLEMS

Steep and Mountainous Watershed Lands

Steep and mountainous watershed lands make up almost one quarter of the earth's land surface and are inhabited by 10 percent of the total world's population. A great proportion of these lands have mesic or humid climates, vegetative cover (often forest) with little arable soil, and low population densities. Some of the most severe problems of steep land watersheds are seen in Nepal where erosion, increased by man's activities, is contributing 250 million cubic meters of silt to the Ganetic Plain each year. According to Napli observers, the beds of the

rivers in the Terai Plain of southern Nepal are rising by 15 to 30 centimeters annually which leads to flooding and changing river courses. The Kosi River, for example, has shifted its course 115 kilometers westward within the past 150 years, leaving 15,000 square kilometers of once fertile land buried under a mass of sand and rubble. This process has left 6.5 million persons homeless.

The ever increasing populations of Nepal and other countries in the region are moving further into the mountains and higher up the slopes to seek a means of livelihood. Even with the aid of terracing, which the farmers of Nepal have been practicing for centuries, these slopes are too steep and the soils too thin for intense cultivation. Nevertheless, a single acre of cultivated land must now support four people. The demands of increasing population result in the cultivation of less suitable soils and steeper lands which leads to a reduction of overall productivity in the country. In the densely populated eastern hills of Nepal, as much as 40 percent of what once was farm land has been abandoned and allowed to revert to bush because it is no longer fertile enough to support crops. These lands are the sites and sources of severe eroding, massive land slides, and severe gully erosion. However, cultivation is responsible only in part for the rapid deterioration of the watersheds. Nepal's forest lands stand in much greater jeopardy. The demands made by increasing numbers of livestock (over 15 million at present) are taking their toll on the forests of the steep hillslopes by fodder harvesting and overgrazing. Forest and range fires also present a serious problem.

In many of the steep and mountainous watershed lands of the world, the effects of timber and firewood extraction, forest clearance for cultivation, grazing, looping for fodder, and burning of the undergrowth, combined with inefficient timber utilization are causing a general degradation of the forests. The destruction of the forests of these steep and mountainous watersheds increases every year. In Nepal, for example, these lands (over 80 percent of the country) are likely to be almost totally denuded by the end of the century.

Dry Watershed Lands

Arid and semiarid regions are not often thought of as watershed lands. However, the water relationships of these regions are perhaps more critical to a greater number of people on earth than those of more humid regions. Water is always in critical balance with arid ecosystems and this balance is presently being upset by man and his animals at alarming rates over vast areas.

Dry regions cover more than one third of the earth's land surface. Slightly over half of the dry area is inhabited by 630 million people. The remainder is so dry and unproductive that it cannot support human life. The degradation of land and water resources by human activities is turning potentially productive dry lands into unproductive

deserts in Asia, Africa and Latin America. This process is called desertification. It has been estimated that a collective area larger than Brazil, with rainfall above the level classified as semiarid, been degraded to desert-like conditions.

About 60 million people in the developing countries live on the semiarid region between deserts and more humid areas. Desert encroachment in West Africa has received the greatest international attention recently. Reliable reports from the Sahara estimate that 650,000 square kilometers of land suitable for agriculture or intensive grazing have been lost to that desert over the past 50 years.

One of the most outstanding examples of the problems of dry watershed lands is the Thor Desert of Western Rajasthan in India. An average of 61 people now occupy each square kilometer of these lands. A consequence of this population pressure has been the extension of cropping to submarginal lands which are fit only for forest or range. Meanwhile, as the land available for forage shrinks, the number of grazing animals swells. The area available exclusively for grazing in Western Rajasthan dropped from 13 to 11 million hectares between 1951 and 1961, while the population of goats, sheep and cattle jumped from 9.4 to 14.4 million. The livestock population is still growing. During the decade of the 1960's the cropped area expanded from 26 percent to 38 percent of the total area, squeezing the grazing area even more.

As long as current land use patterns continue, the livelihood of tens of millions living in the arid lands of India will, at best, remain at its current dismal level. At worst, a prolonged drought in the future will mercilessly rebalance the number of people with the available resources. As it is, relief programs for the arid zones are seriously draining the governments' funds and food stores.

Present land use patterns in desert environments must change so that delicate water relations are not pushed beyond their limits. As the number of people and animals living in the arid zones climbs and the quality of the land on which they must live at the same time declines, the impact will be global unless solutions are found.

Humid Tropical Watershed Lands

There is a common fallacy that the world can fall back on its tropical watershed basin lands. One quarter of the Asian, African and Latin American tropics are occupied by these lands. The Amazon Basin, for example, includes nearly 40 percent of the South American continent, yet it is inhabited by less than 3 percent of its population.

Another common fallacy is that these lands, because they support a rich and diverse plant cover, must also be suited to intensive agriculture. Unfortunately, tropical rain forests are closed systems with most of the available nutrients tied up in the vegetative canopy. The

nutrients are easily released to the soil if the canopy is burned. Thus, these lands are well suited to slash and burn agriculture which has been practiced in tropical regions for thousands of years. It only becomes a serious threat when production pressures become too great to allow a long enough recovery period between slash and burn cycles. There is good evidence that these pressures were largely responsible for the collapse of several jungle civilizations, notably the Mayan civilization of Central America and the ancient Khmer Empire of Cambodia. Their agricultural practices led to cementation and loss of fertility of the lateritic soils they farmed.

Increasing demands for food and fiber are now placing pressure upon tropical watershed lands on a global scale. In eastern Nigeria, for instance, the most densely populated part of Africa south of the Sahara, shifting agriculture has been forced into shorter and shorter rotation cycles to the point that it has become continuous cropping. The result is a loss of nutrients and breakdown of the soil structure. This decline has been severe in Africa where per capita food production has actually declined over the past twenty years.

One of the best examples of the problems of tropical watershed lands are those in the Amazon basin. Most of the soils of the Amazon basin are poor and could perhaps best be exploited through forestry or nonagricultural practices. Only about 4 percent of the Brazilian portion of the Amazon have soils with medium to high fertility. Most of the better soils are in narrow plains along the banks of rivers, and their development for large scale agriculture will require large expenditures for drainage and flood control. Nevertheless, the Amazonian governments have programs to help new farmers from other regions settle in the basin. Since 1971, fifty thousand families have settled along a proposed highway between Peru and the Atlantic. With few financial and administrative resources, and less knowledge of tropical farming techniques, even the most successful produce at subsistence levels. It is probable that many more colonists will find it impossible to make a living and will abandon their plots after the soil has been severely degraded by over-intense, inappropriate cultivation.

THE WATERSHED OR A UNIT FOR DEVELOPMENT

The fundamental unit of water resource management is the watershed basin. It may be a catchment area for the precipitation provided to stream channels or a larger basin which contributes water to a particular river channel or set of river channels. Biologists, ecologists, and biogeographers have turned to the watershed as an ideal unit in which to develop the ecosystem approach. Systems engineers and economists view the watershed as the basis for study and development in terms of river basin planning for economic development. Hydrologists and engineers consider the watershed to be a system within which a balance can be struck between inflow and outflow of water and energy.

The term watershed implies a domain or system within boundaries. The boundaries may be physical ones, such as watershed divides, or they may be defined by processes such as runoff. The watershed domain may be further divided into subcomponents of smaller watersheds or into subprocesses such as overland flow. Watersheds may be controlled with physical structures such as the series of dams operated by the Tennessee Valley Authority in the United States or uncontrolled as are most watersheds in developing countries.

In a social science context, the watershed has recently emerged as a logical unit of understanding and policy making. This emergence is closely connected, in the course of general economic development, with technological change and shifting demands for the main products of a watershed: hydroelectric power, water, timber, livestock, agricultural crops and the amenities.

THE ROLE OF THE WATER RESOURCE MANAGER

The water resource manager may be asked to control a watershed to meet some objective through the application of upstream treatments. His objectives may be to: increase water yields, provide a dependable supply of water for downstream use, improve forest, range and small farm production on the watershed, maintain a specified standard of water quality, reduce erosion and flood hazard, or enhance recreation and wildlife on the watershed. These tasks might involve the selection of appropriate cover types, harvesting methods, and plant cover or crop management systems. The water resource manager may have to consider the feasibility of reservoirs in combination with upstream watershed structures and land treatments. The development of surface or ground water for human and/or animal use or small scale irrigation may also be one of his responsibilities. The water resource manager must be knowledgeable in hydrology and he must be always aware of the needs, customs and traditions of the people who live within and depend directly upon the watershed areas for their livelihoods. The lives of those people living downstream from a watershed are also affected by its multiple and integrated products. Perhaps the most important task of the water resource manager is to apply his skills toward solving, in ways which will be of greatest benefit to mankind, the numerous problems associated with land use which currently threaten large areas of the earth.

It is the task of the water resource manager to reduce this impact, but simply creating new sources of water will not solve the problem. In fact, the development of water in dry environments is often a major cause of desertification. With water, livestock numbers inevitably increase, and each new watering spot becomes a nucleus for further expanding the desert. The water resource manager in dry environments must not only know the techniques of water development, but must confront the dilemma of: what is essential to the survival of society over the long term is usually contrary to what is essential to the survival of the individual over the short term.

The watershed manager in humid, tropical watershed lands must know small farming practices and alternatives to these practices, transport systems and economic marketing, and the hydrology and soils of humid tropical regions. In steep or mountainous regions, he must be familiar with the techniques of erosion control, reforestation, and forest management. He must deal with the problems of shifting cultivation, fuel wood harvesting, and forest grazing. Groundwater development and stream control may be an important part of his job.

THE DEVELOPMENT OF WATER RESOURCES

There is clear evidence that the physical potential exists on earth to feed a much larger population than now lives here. Despite this encouragement, it must be remembered that the resources of individual countries vary widely. Even India is capable of producing much more food than is now being grown because of its abundant sunlight and deep soils.

Water resource development takes a long time before it yields benefits. Political leaders in both the rich and poor countries have short term goals. They focus on immediate and popular concerns. Yet the conservation and production of the resources of watershed lands depend on long term and expensive commitments. Both the developed and developing countries must be ready to make this commitment to the development of the world's watershed lands if future worldwide disaster is to be avoided.

It is important to recognize that the problems of watershed lands do not necessarily arise from physical limitations nor from lack of technical knowledge. The limitations on production and abundance are found in the political and social structures of nations and the economic relations among them. The resources are there, and their successful development depends upon the will of men. The water resource manager can help strengthen this will by presenting and implementing good, practical solutions for developing the productivity of watershed lands which will provide the greatest benefit to man in the long run.

It must be pointed out that solutions do exist. Much is known and much more remains to be learned. The problems are complex and touch sensitive areas of the political, economic and technological structures of nations. Solutions will not be easy to find. They will require knowledge, imagination and courage but they can be obtained when the best minds endeavor to develop wise policies that will also be acceptable to the public.

This course has been developed for medium level technicians and professionals engaged in the management and development of watershed lands in developing nations. A major aim of this syllabus is to provide the water resource technician or manager with information which will help him improve present land use practices and inform him of other concepts and techniques in land and water use.

It should be understood that because of the large scope of this syllabus, exact solutions to each specific problem of watershed lands as they may exist under the physical, social and economic conditions in each of the developing nations cannot be given.

Watershed lands are defined broadly as habitable areas of the earth, but do not include well defined agricultural lands, urban areas, or special reserve areas. Because the production from these lands is linked with water, a basic portion of the course will deal with fundamentals of hydrology; and, because most of the problems in developing the multiple products of watershed lands are of social and economic origin, the course will emphasize this aspect of development.

CHAPTER II

STATISTICAL METHODS

INTRODUCTION

To many, statistical methods and procedures appear to limit progress. At the very least, people may be frustrated when attempting to apply statistical methods and procedures to interpret statistical analyses.

Much of the above-mentioned difficulty may be due to not understanding the basic objectives of statistics. Essentially, two primary objectives exist: to estimate population parameters and to test hypotheses about these parameters.

An example of the first objective is the application of statistical techniques to estimate the mean (average) of a population. The statistician's job is to derive proper methods of collecting the required source data and, then, calculating the desired statistic (*e.g.*, the estimated population mean).

An example of the second objective is to test the hypothesis (theory) that the estimated population mean equals or exceeds a predetermined value. It is the statistician's job to develop appropriate tests of hypotheses to satisfy this objective. Here, emphasis will be placed on the first objective, specifically, to develop estimates of population parameters from a series of random values obtained from a sample of a population.

DEFINITIONS

To apply statistical methods and procedures to natural resource management problems, it is necessary to develop a working knowledge of the terms commonly employed in statistics.

The term *statistics*, for instance, has two accepted meanings. Statistics (plural) refers to the collection or organization of source data (*i.e.*, annual lumber production in Arizona). Statistics (singular) is the science of analyzing the collected measurements and, guided by the results of the analysis, inferring general truths.

A complete aggregate of individuals or items in one category is a *population*. An *infinite* population is composed of practically an unlimited number of individuals or items; while, a *finite* population is made-up of a limited number of individuals or items.

A *population parameter* (*i.e.*, the mean) is a quantitative characteristic which describes a population. A *statistic* is a quantitative characteristic which describes a sample obtained from a population. Statistics based on samples are used to estimate population parameters.

Measurements or observations of small portions of a population is a *sample*. It is not information about the sample which is being sought, rather, about the population from which the sample was taken. The assumption is made that information obtained from a sample also holds for the population.

A measurable characteristic which varies in amount or magnitude (tree volume *etc.*) is a *variable*, or variate. Variables that are capable of exhibiting every possible value within any specified range are *continuous* variables; variables that are manifested in limited graduations or isolated values are *discrete* variables, or discontinuous variables. A variable of an associated pair whose value is considered to depend upon that of the other variable in the pair is a *dependent* variable; a variable of an associated pair whose value is considered to determine (or predict) that of the other variable in the pair is an *independent* variable. (In some cases, two or more independent variables can be used in association with one dependent variable.) The definitions of other terms relevant to statistical methods and procedures may be found in standard references dealing with statistical techniques.

DISTRIBUTION FUNCTIONS

A definite pattern of frequency of occurrence of units of each of a series of equal classes is a *frequency distribution function*. A frequency distribution function shows, for a population, the relative frequency with which different values of a variable (X) occur. By knowing the frequency distribution function, it is possible to determine what proportion of the individuals are within certain size limits.

Each population has its own distinct frequency distribution function. However, there are certain general types of functions that occur quite often. The most common are the normal, the binomial, and the Poisson. The *normal frequency distribution*, which is the familiar

bell-shaped distribution, is widely used in statistical analyses of watershed resources measurement (Figure 1). Theoretically, the normal frequency distribution exhibits the following properties: the mean, median, and mode are identical in value; small variations from the mean occur more frequently than large variations; and positive and negative variations about the mean occur with equal frequency.

The *binomial frequency distribution* is associated with data where a fixed number of individuals are observed on each unit and the unit is characterized by the number of individuals having some particular attribute. The *Poisson frequency distribution* may arise where individual units are characterized by a count having no fixed upper limit, particularly if zero or very low counts tend to predominate.

In addition to knowing the relative frequency that different values of a variable (X) occur in a population, one may also wish to know what proportion of a population lies between specified limits of X. For example, a watershed resources manager might wish to know what proportion of all precipitation events occurring on a river basin lie within a particular interval of X values, where the interval of X values defines a range in precipitation amounts. To obtain this sort of information, it is necessary to construct a *cumulative frequency distribution* function. Normally, to develop a cumulative frequency distribution function, values of X are cumulated starting with the smallest value of X and proceeding to the largest value (Figure 2). Cumulative frequency distribution functions that are developed by starting with the largest value of X and proceeding to the smallest value are commonly referred to as *exceedence curves*.

BASIC TERMS AND CALCULATIONS

To develop an understanding of statistical methods and procedures, it is important to obtain a working knowledge of basic terms and calculations.

Measures of Central Tendency

Many problems in natural resource measurements require the determination of a central value of a series of random values obtained from a sample of a population. Often, some kind of "average" is desired, but this is not the only measure of central tendency.

Perhaps the *mean* (or average) is the most familiar and commonly used measure of central tendency. Given source data obtained from a simple random sample (note: all statistical formulae described in this chapter have their roots in simple random sampling), the mean is calculated as follows:

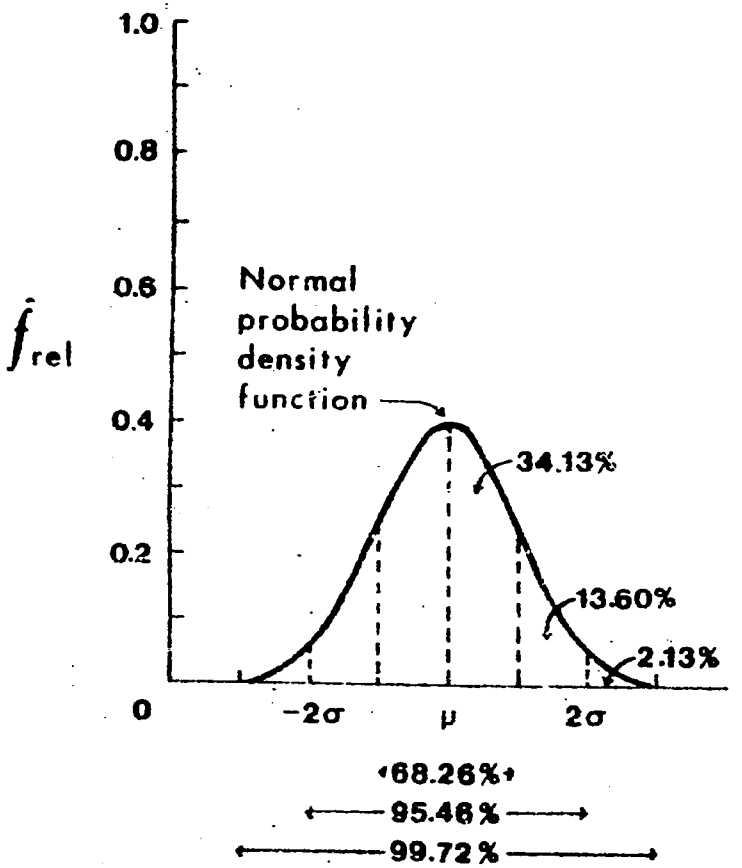


Figure 1. The normal frequency distribution function.

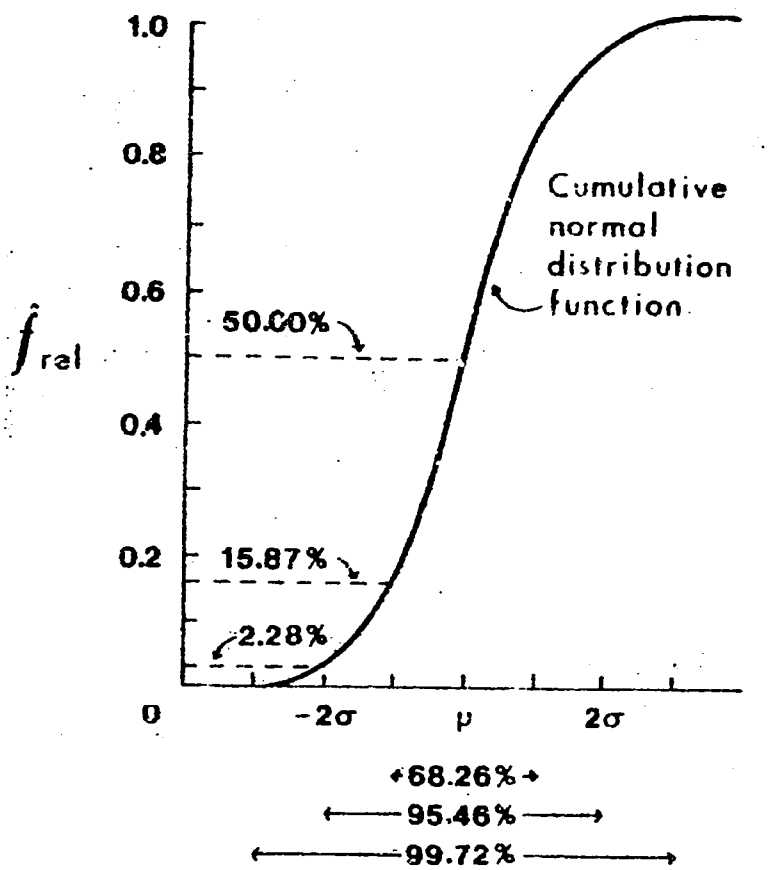


Figure 2. The cumulative frequency distribution function.

$$\bar{x} = \frac{\Sigma x}{n}$$

where:

$\bar{x}$ = estimated population mean
x = individual random value in the sample series
n = number of random values in the sample series (*i.e.*, sample size).

Another measure of central tendency is the *median*. The median of a series of random values obtained from a sample of a population, arranged (ranked) in order of size, is the value halfway through the series. If the number of random values is odd (3, 5, 7, *etc.*), little problem exists in selecting the median. However, if the number of random values is even (4, 6, 8, *etc.*), the "true" median is the value halfway between the two central values.

Still another measure of central tendency is the *mode*. When a series of random values is arranged by classes and frequencies (*i.e.*, a frequency distribution), in many cases one class (or a few classes) show the highest frequency of occurrence. The class (or classes) with the highest frequency of occurrence indicates the mode (or modes).

In applying statistical methods and procedures to natural resource measurement problems, it is often assumed that the basic measurements exhibit a normal frequency distribution. With a normal frequency distribution, the mean, median, and mode are identical. However, if the basic measurements are not normally distributed, these measures of central tendency are not identical. In these latter instances, care must be exercised to select the measure of central tendency most appropriate to the specific problem.

Measures of Dispersion

Measures of central tendency are fundamental descriptions of a series of random values obtained from a sample of a population. However, other measures may also be necessary for a "finer" definition of a series of random values. Measures of dispersion (or variability) serve this purpose since they define the extent to which individuals in a series vary from the central tendency.

The *range* represents the total interval between the smallest and largest values in a series of random values obtained from a sample of a population. It gives preliminary information on dispersion of random values in a series.

Perhaps the most important measure of dispersion is the *variance*, which characterizes the variability of individual random values about the mean. This measure gives an idea of whether most individuals in a series are close to the mean, or spread out. Given basic source data obtained from a simple random sample, the variance is calculated as follows:

$$s^2 = \frac{\Sigma(x - \bar{x})^2}{n - 1}$$

where:

s^2 = estimated variance

and the other terms are defined as above.

Another mathematical expression of the variance, and a formula more easily solved, is:

$$s^2 = \frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n - 1}$$

where all terms are defined as above. The square root of the variance (s) is the *standard deviation*, which is used in calculating the coefficient of variation, among other statistics.

Generally, a series of random values obtained from a sample of a population which exhibits a large mean shows more variability than a series of values from a population with a small mean. The *coefficient of variation* facilitates comparisons of variability about different sized means. It is a measure of relative variability. Given basic data obtained from a simple random sample, the coefficient of variation is calculated as follows:

$$CV = \frac{s}{\bar{x}}$$

where:

CV = estimated coefficient of variation
s = standard deviation (square root of the variance)
$\bar{x}$ = estimated population mean

Usually, there is variation among the individuals in a series of random values obtained from a sample of a population, which can be measured by calculating the variance. It is conceivable, therefore,

that variation may also exist among a series of estimated means calculated from a set of different random samples obtained from a population. The *standard error of the mean* is a measure of dispersion among different sample means, just as the variance is a measure of dispersion among individuals in a series of random values.

Fortunately, it is not necessary to take many different random samples to calculate the standard error of the mean. A satisfactory estimate can be calculated directly from a single sample.

The calculation of the standard error of the mean depends on how the random sample was selected. If the sample was drawn from an infinite population (*i.e.*, a population that is large relative to the sample size), and given basic data obtained from a simple random sample, the standard error of the mean is calculated as follows:

$$s_{\bar{x}} = \sqrt{\frac{s^2}{n}} = \frac{s}{\sqrt{n}}$$

where:

$s_{\bar{x}}$ = estimated standard error of the mean

and the other terms are defined as above.

Confidence Limits

The statistical way of indicating the reliability of an estimate of a population parameter (a statistic) is to establish *confidence limits*. For an estimate of a population parameter made from a normally distributed population, and given basic source data obtained from a simple random sample, confidence limits about an estimated mean are calculated as follows:

$$CI = \bar{x} \pm (s_{\bar{x}})(t)$$

where:

CI = estimated confidence limits
$s_{\bar{x}}$ = estimated standard error of the mean
t = tabular value (Table 1) used to define a statement of the level of probability for statistical inferences.

Table 1. The Distribution of the t Statistic

df	Probability 0.1	0.05	0.01
1	6.314	12.706	63.657
2	2.920	4.303	9.925
3	2.353	3.182	5.841
4	2.132	2.776	4.604
5	2.015	2.571	4.032
6	1.943	2.447	3.707
7	1.895	2.365	3.499
8	1.860	2.306	3.355
9	1.833	2.262	3.250
10	1.812	2.228	3.169
11	1.796	2.201	3.106
12	1.782	2.179	3.055
13	1.771	2.160	3.012
14	1.761	2.145	2.977
15	1.753	2.131	2.947
16	1.746	2.120	2.921
17	1.740	2.110	2.898
18	1.734	2.101	2.878
19	1.729	2.093	2.861
20	1.725	2.086	2.845
25	1.708	2.060	2.787
30	1.697	2.042	2.750
∞	1.645	1.960	2.576

The Distribution of t

A portion of the distribution of the t statistic is given in Table 1. To use with a simple random sample, the column labeled *df* (degrees of freedom) will equal one less than the sample size (n - 1). The columns labeled *probability* refer to the odds specified. In the development of confidence limits at the 90 percent probability level, for instance, the t values in the 0.10 column are used. If confidence limits at the 95 percent probability are specified, the 0.05 column is used *etc.*

SAMPLING TECHNIQUES

Obviously, it may be desirable to have a complete census of a population. A complete enumeration is rarely possible, however, and a sample is usually taken.

Sample Size

Samples cost money, but so do errors. The primary objective of sampling is to take enough observations to obtain a desired level of precision--no more, no less. The number of observations to be taken in a sample depends upon two factors: the inherent variability of the population being sampled and the desired level of precision (*i.e.*, sampling error).

The equation used to calculate a sample size is derived by transforming the relationship expressing the confidence limits for the mean. Here, it is desired to have the product $(s_{\bar{x}})(t)$ equal to or less than some arbitrarily specified level of precision. Thus:

$$E = (s_{\bar{x}})(t)$$

where:

E = specified level of precision

and the other terms are defined as above. This relationship may also be expressed as follows:

$$E = \sqrt{\frac{s^2}{n}}\ (t)$$

The equation used to calculate a sample size is derived by squaring all of the terms in the above relationship, and then solving for n (the sample size). Therefore, assuming that a simple random sample will be implemented, the sample size is calculated as follows:

$$n = \frac{(s^2)(t^2)}{E^2}$$

where:

n = sample size

and the other terms are defined as above. To calculate sample size, it is necessary to have an estimate of the variance, which can be obtained from a preliminary sample of the population. Also, a t value at the appropriate level of probability is needed and the level of precision must be specified.

Size and Shape of Individual Sample Units

The size and shape of the individual sample units affect the cost and precision of sampling. Often, small plots exhibit more variability than large plots and, in many instances, circular plots may be easier to establish than rectangular plots. It is necessary, therefore, to select the size and shape of individual sample units that are compatible with the sampling objectives and the inherent variability of the population being sampled.

Sampling Designs

After computing the sample size and selecting the appropriate size and shape of the individual sample units, it becomes necessary to allocate the sample units to obtain source data necessary to estimate the required population parameters. The problem is to decide on the most efficient sampling design in terms of the sampling objectives and the characteristics of the population.

Many sampling designs and variations of sampling designs exist. Three basic sampling designs often employed in natural resource measurements are: simple random sampling, stratified random sampling, and systematic sampling.

The fundamental idea behind *simple random sampling*, when allocating a sample of n units is that every possible combination of n units has an equal chance of being selected. And, the selection of any given sample unit is completely independent of the selection of

all other units. (All of the statistical methods and procedures previously discussed in this chapter have their roots in simple random sampling.)

Often, previous knowledge of a population can be used to increase the precision, or usefulness, of a sample. *Stratified random sampling* takes advantage of certain types of information about a population by grouping homogeneous units of a population together on the basis of some characteristic (vegetation, cover type, age class, utilization class, *etc.*). Then, each unit, or stratum, is sampled (using a simple random sampling design) and the group estimates are combined to estimate population parameters.

As the name implies, sample units in a *systematic sample* are allocated, not randomly, but mechanically, according to a predetermined pattern. Systematic sampling has been widely used in natural resource measurements for two reasons: the location of individual sample units in the field is often easier and cheaper, and there is a feeling that a sample deliberately spread out over a population may be more "representative" than a simple random sample. Statisticians may not argue against the first reason, but they are less willing to accept the second. Estimation of sampling errors of a sample requires more knowledge about a population than is usually available.

REGRESSION ANALYSES

An important statistical tool often used in analyzing natural resource measurements is *regression analysis*. The basic objective of regression analysis is to quantify relationships between two or more variables.

A *simple regression* defines the relationship between a dependent variable (Y) and one independent variable (X). A simple *linear* regression is used with a straight-line relationship between two variables. Other simple regression analyses may involve nonlinear relationships (parabolic, exponential, logarithmic, *etc.*).

The general model for a simple regression is:

$$Y = a \pm b\ (X)$$

where:

Y = dependent variable
X = independent variable
a,b = regression coefficients estimated by statistical formulae, as given below:

$$b = \frac{\Sigma(XY) - \frac{(\Sigma X)(\Sigma Y)}{n}}{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}$$

$$a = \overline{Y} - b(\overline{X})$$

There are several methods of determining "how well" a regression line fits the sample data. Often, the coefficient of determination (r^2) is calculated, as follows:

$$r^2 = \frac{\left(\Sigma(XY) - \frac{(\Sigma X)(\Sigma Y)}{n}\right)^2}{\left(\Sigma X^2 - \frac{(\Sigma X)^2}{n}\right)\left(\Sigma Y^2 - \frac{(\Sigma Y)^2}{n}\right)}$$

One common means of interpreting the coefficient of determination is: if the r^2 value is 0.65, "65 percent of the variation in Y is associated with X." For example, 65 percent of the variation in annual precipitation amount is "explained" by elevation.

Frequently, the dependent variable is related to more than one independent variable. If this relationship can be estimated, using *multiple regression* analysis, it may allow more precise predictions of the dependent variable than is possible by a simple regression.

The general model for a multiple regression is

$$Y = a \pm b(X_1) \pm c(X_2) \pm \ldots$$

where:

a,b,c = estimated regression coefficients.

KEY TO BASIC STATISTICAL TESTS

Many of the foregoing definitions are basic. The concepts presented are quite general and underlie most of statistical theory. Little has been offered in terms of specific direction for the user. Obviously, further and more specialized training is one remedy. However, until this is obtained, there are several points that a user should consider to improve his general statistical performance:

(1) First, and probably most importantly, *understand the method you intend to use.* It should be evident that statistics is an extensive and complex subject. In fact, statisticians are often unsure of their own conclusions and commonly discuss

them with their colleagues for verification. So, *be sure that you know the method thoroughly;* then, you will be much less likely to misuse it.

(2) *Keep it simple.* Where there is a choice, use the simpler method. There is no need to apply the latest analysis tool if an older, simpler one tells us what we want to know. Furthermore, there is less chance of going wrong when the simpler method is used.

(3) *Plan ahead.* To obtain an adequate performance, planning must be done at the outset. Be sure to allow enough time for all aspects of an investigation. Unfortunately, a common practice is to leave analysis and interpretation to a time when there is no possible way to do an adequate job.

(4) *Adopt a critical attitude* when examining the results of an analysis. Try to let the data (rather than your preconceptions) lead your thoughts.

(5) *Statistical analysis cannot be completely reduced to a routine process.* In particular, do not be led astray by "computer analysis" packages. While many computer programs are good tools, it should be kept in mind that computers do not analyze --and they never will. Become familiar with programs which are useful, but do not surrender your analyses to them.

(6) *Respect your professional judgment.* Your training and experience give you an ability to see the elements and relationships in your science and profession better than a layman.

To assist watershed resources managers in selecting the appropriate statistical test to apply in given situations, the following key to basic statistical tests is presented. While this key includes many of the commonly employed statistical methods and procedures available for consideration, the user is advised to consult statistical references before making a final decision as to approach in analyses.

Step Number	Go to Step Number
1. Enumeration (or attribute or discrete) data only	2
1. Continuous (or measurement) data; or both continuous and enumeration data	4
2. Only two criteria of classification for each attribute	CHI-SQUARE 2x2
2. More than two criteria of classification for one or more of the attributes	3

Step Number		Go to Step Number
3.	Two criteria for one attribute, more than two for the other . . . . . CHI-SQUARE Rx2	
3.	More than two criteria for each attribute . . . . . CHI-SQUARE RxC	
4.	One group of sampling units	5
4.	Two or more groups of sampling units	8
5.	Two variables measured in each sampling unit	6
5.	More than two variables measured in each sampling unit . . . MULTIPLE REGRESSION	
6.	Neither variable dependent on the other . . . . . CORRELATION	
6.	One variable dependent on the other	7
7.	Straight line relation between variables . . LINEAR REGRESSION	
7.	Curved line relation between variables. CURVILINEAR REGRESSION	
8.	One variable measured for each sampling unit	9
8.	Two or more variables measured for each sampling unit	12
9.	Only two groups of sampling units	10
9.	More than two groups of sampling units . . . . . ANALYSIS OF VARIANCE	
10.	Individuals from one group paired with those in the other. t-TEST, PAIRED INDIV	
10.	Individuals not paired	11
11.	Groups of equal size . . . . . t-TEST, EQUAL GROUPS	
11.	Groups of unequal size . . . . t-TEST, UNEQUAL GROUPS	
12.	Two variables measured in two or more groups . . . . . COVARIANCE	
13.	Three or more variables measured in two or more groups . MULTIPLE COVARIANCE	

CHAPTER III

THE HYDROLOGIC CYCLE

INTRODUCTION

The hydrologic balance or water budget is both a fundamental concept of hydrology and a useful method for the study of the hydrologic cycle. The hydrologic cycle represents the processes and pathways involved in the circulation of water from land and water bodies, to the atmosphere and back again (Figure 1). The cycle is complex and dynamic but can be simplified if we categorize components into input, output or storages. Input such as rainfall, snowmelt and condensation must balance with changes in storage and with outputs which include streamflow, groundwater, and evapotranspiration. The water budget is essentially an accounting procedure which quantifies and balances these components.

The quantities of water in the atmosphere, soils, groundwater, surface water and other components are constantly changing because of the dynamic nature of the hydrologic cycle. At any one point in time, however, quantities of water in each component can be approximated. If we consider the total water resource on the earth, only about 3 percent is fresh water. About 77 percent of this fresh water is tied up in the polar ice caps and glaciers, and 11 percent is stored in deep groundwater aquifers, leaving 11.6 percent for active circulation. Of this 11.6 percent, only 0.55 percent exists in the atmosphere and biosphere (from the top of trees to the lowest roots). The atmosphere redistributes evaporated water by precipitation and condensation. Components of the biosphere partition this water into runoff, soil water storage, groundwater or back to the atmosphere.

The hydrologic processes of the biosphere and the effects of vegetation and soils on these processes are of particular interest to watershed managers. Processes such as precipitation, infiltration, percolation, evaporation, transpiration, surface-runoff, subsurface flow and groundwater flow can all be affected by land management activities. Likewise, man can alter the magnitude of various storage

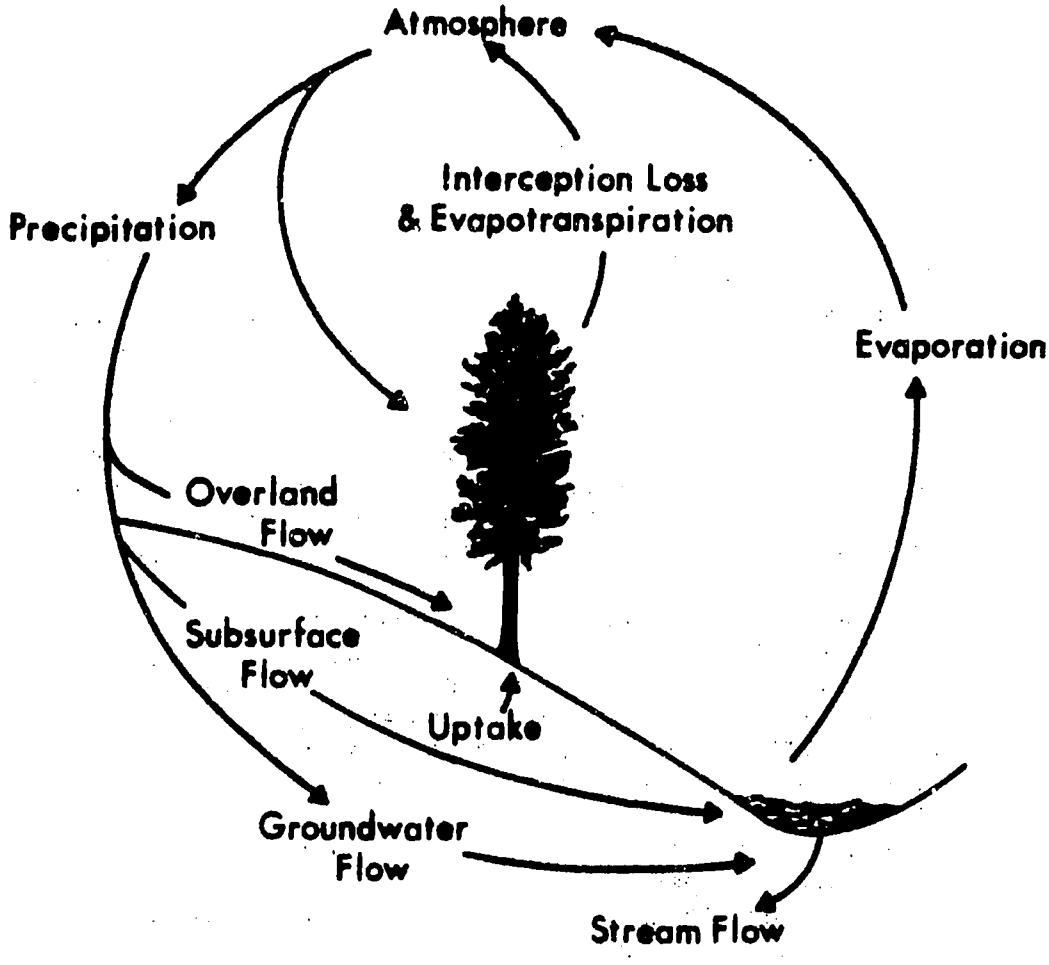


Figure 1. The hydrologic cycle.

components including soil water, snowpacks, lakes, reservoirs and rivers. With a water budget we can examine existing watershed systems, quantify the effects of management impacts on the hydrologic cycle and in some cases predict or estimate the hydrologic consequences of proposed or future activities.

HYDROLOGIC PROCESSES

Precipitation

Precipitation occurs when three conditions in the atmosphere are met: (1) the atmosphere becomes saturated, (2) small particles or nuclei are present in the atmosphere upon which condensation or sublimation can take place, and (3) water or ice particles must unite and grow large enough to fall under the influence of gravity. Saturation results when either the air mass is cooled until the saturated vapor pressure is reached or when moisture is added to the air mass. Rarely does the direct introduction of moist air cause precipitation. More commonly precipitation occurs when an air mass is lifted, becomes cooled, and reaches its saturated vapor pressure. Air masses are lifted as a result of (1) frontal systems, (2) orographic effects, or (3) convection. Different storm and precipitation characteristics result from each of these lifting processes.

Frontal precipitation occurs when two air masses of different temperature and moisture content are brought together by general circulation and air becomes lifted at the frontal surface. A *cold front* results from a cold air mass replacing and lifting a warm air mass. Conversely, a *warm front* results when warm air rides up and over a cold air mass. Cold fronts are characterized by high intensity rainfall or relatively short duration and usually have less areal extent than warm fronts. Widespread, gentle rainfall is more characteristic of warm fronts.

Orographic precipitation occurs when an air mass is forced up and over mountain ranges as a result of general circulation. As the air mass becomes lifted, a greater volume of the air mass reaches saturation vapor pressure resulting in a general increase in precipitation with increasing elevation. Once the air mass passes over mountains, a lowering and warming of the air occurs. This results in a rain shadow effect on the leeward side of mountain ranges.

Convective precipitation, as characterized by summer thunderstorms, is the result of excessive heating of the earth's surface. When the air adjacent to the surface becomes warmer than the air mass above, lifting occurs. As the air rises and condensation takes place, the latent heat of vaporization is released, more energy is added to the air mass and consequently more lifting occurs. Rapidly uplifted air can reach high altitudes where water droplets become frozen and hail forms or becomes

intermixed with rainfall. Such rain or hail storms are of the most severe precipitation events anywhere. High intensity, short duration rainfall over rather limited areas characterize convective storms. Numerous thunderstorms can occur over a widespread area, however, and can cause flash flooding.

Interception--Net Precipitation

Once rainfall or snowfall has occurred, the type, extent, and condition of vegetation can strongly influence where and how much precipitation reaches the soil surface. Dense coniferous forests in northern latitudes and the multi-storied canopies of the tropics can catch and store large quantities of precipitation which ultimately evaporate and are lost from the watershed. In the tropics, over 70 percent of the annual precipitation may be lost via interception. As we proceed to more arid or semi-arid environments, and more sparse vegetation, the interception losses become less important. Although we generally consider forests to have the highest interception losses, at times, grasses may intercept 10 to 20 percent of gross precipitation.

Not all the precipitation which is caught by a forest canopy is lost to the atmosphere. Much may drip off the foliage or run down the stems and thereby reach the soil surface. Conversely, not all the precipitation that penetrates the forest canopy becomes available for either soil water or runoff. The litter which accumulates on the forest floor can store large quantities of precipitation which ultimately evaporate.

In most water budget studies, interception loss is considered to be an important storage term which should be subtracted from gross precipitation. The result is *net precipitation*, or that amount of precipitation that is available to either replenish soil water deficits or become surface, subsurface or groundwater flow out of the system.

Movement of Water Into and Through the Soil

The rate of new precipitation, once it reaches the forest floor or soil surface, depends upon the soil surface conditions and the physical characteristics of the soil itself. Of primary interest are those factors which affect the rate at which water can enter the soil and the subsequent rate of movement through the soil.

Plant material or litter on the soil surface influences the amount and rate of movement of water into the soil surface. Litter can be viewed as two hydrologically distinct layers: (1) an upper horizon composed of leaves, stems and other undecomposed plant material, and (2) a lower horizon of decomposed plant material which behaves much like mineral soil. The upper horizon protects the soil surface from the

energy of raindrop impact which could displace smaller soil particles into voids and effectively seal the soil surface. Plant debris also hinders any surface runoff which might occur and, in effect, minimizes overland flow. The lower horizon has a substantial storage capacity, over 200 percent by weight in some instances. Thus plant litter is important as both a storage component and as a protective cover which maintains an "open" soil surface condition favorable for high rates of water entry into the surface.

The process by which water enters the soil surface is called *infiltration*. Infiltration results from the combined forces of capillarity and gravity. If we applied water to a dry, medium textured soil, a very rapid initial infiltration rate would be observed. This high initial rate is due to the strong physical attraction of soil particles to water (capillarity). As time proceeds and the soil water content increases, the rate of infiltration eventually becomes a constant. At this time, infiltration is only as rapid as the rate which the soil can drain under the influence of gravity. The process of saturated flow through the soil mantle under gravitational forces is called *percolation*.

Evapotranspiration

Evaporation from soils, plant surfaces and water bodies, and transporation through plant stomata are often considered collectively as evapotranspiration (ET). Evapotranspiration is of particular interest to watershed managers because it strongly affects the water yield characteristics of an area and is often influenced by forest and range management practices.

The evaporation process is simply the net loss of water from a surface by means of a change in state of water from liquid to vapor. The requirements for evaporation or transpiration are:

(1) a flow of energy to the evaporating or transpiring surface;
(2) a flow of vapor away from these surfaces; and
(3) a flow of liquid water to these surfaces.

If one or more of these flows are changed, there is a corresponding change in the total ET loss from a surface. Conditions that control the net flow of energy by radiation, convection, and conduction to evaporating surfaces determine the amount of energy available for the latent heat of vaporization. The albedo or reflectivity of the evaporating surface determines the proportion of incident solar radiation that is absorbed by the surface. This absorbed solar radiation plus the net longwave radiation constitutes the net all-wave radiation which is available to evaporate water, heat the air, or heat the soil system. When water is readily available, most of this net radiation is utilized in the ET process. Some studies have shown that over 80 percent of net radiation is utilized in ET for well-watered soils with a dense

vegetative cover. As water becomes limiting, a greater proportion of the net radiation goes into heating the air and soil surfaces.

Runoff

Runoff refers to the various processes and pathways by which excess water becomes streamflow. Excess water represents that part of total precipitation which runs off the land surface and that which drains from the soil and is thus not consumed by ET. Some water flows rather quickly to produce streamflow yet other pathways have a detention storage time which may take weeks or months for excess precipitation to show up as streamflow. If we were to identify the major pathways of flow and compare these with a streamflow hydrograph (the graphical relationship of streamflow discharge (m^3/sec) plotted against time) from a watershed, the runoff process can be somewhat simplified (Figure 2).

A perennial stream, *i.e.*, one which flows throughout the year, is most likely being fed by groundwater, pathway "D" (Figure 2). This component sustains streamflow between periods of precipitation or snowmelt. Because of the long and tortuous pathways involved, groundwater flow, hence baseflow, does not respond quickly to moisture input.

Once rainfall or snowmelt occurs, several additional pathways of flow feed streamflow. The most direct pathway from precipitation to streamflow is that part which falls directly into the stream channel, called *channel interception* (A in Figure 2). This component causes the initial rise in the streamflow hydrograph and ceases soon after precipitation stops. *Surface runoff* or *overland flow* occurs from impervious areas or areas in which the rainfall rate exceeds the infiltration capacity of the soil (B). Some surface runoff is detained by the roughness of the soil surface, but nevertheless represents a quick flow response to moisture input, second only to channel interception. During a rainstorm, this component of the hydrograph would be relatively large for urban areas but typically insignificant for forested areas with deep soils.

Subsurface flow or *interflow* is that part of precipitation which infiltrates, yet arrives at the stream channel over a short enough time period to be considered a part of the storm hydrograph, illustrated as pathway "C" (Figure 2). This is considered to be the major contributing pathway of storm hydrographs from forested watersheds.

The sum of channel interception, surface and subsurface flow is called *direct runoff* or *stormflow*. Direct runoff is the part of the hydrograph of interest when we look at the flood-producing characteristics of most watersheds.

Although we can conceptually visualize the four major pathways of flow, subsurface flow is particularly difficult to measure or separate from the others. Also, the actual pathway from rainfall to

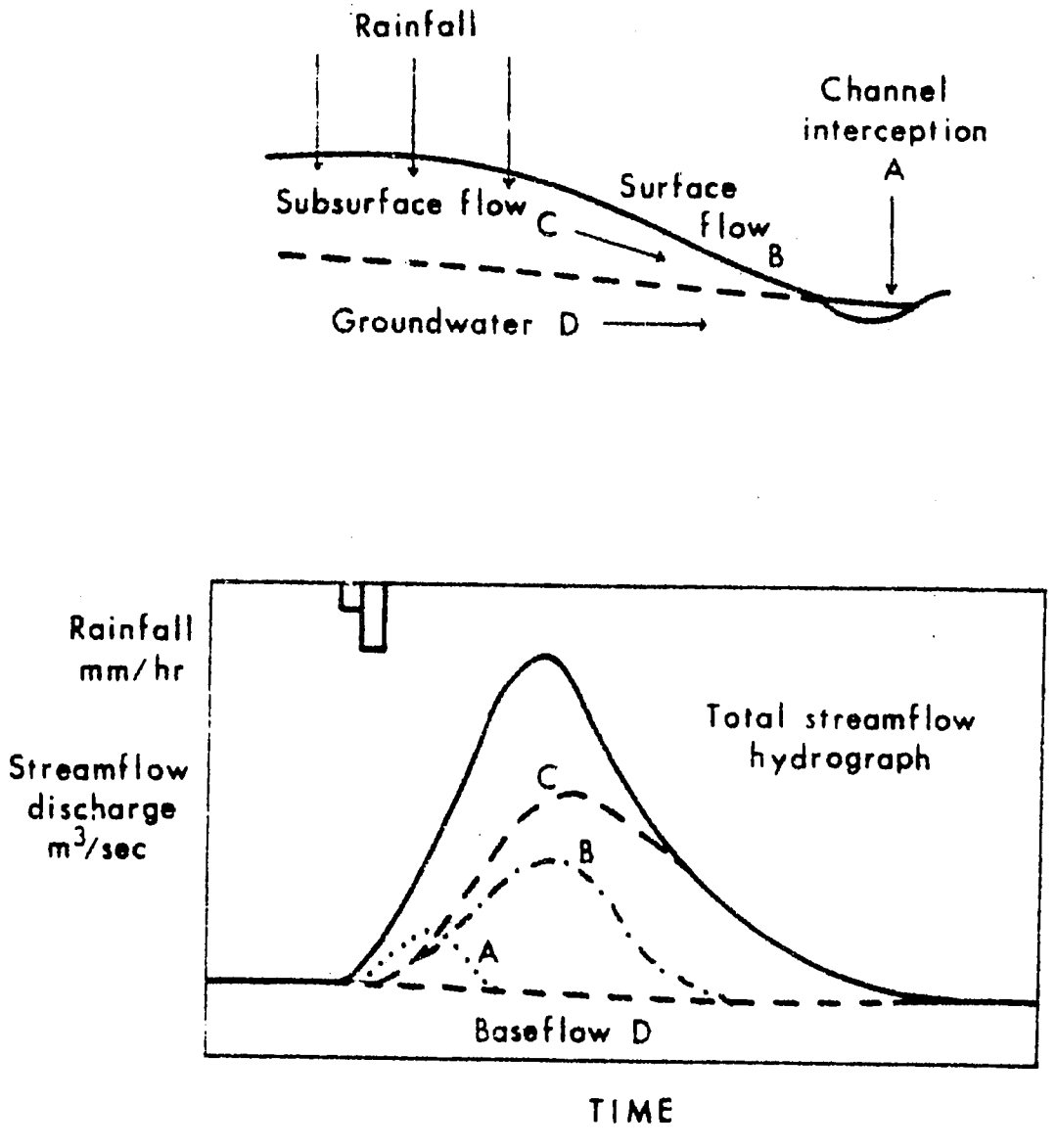


Figure 2. The relationship between pathways of flow from a watershed and the resultant streamflow hydrograph.

streamflow may in reality involve surface and subsurface flow. Water may infiltrate in one area and exfiltrate downslope and run over the land surface for some distance. Conversely, some surface runoff may collect in depressions in the land surface to be evaporated or infiltrated at some later time. By viewing the total streamflow hydrograph, therefore, we are seeing the total integrated response of a watershed to some quantity of moisture input.

WATER BUDGET CONCEPT

The water budget is simply an application of the conservation of mass principle to the hydrologic cycle. That is, for a given watershed and a certain time interval:

$$I - O = \Delta S$$

where:

I = inflow of water to the system
O = outflow of water from the system
ΔS = change in storage of the volume of water in the system.

Substituting with the hydrologic components of a watershed or river basin, the above relationship for a given time interval becomes:

$$P - (Q + ET) \pm L = \Delta S$$

where:

P = total precipitation
Q = total runoff or streamflow, including measured groundwater flow
ET = total evaporation and transpiration losses
L = leakage out of the system by deep seepage (-) or leakage into the system (+) from an adjacent watershed
ΔS = change in storage in the system

Water budgets can be determined for small plots, headwater drainages, large river basins or even continents. If a water budget was to be determined over one year for all land and water areas, the total change in storage would usually be very small.

By looking at the ratio ET/P we can make relative comparisons of the abundance of water. A high ratio indicates a more arid climate (Australia), a lower ratio a more wet climate (Europe). Water budgets for such large areas do not tell us anything about the distribution of precipitation and streamflow within the continents. The unequal distribution of water supplies over continental areas and with respect to season results in many of our water resource problems. Thus, water

budget studies are typically performed on river basins or individual watersheds, and often for time periods shorter than one year.

THE WATER BUDGET AS A HYDROLOGIC METHOD

The application of a water budget as a hydrologic tool is relatively simple; if all but one component of a system can either be measured or estimated, then we can solve directly for the unknown part.

The annual water budget for a watershed or drainage basin is often used because of the simplifying assumption that changes in storage over a year period are very small in many instances. Computations for the water budget could be made, beginning and ending with wet months (A - A') or dry months (B - B') as illustrated in Figure 3. In either case, the difference in soil water content (storage) between the beginning and ending of the period is small. By measuring the total precipitation and streamflow for the year, the annual evapotranspiration (ET) can be estimated from the following:

$$ET = P - Q$$

Provided that a reasonable estimate of precipitation on the watershed is obtained, the next major assumption is that the total outflow of liquid water from the watershed has been measured. This implies that there is no loss of water by deep seepage to underground strata and that all groundwater flow from the watershed is measured at the gaging site. If certain kinds of geologic strata such as limestone underlie a watershed, the surface watershed boundaries may not coincide with the boundaries governing the flow of groundwater. In such cases there are two unknowns in the water budget, ET and groundwater seepage (L), which result in:

$$ET + L = P - Q$$

If losses to groundwater are suspected, they can sometimes be estimated by specialists in hydrogeology who have knowledge of geologic strata and respective hydraulic conductivities.

The change in storage can sometimes be difficult to quantify when we cannot assume that change in storage is small over the time interval. Estimates of change in storage become more difficult as computational interval diminishes and as the size of the area under investigation increases. The change of storage for a small vegetated plot may involve only periodic measurements of soil water content. Such measurements can be made gravimetrically (weighing a known volume of soil, drying the soil in an oven and reweighing), with neutron attenuation probes or other methods. As the size of the area increases, the storage changes of surface reservoirs, lakes and groundwater must also be considered. Stage-elevation-outflow data are needed to evaluate

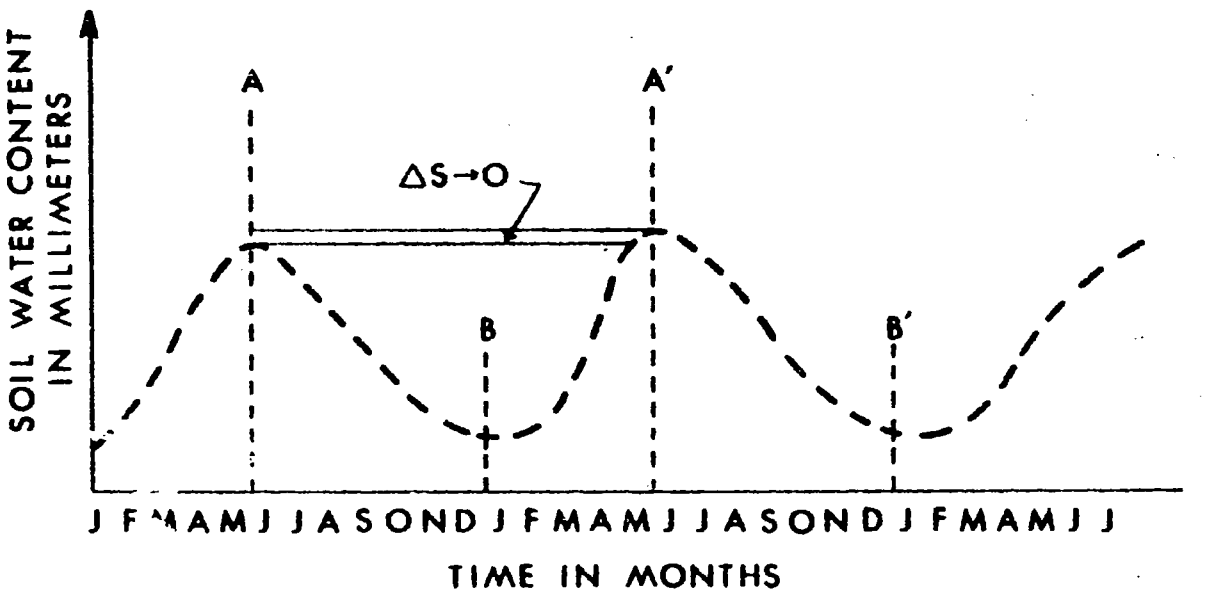


Figure 3. Hypothetical fluctuation of soil moisture on an annual basis.

changes in lake or reservoir storage, and are not particularly difficult to analyze when compared with storage changes in surface soils and geologic strata.

The soil-water-storage component is usually distinguished from geologic strata in water budget computations, as that part which can be depleted by evapotranspiration. Diurnal as well as seasonal changes in storage of the soil mantle can be significant. The underlying geologic strata, on the other hand, represents a zone in which changes in storage are slow. Recharge and drainage account for changes in storage within strata below the soil mantle. These strata along with unconsolidated sand and gravel deposits are the sources of sustained streamflow yield (baseflow) from many watersheds.

Energy Budget

Solar energy is the driving force of the hydrologic cycle. As with the water budget, the components of the energy cycle can be identified and partitioned. Some of these components can then be related to parts of the water budget. The linkage between the water and energy budgets is direct; net energy available at the earth's surface is apportioned largely as a result of quantities of water in the various storage components. The primary purposes for studying the energy budget, like the water budget, are to develop a better understanding of the hydrologic cycle and to be able to quantify or estimate certain parts of the cycle. The energy budget has been widely used to estimate evaporation from bodies of water, the potential evapotranspiration for terrestrial systems, and has also been used to estimate snowmelt.

The earth's surface neither gains nor loses significant quantities of energy over long periods of time, but there may be a net gain or a net loss for any given time interval due to different types of solar radiation. The net radiation is the residual of incoming and outgoing short-wave and long-wave radiation. The albedo or reflectivity of the terrestrial system determines the proportion of total incoming short-wave radiation which is reflected from natural surfaces back into the atmosphere. The apportionment of solar radiation is also affected by weather conditions. On the average, about 85 percent of the total downward stream of solar radiation is direct solar, but during cloudy days the diffuse or scattered short-wave radiation is the only short-wave input. Likewise, the long-wave radiation components are affected by atmospheric conditions. A cloudy or hazy atmosphere essentially traps long-wave radiation which would otherwise be lost from the earth, resulting in a larger incoming component than an outgoing component. The emitting constituents of long-wave radiation in the atmosphere are primarily CO_2, O_3 and the liquid and vapor forms of water. Terrestrial objects absorb and radiate long-wave radiation very efficiently, approaching 100 percent. Therefore, reflectivity of long-wave radiation by terrestrial objects is considered negligible.

The energy budget (or energy balance) can be described by:

$$R_n = (S + s)(1 - \alpha) + I\downarrow - I\uparrow$$

where:

R_n = net radiation in langleys/time
S = direct solar radiation in langleys/time
s = indirect, scattered solar radiation in langleys/time
α = albedo, or reflectivity of surface to solar radiation
$I\downarrow$ = incoming longwave radiation in langleys/time
$I\uparrow$ = outgoing longwave radiation in langleys/time

Net radiation may either be positive or negative for any arbitrary time interval. When positive, R_n represents excess radiation energy for some time interval, which can be allocated in the following manner:

$$R_n = (L)(E) + H + G + P_s$$

where:

L = lantent heat of vaporation in calories/gram
E = evaporation in grams or centimeters^3
H = sensible heat in langleys
G = heat of conduction to ground in langleys
P_s = energy of photosynthesis in langleys

The net radiation (R_n) available at a surface is important from a hydrologic standpoint because it is usually the primary source of energy for evaporation, transpiration and snowmelt. Typically when snow is present, the majority of net radiation is apportioned to snowmelt (80 cal g^{-1}). In snow-free systems, the allocation of net radiation is highly dependent upon the presence or absence of water. If water is abundant and is readily available for evaporation and transpiration, then large amounts of energy are consumed in the evaporation process (about 585 cal g^{-1} at common terrestrial temperature). Little energy is left to heat the air or ground. On the other hand, if water is limiting, a greater amount of energy is available to heat the air, the ground surface and other terrestrial objects. Losses (or gains) of energy to the interior earth do not change rapidly with time and are usually negligible. Similarly, energy consumed in photosynthesis, although of unmeasurable importance to life on earth, is a very small quantity in hydrologic terms and is usually not considered.

WATER BUDGET EXAMPLE

Each watershed is a unique system which responds to precipitation and energy inputs according to its biological and physical characteristics. The following example should provide the reader with some insight into the usefulness of the water budget method.

Streamflow yield and other components of the hydrologic cycle can be obtained for tropical ecosystems by using a water budget to couple climatological records with knowledge of the watershed system. Average soil texture and depth, and the rooting depth or extent to which the existing forest community can deplete soil water should be known. Generalized relationships of soil texture and "plant available water" (Figure 4) can then be used with estimates of soil depth to obtain values of the total soil water holding capacity and the total water available for evapotranspiration. For most tropical forest ecosystems, roots are assumed to fully occupy the soil system and evapotranspiration is considered to occur at or near the potential rate. Estimates of potential ET and rainfall are then coupled with the above soil-plant characteristics to provide an accounting of water surplus or deficit for given time increments.

An example of mean monthly water budgets based on climatological data from two different areas in Thailand is presented in Table 1. The mean monthly rainfall (item 1) is the input item of the accounting method. Potential ET for each month is listed as item 4. Actual ET (item 5) is either the total available moisture (item 3) or the potential ET (item 4), whichever is smallest. The available soil water is determined as the difference between field capacity and permanent wilting point. The quantity of soil water available to plants when soils are fully recharged for Chanthaburi and Chiang Mai are 279 mm and 124 mm, respectively. The first month's calculation, without actual soil-water content data, would appear to be somewhat of a guess. Errors associated with unknown antecedent soil water status can be minimized, however, if the accounting begins with a month in which the soil is typically recharged with water. The month which ends the rainy season, in these examples October, is a good starting month. The total available moisture (item 3) is determined from the sum of the rainfall and the initial soil moisture content (item 2). The remaining available moisture (item 6) is determined as the difference between total available moisture and actual ET. Any amount in item 6 which is in excess of the soil-water capacity is calculated as runoff in item 8.

Historical data rather than mean monthly values can be analyzed in a similar manner as Table 1, if we were interested in evaluating the water yield associated with some observed sequence of rainfall, perhaps a drought period. Water budget analyses of drought sequences are useful for determining storage requirements for water supply or hydroelectric reservoirs. Likewise, sequential monthly values for several years could be analyzed "before and after" some management activity which

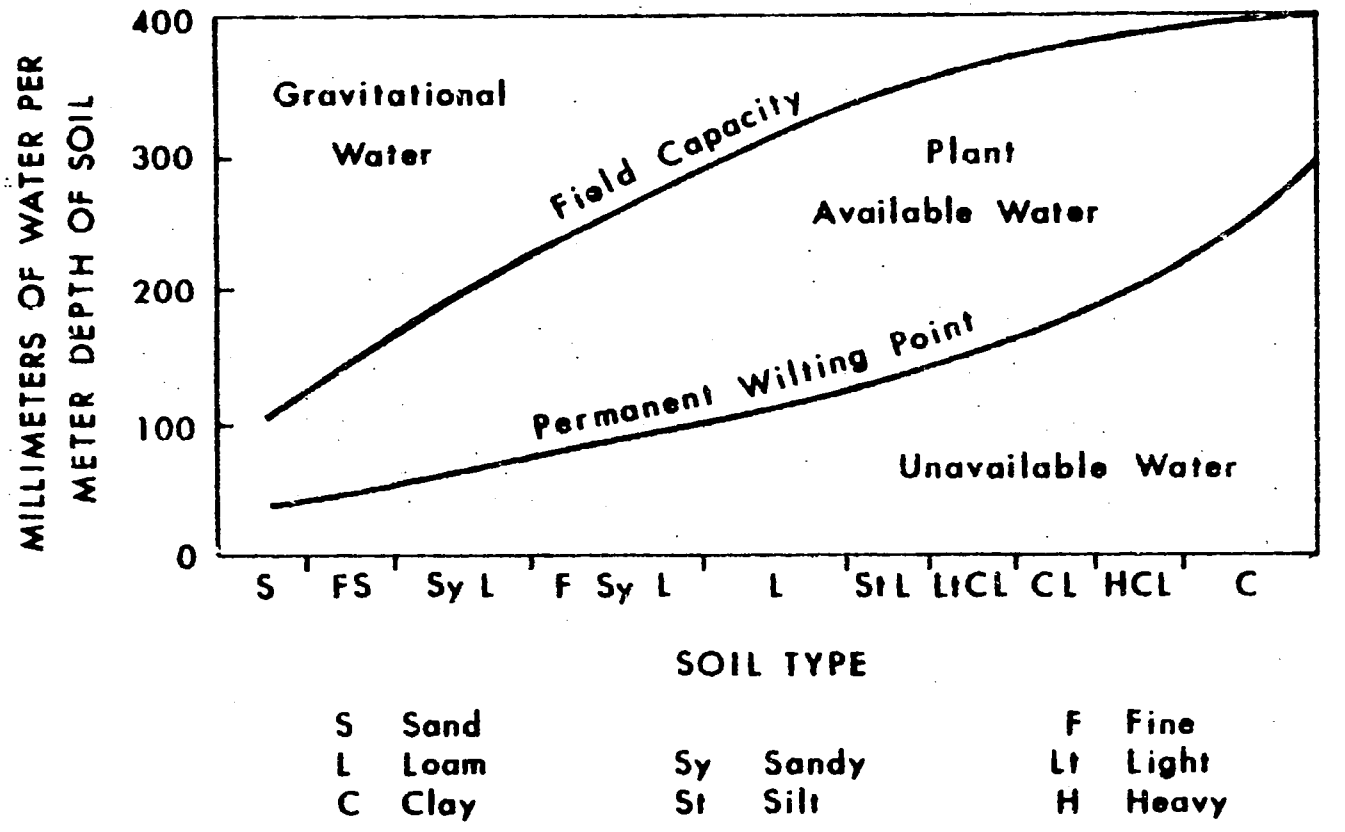


Figure 4. Typical water characteristics of different textural soils.

Table 1. Average monthly water budgets for two stations in Thailand.

Station: Chanthaburi, Thailand	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YR
							mm						
1. Average rainfall	231	74	15	48	46	76	117	325	498	444	439	478	2791
2. Initial soil moisture	279	279	238	136	75	18	0	9	2[illegible]	279	279	279	--
3. Total available moisture	510	353	253	184	121	94	117	334	713	723	718	757	--
4. Potential ET	123	115	117	109	103	110	108	119	123	128	129	124	1468
5. Actual ET	123	115	117	109	103	94	108	119	123	128	129	124	1392
6. Remaining available moisture	387	238	136	75	18	0	9	215	590	595	589	633	--
7. Final soil moisture	279	233	136	75	18	0	9	215	279	279	279	279	--
8. Runoff	108	0	0	0	0	0	0	0	311	316	310	354	1399

Station: Chaing Mai, Thailand													
1. Average rainfall	130	46	10	5	10	13	51	127	132	198	232	290	1244
2. Initial soil moisture	124	124	63	0	0	0	0	0	24	46	124	124	--
3. Total available moisture	254	170	73	5	10	13	51	127	156	244	356	414	--
4. Potential ET	114	107	102	99	85	87	87	103	110	117	120	112	1243
5. Actual ET	114	107	73	5	10	13	51	103	110	117	120	112	935
6. Remaining available moisture	140	63	0	0	0	0	0	24	46	127	236	302	--
7. Final soil moisture	124	63	0	0	0	0	0	24	46	124	124	124	--
8. Runoff	16	0	0	0	0	0	0	0	0	3	112	178	309

affects the actual ET. For example, the effect of clearcutting on water yield can be estimated by changing the effective rooting zone in the soil system after clearcutting and recomputing the water budget. Approximate effects on water yield may then be obtained as the results of a modified "effective soil water storage capacity."

A water budget analysis is only as good as the *input data* and the *assumptions* which have been made. Such assumptions include: (1) there are no deep seepage losses or "leakage" from or to the system, (2) transpiration responses are linearly related to available soil water content (unless better knowledge of physiological responses is available), and (3) rainfall intensitites do not affect the volume of runoff, *i.e.*, runoff only occurs when field capacity is exceeded. The assumption on leakage is always difficult to evaluate. Likewise, the manner in which the community of forest species respond to diminishing soil water content is unknown. The third assumption for tropical forest ecosystems is likely valid because of the extremely high infiltration capacities of soils.

CHAPTER IV

INVENTORY TECHNIQUES

INTRODUCTION

Fundamental to watershed resources management is an accurate evaluation of the components of the ecosystem. Techniques to measure or inventory precipitation, streamflow, water quality, timber, range and wildlife are presented.

PRECIPITATION MEASUREMENTS

The measurement of precipitation is an integral part of most hydrologic projects. Information on precipitation--amount, intensity, type, frequency, duration--is essential to much of the research and to the development of operational programs in the management of watershed lands.

Types of Gauges (Point Measurements)

Three types of precipitation gauges are now in general use: the standard gauge--size varies with standards established in individual countries--(usually read after each storm event or at relatively short predetermined time intervals); the storage gauge (manufactured in several sizes and read only periodically); and the recording gauge which records rate of precipitation as well as depth.

Selection of Raingauge Sites

Three general types of natural factors which affect the variation in amounts of precipitation over an area are: weather itself, in terms of area distribution of condensation processes and types of circulation of and within storms; topography of a scale large enough to affect the weather; smaller scale terrain effects which influence the performance of the gauge. The selection of a gauge site, which is representative of the surrounding area, will be influenced primarily by the latter factor.

Local anomalies in the rainfall pattern may be produced by small-scale topographic influences or by obstructions which distort the wind pattern in the immediate vicinity of the gauge. This distortion may make the particular gauge site nonrepresentative of the general region, introducing an error in the determination for the area. In regions of flat topography, this factor is usually of minor importance. In mountainous terrain, it may account for much of the variation in precipitation measurements. Variation in precipitation may be attributed in some cases to variations in the local exposure of gauge sites rather than in actual differences in the distribution of precipitation.

An ideal exposure would eliminate all turbulence and eddy currents near the gauge. Individual obstructions, whether a building or a tree, may set up serious eddy currents and, as a general rule, should not be closer to the gauge than twice (preferably four times) the height of the object above the gauge. When objects are numerous and uniform, such as in a forest opening, their height above the gauge should not exceed about twice their distance from the gauge.

At exposed sites, compensate for the lack of natural protection by shielding or by using pit gauges. The Nipher shield is recommended if the precipitation is primarily rain, the Alter shield if a substantial portion of the precipitation is snow.

Number of Gauges Required

The number of rain gauges required to measure precipitation will increase with the size of the watershed. The use of random sampling as a means of excluding bias in the selection of gauge sites and for estimating the number of gauges needed is suggested. However, in areas of dense brush or forest, this type of rainfall sampling may not be practical owing to the difficulty of obtaining adequate sampling sites.

Rainfall variability on a watershed for monthly, seasonal, or annual periods can be estimated at much lower operating cost by using a regular network which is read after each storm event. By reading storage gauges monthly or seasonally, the effects of storm types on variability may be lost, but systematic differences in precipitation between parts of the watersheds for these longer periods can be estimated.

Methods of Calculating Mean Watershed Precipitation

The mean depth of precipitation over a watershed is required in most hydrologic investigations. Several procedures are used in deriving this value. The three most common are the arithmetic, the Thiessen, and the isohyetal methods.

Arithmetic Method

A straight arithmetic average is the simplest of all methods for estimating the mean rainfall on a watershed (Figure 1). This method yields good estimates in level terrain if the gauges are numerous and uniformly distributed. Even in mountainous country with a dense rain gauge network, arithmetic averages will yield fairly accurate results if the orographic influences on precipitation are considered in the selection of gauge sites. However, if gauges are relatively few and irregularly spaced and precipitation over the area varies considerably, the arithmetic mean is likely to differ greatly from the results derived by other methods.

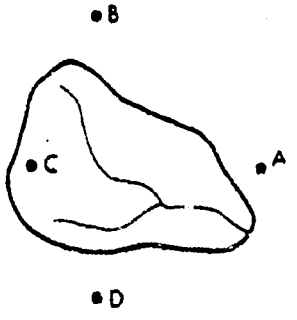
Thiessen Method

This method involves determination of an area of influence for each station. Polygons are formed from the perpendicular bisectors of lines joining nearby stations (Figure 1). The area of each polygon is determined and is used to weigh the rainfall amount of the station in the center of the polygon. The entire area within any polygon is nearer to the rainfall stations contained therein than to any other, and it is, therefore, assumed that the rainfall recorded at that station should apply to that area. The results are usually more accurate than the arithmetic average unless a large number of gauges are used. The Thiessen method allows for nonuniform distribution of gauges by providing the weighting factor for each gauge. The method assumes linear variation of precipitation between stations and makes no attempt to allow for orographic influences.

Isohyetal Method

In the isohyetal method, station location and amounts are plotted on a suitable map, and contours of equal precipitation (isohyets) are drawn (Figure 1). The average depth is then determined by computing and dividing by the total area. Many investigators indicate this as theoretically the most accurate method of determining mean watershed precipitation. But it is also by far the most laborious.

The accuracy of the isohyetal method depends upon the skill of the analyst. An improper analysis may lead to serious error. If linear interpolation between stations is used, the results will be essentially the same as those obtained with the Thiessen method.



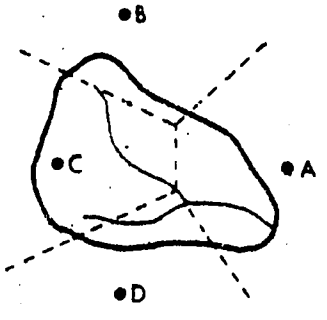
SOURCE DATA:

Daily rainfall measured at each gage in centimeters

A	B	C	D
4	8	10	6

$$\text{Arithmetic Mean} = \frac{4 + 8 + 10 + 6}{4}$$

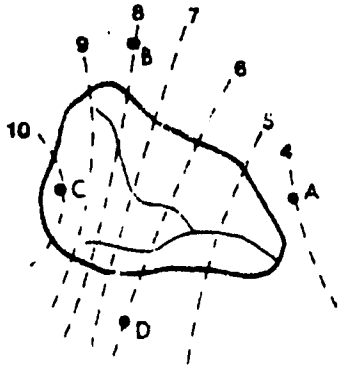
$$= 7 \text{ centimeters}$$



THIESSEN POLYGON:

Station	Depth (cm)		Area in Polygon*		Volume (cm)
A	4	x	.28	=	1.12
B	8	x	.09	=	0.72
C	10	x	.49	=	4.90
D	6	x	.14	=	0.84
			sum	=	7.6 cm

*As a fraction of total area



ISOHYETAL:

Mean Depth (cm)		Area Between Isohyets*		Volume (cm)
4.5	x	0.12	=	0.54
5.5	x	0.25	=	1.38
6.5	x	0.14	=	0.91
7.5	x	0.13	=	0.98
8.5	x	0.18	=	1.53
9.5	x	0.14	=	1.33
10.5	x	0.04	=	0.42
		sum	=	7.1 cm

Figure 1. Methods for estimating average rainfall for a watershed.

STREAMFLOW MEASUREMENTS

Measuring Streamflow

Streamflow data is perhaps the most important information needed by both the engineer and the water resource manager. Peak flow data are needed in planning for flood control or engineering structures (*e.g.*, bridges, culverts, *etc.*). Minimum flow data are required for estimating the dependability of water supplies. Total runoff and its variation must be known for design purposes (*e.g.*, investigative works, storage reservoir, *etc.*).

A stream hydrograph (see Figure 2, page 29) is a record of the discharge of a watershed as it changes with time. It provides a record that shows the effects of the hydrologic processes which occur in a watershed and, therefore, the hydrologic condition of the watershed.

Analyses of single storm hydrographs (the reaction of a stream to a rainstorm event or period of snowmelt) can indicate the condition of a watershed and provide information on the effects of land use and management practices. Storm hydrographs can be separated into components of quick return flow (primarily surface runoff) and subsurface runoff (base flow and interflow).

The stage of water in a stream is readily measured at some point on a stream reach with a staff gauge or a clock-driven water level recorder. The problem is to convert a record of the stage of a stream to discharge or quantity of flow per unit of time. This is done either by stream gauging or with precalibrated structures such as flumes or weirs constructed in the stream.

Measuring Discharge

One of the simplest ways of measuring discharge is to observe how far some floating object tossed into the stream travels in a given length of time. A measurement of the cross sectional area of the stream should be made simultaneously; the two should then be multiplied together:

$$Q = VA$$

where:

Q = discharge in cubic meters per second
V = velocity in meters per second
A = cross section in square meters

However, a simple measurement such as this would not be very accurate, particularly for a large stream because velocity varies from point to point with depth and width over the cross section of a stream.

The velocity at the surface is greater than the mean velocity of the stream; thus, a reduction factor is needed if the velocity is measured at the surface. Generally, it is assumed to be about 85 percent.

If the cross section of a stream is divided into finite vertical sections, the velocity profile can be estimated by measuring individually the mean velocity of each section. The area of each section can be determined and the average discharge of the entire stream is then computed as the sum of the product of area and velocity of each section as follows:

$$\sum_{1}^{n} A_i V_i$$

where: n = the number of sections

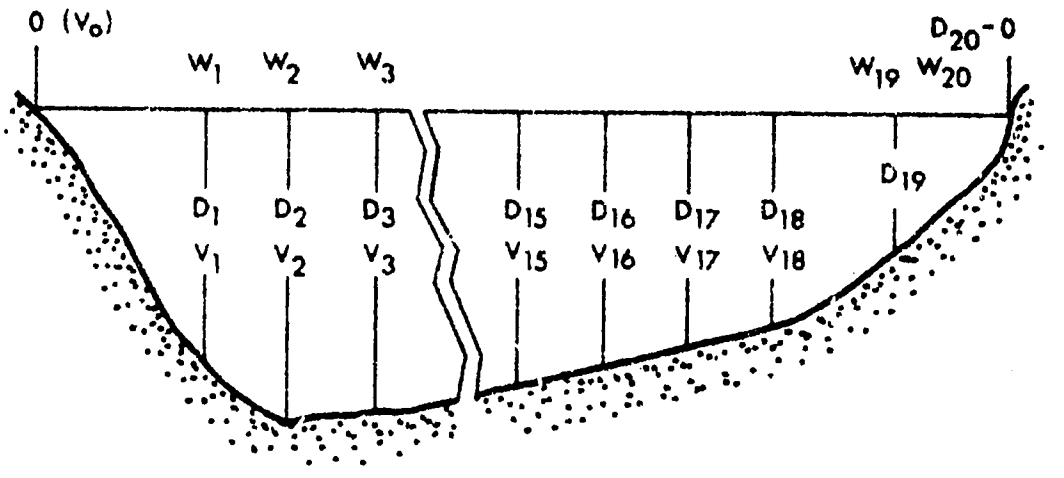
The greater the number of sections, the closer the approximation. However, for practical purposes, 10 sections are usually enough under ideal conditions, but 20 are commonly used. The actual number then depends upon the stream's channel and the rate of change in the stage. The following rules should be observed: depth and velocity should not vary greatly between verticals, and the measurements should be completed before the stage changes too much (a 15 centimeter change is too much for most cases).

There are two ways to estimate areas. They are: the midsection method where each vertical is considered the midpoint of a rectangular subsection extending halfway to the midsection of the other vertical, and the mean section method where each section is considered a trapezoid. The midsection method is most commonly used (Figure 2).

Velocity and depth of verticals can be taken by wading into the stream, from cable car, boat or bridge. Velocity is usually measured with a current meter. There are several ways of performing a velocity measurement. For depths greater than 0.5 meter, two measurements are made for each section at 20 and 80 percent of the total depth. For depths less than 0.5 meter the current meter is set at 0.6 of the depth. For shallow streams less than 15 centimeters, a pygmy meter is used which is simply a smaller version of a current meter.

The most critical aspect of stream gauging is the selection of a control, that is, the point on the stream for which a rating curve is to be developed.

In a longitudinal profile of a stream bed and the water surface for a given reach, ABCDEF represents the profile of the water surface during a low stage of the stream (Figure 3). At this stage the section at C serves as a control for the reach extending up to B and the section at C is the control for the reach leading up to D. The reaches AB, CD,



$$Q = \frac{W_1 + W_2}{2} V_1 D_1 + \frac{W_2 + W_3}{2} V_2 D_2 \text{ etc.}$$

W width cm
D depth cm
V velocity cm/sec
Q discharge cm^3/sec

Figure 2. Measurements needed to record channel cross section and velocity.

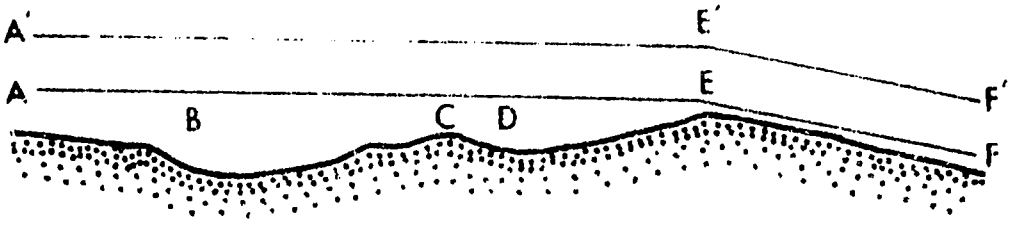


Figure 3. Longitudinal profile of a stream.

and EF act as their own controls throughout their respective lengths at this low stage. When the water surface rises approximately to the stage represented by the profile A'E'F', the section at E becomes the control for the entire length of channel from A to E.

Except in places where a rock outcrop creates either a waterfall or a rapids with considerable drop, longitudinal river profile is a practical necessity in determining the location of the various controls in any given length of stream channel. The best control is the one that is the most nearly permanent and that functions as a control throughout all stages of the river.

There must be of course a nearby gauging station equipped with a water stage recorder that has hydraulic connections with the water in the stream.

Precalibrated Structures for Streamflow Measurement

Weirs and Flumes

On small watersheds, (less than 800 hectares in size), particularly experimental watersheds, precalibrated structures are often used because of their convenience and accuracy. The most common types of precalibrated structures are weirs and flumes. Weirs are often preferred for gauging small watersheds particularly those with perennial flows. Where heavy sediment-laden flows are common, flumes are often more convenient. A flume is a stabilized channel (without an impoundment) with access to a stilling well. Flumes also must be used where the gradient of the stream is particularly low.

Weirs or flumes can be constructed of concrete, (because of its strength and permanence, probably is used the most), treated wood, concrete blocks, metal and many other materials. The notch of a weir is often a steel blade set into concrete, and flumes are often lined with steel for permanence.

Weirs. As used here, a weir includes all components of a stream-gauging station that incorporates a notch control (Figures 4 and 5). An impoundment of water (the weir basin) is formed upstream from the wall or dam containing the notch. A stilling well with water-level recorder is connected to the weir basin. A gaugehouse or some other type of shelter is provided to protect the recorder.

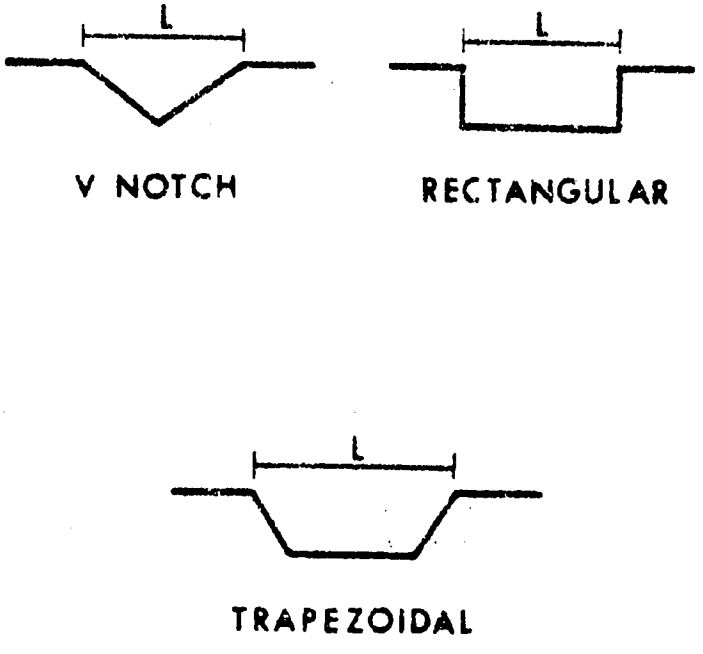


Figure 4. Types of notches.

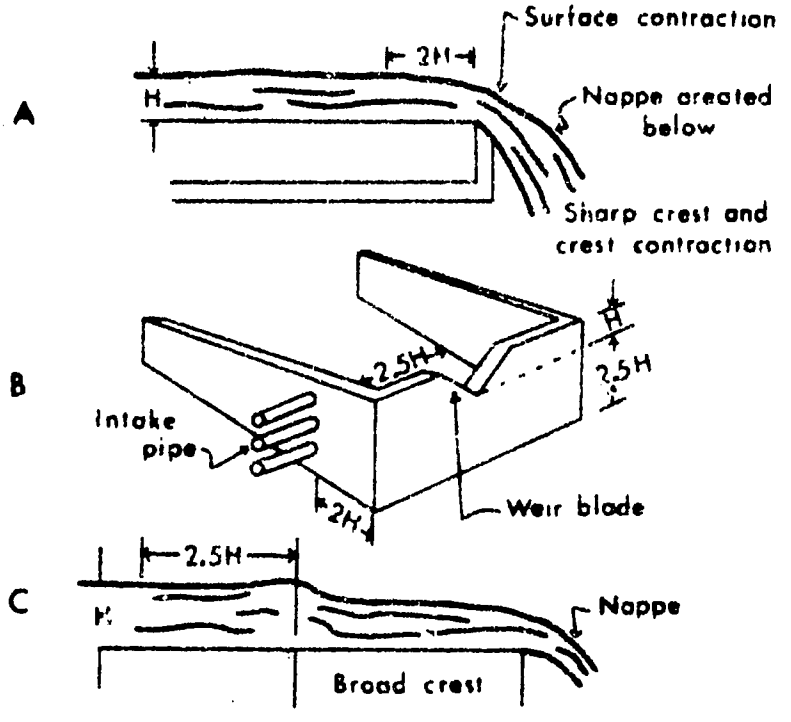


Figure 5. Schematic diagrams of general hydraulic relationships for weirs. A = flow characteristics over a sharp-crested weir. H = the depth of water producing the discharge. B = minimum requirements for proper discharge when H equals greatest expected depth for a sharp-crested V-notch weir with end and crest contractions. C = flow characteristics over a broad-crested weir of rectangular cross section.

The cutoff wall or dam is used to divert through the notch all water (above or below the streambed) moving down the channel. Where possible, the cutoff wall is tied into bedrock or other impermeable material so that no water can flow under or around it. But where leakage is apt to occur, the weir basin is sometimes constructed as a watertight box.

The edge or surface over which the water flows is called the crest. Weirs can be either sharp crested or broad crested. A sharp-crested weir has a blade with a sharp upstream edge so that the passing water touches only a thin edge and springs clear of the rest of the crest.

A broad-crested weir has a flat or broad surface over which the discharge flows. Broad-crested weirs are generally used where sensitivity to low flows is not critical and where sharp crests would be dulled or damaged by sediment or debris.

The rectangular weir has vertical sides and horizontal crest. Its major advantage is its capacity to handle high flows. However, the rectangular weir does not provide for precise measurement of the low flows of small experimental watersheds--a small increase in head will give only a slightly increased discharge.

The trapezoidal weir is similar to the rectangular weir. Its sides, of course, are sloped from the vertical. It has a smaller capacity than a rectangular weir of the same crest length; the discharge is approximately the sum of discharges from the rectangular and triangular sections.

Sharp-crested V-notch or triangular weirs are often used where accurate measurements of low flows are important. The V-notch weir may have a rectangular section above to accommodate infrequent high flows.

Flumes. A flume is an articifial open channel built to contain flow within a designed cross section and length. The types of flumes that have been used on small watersheds are described here.

HS, H and HL flumes developed and rated by the Soil Conservation Service have converging vertical sidewalls cut back on a slope at the outlet to give them a trapezoidal projection. These have been used largely to measure intermittent runoff.

The Venturi flume has a gradually contracting section leading to a constricted throat and an expanding section immediately downstream. The floor of the Venturi flame is the same grade as the stream channel, whereas that of the Parshall flume (described below) is depressed in the throat section. Stilling wells for measuring the head are at the entrance and at the throat; the difference in head at the two wells is related to discharge. Venturi flumes are rectangular, trapezoidal, triangular, or any other regular shape. They are widely used in measurement of irrigation water.

The Parshall flume, a modification of the Venturi flume, measures water in open conduits and is widely used, especially for measuring irrigation water. It consists essentially of a contracting inlet, a parallel-sided throat, and an expanding outlet, all of which have vertical sidewalls. It can measure flows under submerged conditions. Two water-level recorders are used when measuring submerged flow, one in the sidewall of the contracting inlet and the other slightly upstream from the lowest point of the flow in the throat. When measuring free flow, only the upper measuring point is used.

The San Dimas flume measures debris-laden flows in mountain streams. It is rectangular and has a sloping floor (3 percent gradient) that functions as a broad-crested weir except that the contraction is from the sides rather than the bottom; therefore, there is no barrier to cause sediment deposition. Depth measurements are made in the parallel-walled section at about the midpoint. Rapid flow keeps the flume scoured clean.

Summary. The type of flume or weir to be used depends upon several factors: maximum and minimum flows; accuracy needed in determining total discharge, high flows, and low flows; amount of sediment or debris that is expected, and whether it is suspended or bedload; channel gradient; channel cross section; underlying material; accessibility of site; financial limitations; and length of study.

Maximum and minimum flows likely to be encountered must be estimated before construction. Such estimates can be made from observation of high and low flows and high watermarks and from information given by local residents, or they might be based on the area of the watershed and records from other gauging stations in the region. Maximum expected flood peaks can also be estimated from rainfall, soil, and cover data, using a method developed by the U.S. Soil Conservation Service. The maximum and minimum flow to be measured at any degree of precision depend upon the objectives of the study and the extremes that might occur.

WATER QUALITY MEASUREMENTS

To evaluate the kinds and amounts of substances present in water, representative water quality measurements are obtained. Usually, a sampling program is necessary, as continuous monitoring of water quality is difficult. A good water quality sampling program requires knowledge of the system being sampled and an understanding of the time and space distribution patterns of the variables being sampled. A major source of error in obtaining water quality information is a nonrepresentative sampling effort.

Quite often, a *grab sample* obtained in a clean glass or plastic container is satisfactory for preliminary analysis. A single grab sample is representative of the stream discharge only at the time of

sampling. Samples collected weekly or monthly can provide an indication of water quality over time for many streams.

Once obtained, grab samples may have to be treated to protect against degradation of the contents. For example, if water samples are to be used later for organic analysis, the sample may have to be frozen or otherwise preserved. If a water sample is to be retained for later analysis, the sample container should be marked so that its identity is not lost.

Chemical Quality

The chemical constitutents of water are derived from many sources, including gases from the atmosphere, weathering products of rocks and soils, and decomposition of plants and other organic materials. Many land management activities on a watershed can affect the kinds and amounts of chemical constituents present.

Methods of determining chemical quality of water include analysis of a standard volume of water obtained in a grab sample and direct measurements of a particular constituent in the aquatic environment.

Photometric or *colormetric* methods involve the addition of a measured amount of a reagent to a standard volume of water, and then relating the intensity of color to the concentration of the substance present. Required instrumentation consists of a light source, a photocell, and a meter (Figure 6). The amount of light absorbed is proportional to the amount of substance in the water.

Titrametric or *volumetric* methods require the addition of reagents of known concentration to a standard volume of water. These methods are designed to give an abrupt color change after a certain amount of reagent is added (Figure 7). The concentration of the chemical constituent in the water is proportional to the amount of reagent added.

Instrumentation is available to permit direct measurement of some chemical substances in the aquatic environment. Standardized oxygen and pH probes have been developed to measure dissolved oxygen and pH *in situ*. Similarly, electrode probes can be used to determine the concentration of many chemical ions.

Sediment Measurements

Sediment refers to the rock and mineral particles transported by water; while, *sedimentations* is the process of deposition of transported particles from water. Sediment is often divided into two components: *suspended sediment* and *bedload*. Usually, measurements of

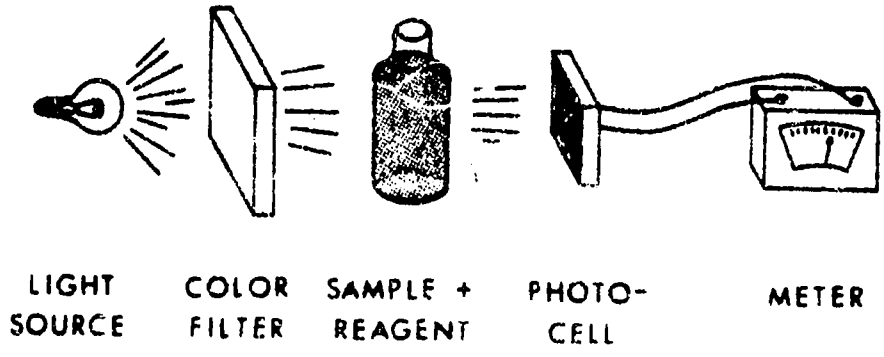


Figure 6. Photometric method for determining the chemical quality of water.

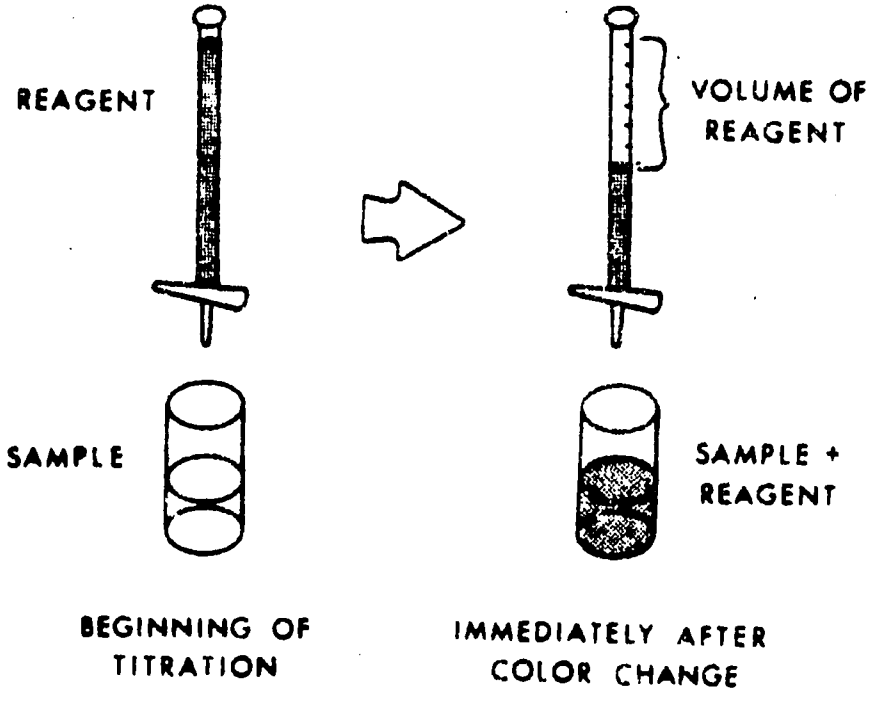


Figure 7. Titrametric method for determining the chemical quality of water.

suspended sediment and bedload are made separately because of differences in sizes of particles and in distribution of the particles in a stream.

Suspended Sediment

Suspended sediment usually consists of small particles (clays, silts, and fine sands) kept aloft from the stream channel by the turbulence of flowing water. As suspended sediment concentrations vary with depth and distance across a stream, a major difficulty in determining suspended sediment amounts for a stream is obtaining a representative sample.

Various techniques are available to estimate suspended sediment. The collection of grab samples is a common procedure, especially for small streams. However, this method may not be reliable because of the problems mentioned above.

Single-stage samplers, consisting of a container with an inflow and an outflow tube at the top, are commonly used on small, fast-rising streams. A single-stage sampler begins its intake when the water level exceeds the height of the lower inflow tube, and continues until the container is full. Therefore, only the rising stage of the hydrograph is sampled, which may limit the use of the data.

Depth-integrating samplers minimize the sampling bias involved with fixed, single-stage samplers. A depth-integrating sampler has a container that allows water to enter as the sampler is lowered and raised at a constant rate. Consequently, a relatively uniform sample for a given vertical section of a stream is obtained. Depending upon the size of the stream, a number of these samples can be taken at selected intervals across the channel.

After a suspended sediment sample is obtained, the liquid portion is removed by evaporating, filtering, or by using a centrifuge, and the amount of sediment is weighed. Often, the dry weight of suspended sediment is expressed as a concentration in milligrams per liter (or in ppm).

Bedload

Bedload is the larger, heavier sediments (sands, gravels, and cobbles) that slide, roll, or bounce along the bottom or bed of a stream channel.

No single device for measuring bedload is reliable, economical, and easy to use. While a number of bedload samplers exist, none are widely used. Estimates of bedload can be obtained by measuring the amount of material deposited in basins or traps behind sediment dams.

Bacteriological Quality

To index the presence of specific pollutants and to detect changes in water quality, indicator organisms are commonly sampled. For example, analysis of fecal coliform, a bacteria that characteristically inhabits the intestines of warm-blooded animals, can be used as an indicator of pollution by humans or other animals.

A parameter relating to the amount of biodegradable materials present in water is the biochemical oxygen demand (BOD). BOD measurements require a laboratory examination over a 5-day period, and often provide a satisfactory index to the amount of organic material present.

Temperature Measurements

The temperature of water acts as a regulator of biological activity and, therefore, is important in evaluating the types of organisms present in a given body of water. Surface temperatures can be measured with standard liquid-in-glass thermometers. Thermocouples are frequently used to obtain temperatures at lower depths.

TIMBER INVENTORY TECHNIQUES

Timber inventories are concerned with the measurement of individual trees, forest stands, growth rates, and site quality. As timber overstories often relate to the production and uses of associated watershed resources, knowledge of the general concepts of timber inventory can be useful.

Individual tree measurements form the basis for estimating the volume of primary wood products which may be derived from trees. Also, individual tree measurements coupled with a measure of tree density can describe the value of a forst. Individual tree measurements normally considered include measurement of diameter, height, volume and age.

The most frequent individual tree measurement made is diameter breast high (dbh), which is the average stem diameter at 1.3 meters above the ground. Other measurements of diameter may be taken at any arbitrary reference point. Tree diameters are measured with instruments collectively known as *dendrometers*, such as a diameter tape or caliper. In addition to diameter, height measurements are necessary to estimate the volume of a tree. Two height measurements commonly taken are total height and merchantable height, with total height being the distance from the ground to the tip of the tree and merchantable height being a measure of the usable portion of a tree. Heights are measured with instruments collectively known as *hypsometers*, including the Abney level and clinometer.

Given knowledge of diameter and height, the volume of a tree can be estimated from an appropriate volume table. A volume table specifies the average volume of a tree in terms of diameter and height. Volume units are frequently cubic meters, and volume tables may include the volume of the stump, bark, limbs, *etc.*

The average growth rate of a tree is its volume divided by its age. While the volume of a tree is relatively easy to determine, quantification of age is more difficult. There are three common methods used to ascertain the age of a tree--by general appearance (size, shape of crown, texture of bark, *etc.*), by branch whorls, or by annual rings. Unfortunately, tree growth is generally not characterized by annual rings in many forest regions of the world, such as tropical forests.

A primary objective of any timber inventory is to obtain estimates of the density of forest stands. Expressions of density are many, with number of trees, basal area (cross-sectional area at dbh of all trees on a hectare), and volume. Obviously, it would be desirable to have a complete census of all of the individual trees in a forest stand. This is rarely possible, however, and sampling is commonplace.

There are many considerations such as sample size, plot size, sampling design, *etc.* involved in developing an efficient sampling scheme to describe the density of a forest stand. Most of these considerations are discussed in standard forest mensurational references and, therefore, will not be detailed here.

The estimation of growth rates of individual trees and forest stands is an important part of timber inventory. Generally, past growth rates are analyzed to establish a pattern for projecting growth into the future. Many techniques designed to evaluate past growth rates of individual trees have been developed, with remeasurement of permanently marked trees and use of growth percent formulas (simple interest formula, Pressler's formula, *etc.*) commonly employed. Two commonly used methods of estimating the growth of forest stands are through applications of yield tables and stand structure analysis. Expression of growth may be gross or net, depending upon whether or not mortality is considered.

The determination of site quality is important in identifying the productivity, both present and future, of forest stands. Site is considered to be the aggregate of all environmental conditions affecting the growth and survival of a forest or other plant community. Theoretically, it is possible to determine site quality by measuring all of the many factors affecting the productivity of forest stands and integrating them into a single index. However, such an approach may not be of much value to a practicing forester.

Of all the measures of site quality, tree height in relation to age has been found the most practical, consistent and useful (Figure 8). Height growth is sensitive to differences in site quality, little affected

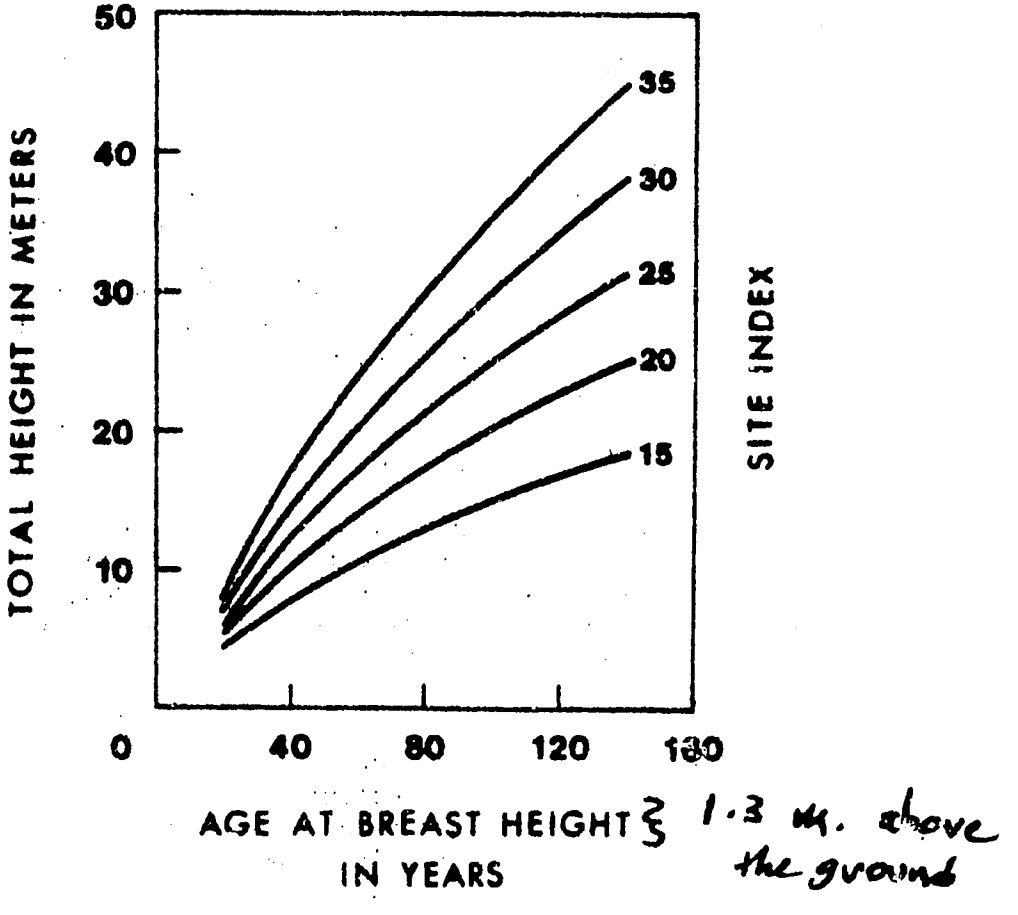


Figure 8. Site-index relationships for young-growth ponderosa pine in the southwestern United States. The index age is 100 years at breast height.

by density of the forest stand, and strongly correlated with volume. This measure of site quality is termed site index, with the usual practice being to define site index in terms of total height of dominant or co-dominant trees in well-stocked, even-aged stands at specified ages.

RANGE INVENTORY TECHNIQUES

Quite often, forage is produced for domestic livestock and wildlife on a watershed. Therefore, range inventories may be necessary to characterize watershed resources for multiple benefits. Range inventories are commonly designed to measure forage production and utilization for purposes of determining carrying capacities.

Clipped plots may be used to determine the weight of forage produced over a growing season. The general procedure is to locate plots of known area and clip forage plants as near to the ground as practical. Individual plant species may be clipped separately and weighed in the field if their growth characteristics allow for easy separation. If too much time is required in the field to separate the plants, total forage clipped on plots may be saved for subsequent sorting and weighing in the laboratory.

While plots of any size can be used, a 1-square-meter plot (one meter on a side) is often recommended. With this plot size, the forage in grams, multiplied by 10, will be converted to forage yield in kilograms per hectare. Sampling design selected is dependent on desired level of precision, costs, *etc.* Forage production near the end of the major growing season is often of primary importance, although biases may exist from sampling at this time because important forage species may have reached peak development earlier.

Utilization of forage plants is expressed as the percentage of the current forage weight that has been removed by grazing animals. There are many different techniques for determining utilization, but the simplest method is to select a key species (a palatable and abundant plant) and estimate the percentage use of this species. These estimates can be made in conjunction with clipping of forage plants to determine production. In fact, if utilization is heavy, clipped weights will have to be adjusted to account for the portions of plants removed by grazing.

A primary use of forage production is to calculate carrying capacity. Perhaps the best way to illustrate the calculation of carrying capacity is through an example.

Usually, domestic livestock carrying capacity is expressed in terms of animal unit months (AUM). An animal unit is the equivalent of 450 kilograms of animal live weight, or a cow and a calf. The forage required to provide for one animal unit month is variable, depending

upon the ecosystem. For purposes of illustration, approximately 450 kilograms of forage (dry weight) will be assumed to be the forage requirement.

A proper use factor is used to control the amount of forage produced that is subsequently utilized by domestic livestock. Through the proper use factor, use of the forage resource can be adjusted to reflect the condition of the range. In the hypothetical example, a proper use factor of 0.65 (65 percent) has been selected. Given this information, and assuming that the forage produced (dry weight) is 375 kilgrams per hectare, the carrying capacity would be estimated as

$$\text{Carrying capacity} = \frac{(\text{forage produced})(\text{proper use factor})}{(\text{forage requirement})}$$

$$= \frac{(375)(0.65)}{(450)} = 0.5 \text{ AUM per hectare}$$

Therefore, one animal unit could graze on 1 hectare for 0.5 months, with two hectares required to provide forage for 1 AUM. Twenty-four hectares would be needed to carry one animal unit for a year.

WILDLIFE INVENTORY TECHNIQUES

Management of wildlife resources is an effort to attain a balance between the food and cover available and the animal populations that are favored. Wildlife inventory problems are generally threefold: estimation of numbers of animals, determination of animal productivities, and evaluation of wildlife habitats.

There is voluminous literature on methods of estimating numbers of animals. If the more commonly used methods are grouped, three primary approaches become evident: a direct method of census, an indirect method of indexing, and a ratio method of assessing population change. Direct census methods include aerial countings, which are used when animals congregate and where vegetative overstories are minimal. One of the oldest procedures is through driving, where a line of observers moves through an area like beaters with other observers stationed at the end of the census area to count the animals pushed ahead. Variable strips are often employed to count animal numbers, particularly in situations where extensive areas are to be inventoried.

Indirect methods of indexing population numbers are based on counts of something other than the animals themselves. Such methods are commonly used to census smaller, quickly producing animals and on big game ranges less accessible to direct counting. Call counts are widely used to assess game bird populations. To calculate population numbers, direct censusing is required from a sample to obtain a ratio of call counts to actual numbers. Pellet group counts are often used

in an indirect census of big game. Through knowledge of defecation rates, counts of pellet groups accumulated over time can be converted to estimates of population numbers.

The more commonly used ratio methods fall into two categories--those based on the banding or marking of animals and those based primarily on kill data from legal hunting. The first category is illustrated by a calculation procedure known as the Lincoln index. Here, a number of animals are captured, banded or marked, and then released back into the population. When animals from the population are later recaptured, the ratio of total banded animals to the banded animals recovered can be used to calculate the size of a population. An example of the second category is Kelker's ratio, which requires data on population structure and changes in sex and age ratios resulting from legal hunting.

The second classic division of wildlife inventory, productivity, has its base in the census, but usually involves further computation and comparison with past records. Generally, the smaller the animal, the faster their production, normal population loss, and regeneration each year. The average tree squirrel lives less than one year, but even larger animals have a turnover or replacement by new individuals. Therefore, a variety of animals are being managed and the changes in composition within a group must be measured, accordingly. Both hunted and non-hunted populations should be censused with production measurement. Hunted populations vary because the hunting can definitely modify the population: non-hunted populations vary because of natural losses.

Evaluation of habitats is a third classic wildlife inventory. Measurement of habitat quality can be broken down into the elements of habitat required by most wildlife species and then treated separately to judge a habitat's ability to support a population of animals. Habitat elements to consider in an inventory include water, food, cover (both protective and thermal), and spatial arrangement of water, food and cover. Most wildlife need all of these elements within their normal daily range of movement. If these basic elements of habitat periodically reoccur in several locales over a watershed, highly productive wildlife populations are more likely to develop.

CHAPTER V

HYDROLOGIC METHODS

INTRODUCTION

Hydrologic information is required for most watershed resources planning activities, studies, or projects. Often there are few hydrologic, meteorologic, and biophysical data available at locations of interest. Even with adequate data, it is sometimes difficult to decide upon the most appropriate hydrologic method to use. Numerous methods exist for determining hydrologic characteristics such as peak streamflow, stormflow volumes, mean annual water yield, and critical low-flow sequences. Hydrologic methods range in complexity from simple mathematical equations for predicting peak flow up to complex computer models capable of simulating continuous streamflow records. This chapter presents an overview of hydrologic methods and discusses guidelines for application.

CRITERIA FOR SELECTING METHODS

Selecting the appropriate hydrologic method should involve careful consideration of:

(1) the type of information required,

(2) available data and information,

(3) physical and biological characteristics of the watershed,

(4) technical capabilities of the individual performing the study, and

(5) time and manpower constraints.

Study objectives usually dictate the type of information required (Table 1) and, in some cases, indicate which method should be used. Sizing culverts for rural roads, for example, require peak flow

estimates associated with some predetermined risk. Runoff is usually from small, simple drainages and errors in the estimate of peak flow do not result in great economic loss. Therefore, simple, quick methods are applicable. Conversely, peak flow estimates for flood plain mapping may require a more complex but reliable method. More time and effort may be justified in flood plain mapping if errors could result in large economic loss or loss of life.

Table 1. Project Objectives and the Corresponding Hydrologic Information Needed.

Objective	Hydrologic Information Needed
Storm drainage - culvert design	Peak flow rates for small contributing area
Flood plain delineation	Peak flow rates and associated stages
Conservation storage requirements for a reservoir	Streamflow rates or volumes during critical drought periods
Water quality assessment	Volumes, discharge rates for selected events
Feasibility for min-hydro project	Low streamflow sequences during critical drought periods
Land use impacts on water yield	Runoff volumes over time

After determining which hydrologic characteristics are of interest, an assessment must be made of available information and data. Streamflow, precipitation, and other data are often insufficient for all but the simplest of hydrologic methods. Sometimes climatic and hydrologic information from previous work in proximity to the study area is useful.

Watershed characteristics including size, shape, vegetative cover, topography, soils, and geology must also be evaluated in selecting an appropriate method. Some hydrologic methods can only be used for small, homogeneous drainages, while others can be applied to large complex watersheds. Before some techniques can be used, watersheds must be subdivided according to soil, vegetation, and topography.

The capacity or capability of the individual or organization performing the study is another important consideration. One should be knowledgeable about the methods used and their limitations. A

common constraint with current technology is the availability and type of computer facilities and software. Computer programs are invaluable for most large-scale water resource investigations.

SIMPLIFIED METHODS

Simplified methods are those which have been developed for small, relatively homogeneous watersheds or for situations where a quick estimate is desired. Too many such methods exist for thorough coverage here. Our purpose is to illustrate some commonly used methods.

Direct Transfer of Hydrologic Information

Hydrologic information can be directly transferred from a gauged to an ungauged watershed if the two watersheds are hydrologically similar. The hydrologic similarity between two watersheds depends on the following:

(1) watersheds should be within the same meteorological regime;

(2) physical and biological characteristics such as soils, geology, topographic relief, type and extent of vegetative cover, land use, watershed shape, and drainage density should be similar; and

(3) the differences in drainage area between watersheds should be within an order of magnitude.

The method of direct transfer can be applied in two ways. First, the entire historical record from the gauged watershed may be transferred, with minor adjustments for differences in the size of drainage areas. The observed streamflow record could be multiplied by the ratio of ungauged to gauged watershed area. The second approach would be to transfer hydrologic characteristics (such as the 100-year flood peak), again, adjusting for drainage area differences. The entire flood frequency curve for an ungauged location may be estimated by adjusting curves developed from a similar but gauged watershed.

The direct transfer approach is applicable only if the assumption of hydrologic similarity is met. The method is quick and easy to use. If a significant amount of adjustment is needed to transfer hydrologic information from the gauged to the ungauged watershed, however, poor estimates will result.

Simplified Formulae

Numerous mathematical formulae have been developed to estimate hydrograph characteristics such as peak flow. A thorough discussion of such methods is presented in most hydrology textbooks. Simplified formulae relate some hydrographic characteristic to certain measurable

watershed characteristics. These methods are restricted to small, simple watersheds, and have been used most frequently to design urban drainage systems and road culverts.

The rational method is perhaps the most commonly used simplified formula. This approach can be used to estimate peak flow from rainfall of uniform intensity and distribution over the watershed. The basis of the rational method is that the maximum rate of runoff occurs when the entire watershed area contributes at the outlet. Therefore, peak flow estimates are valid only for storms in which the rainfall period is at least as long as the watershed time of concentration. Time of concentration is the time required for the entire watershed to contribute runoff at the outlet. The rate of runoff for peak flow (Q_p) in cubic meters per second, is related to some percentage of rainfall intensity:

$$Q_p = CIA$$

where:

C = runoff coefficient relating proportion of rainfall contributing to peak runoff.

I = rainfall intensity in mm/hr

A = drainage area in hectares

The assumption that rainfall intensity is uniform over the entire watershed for a period equal to the time of concentration is seldom met under natural conditions. To apply this method, rainfall intensity-duration values associated with an acceptable risk are used.

Peak flow estimates by the rational method are highly dependent upon the runoff coefficient (C) selected. Runoff coefficients are presented in most hydrology and engineering textbooks. A relatively flat area with 30 percent impervious area would have a runoff coefficient of about 0.40. Moderately steep watersheds with 70 percent impervious area may have runoff coefficients up to 0.80.

Similar simplified formulae have been developed for regions around the world. The values of peak flow obtained from such formulae should be used with caution and must be viewed as quick and rough estimates. Such methods are useful, however, and will continue to be widely used because they are simple and require very little information or data.

GENERALIZED RAINFALL-RUNOFF METHODS

Some hydrologic investigations require more detailed information than can be provided by the simplified methods previously

discussed. Generalized rainfall-runoff methods include techniques of hydrograph analysis, dynamic hydraulic routing, and continuous streamflow synthesis. Each method is an abstraction of the physical system and uses generalized mathematical functions for estimating rainfall-runoff characteristics. Such methods are usually referred to as hydrologic models.

Unit Hydrograph Concept

The unit hydrograph concept provides the basis for several hydrologic models of greater complexity and wider application than the simplified formulae. Unit hydrograph (UHG) models do not simulate or even attempt to quantify the various hydrologic processes involved from rainfall to streamflow. Rather, this method relies on parametric or "blackbox" relationships between rainfall input and streamflow output (Figure 1).

The unit hydrograph is defined as that hydrograph which represents *1 unit (1 millimeter) of direct runoff* and *is unique for each watershed*. The concept can best be understood by examining the isolated storm method of developing a UHG (Figure 2). Streamflow records for the watershed are first examined for single-peaked, isolated hydrographs which result from short duration rainfall of relatively uniform intensity. Once a hydrograph is selected, the *direct runoff volume* is determined by separating the more uniform baseflow from the rapidly changing stormflow component. The direct runoff volume is converted into millimeters of depth for the watershed area. Next, the mean watershed rainfall, which caused the direct runoff hydrograph, is determined. This rainfall is distributed with respect to time. The total rainfall amount is then compared to the direct runoff volume. Losses are determined as the difference between mean watershed rainfall and direct runoff (effective rainfall). The magnitude of losses is a function of antecedent moisture conditions. In Figure 2, a uniform loss rate was assumed. The duration of effective rainfall is then determined (in this case 2 hours). The ordinates of direct runoff for the storm are then divided by the millimeters of direct runoff to yield ordinates corresponding to 1 millimeter of direct runoff.

The duration of effective rainfall defines the unit hydrograph, *i.e.*, a UHG developed from an effective rainfall of 6-hour duration is a 6-hour UHG. (A 2-hour UHG was determined in Figure 2.)

The unit hydrograph is actually an index of runoff for a particular watershed and represents the integrated response of that area to a given rainfall input. The shape of the UHG is characteristic of the watershed for a given intensity of effective rainfall. The UGH method assumes that the effective rainfall and loss rate are relatively uniform over the entire watershed area. Also, the watershed characteristics which affect runoff response must remain constant from the time that the UHG is developed until the time that it is applied.

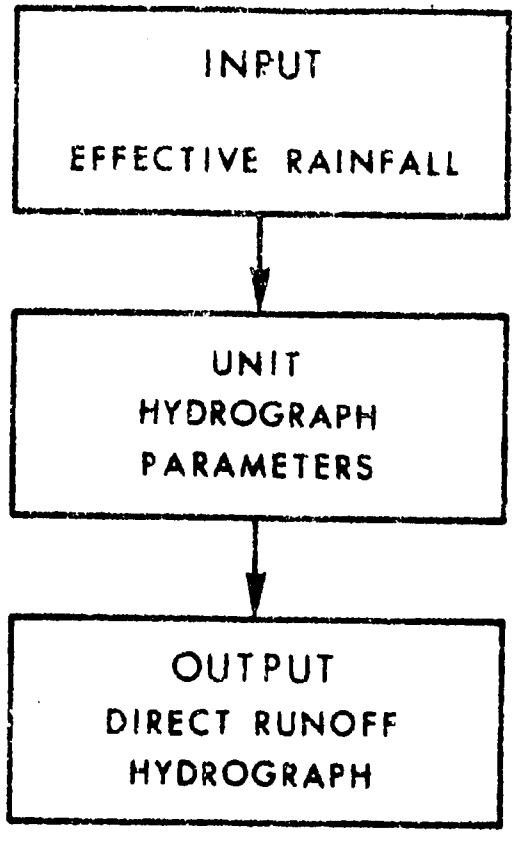
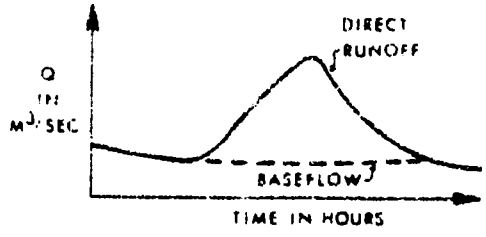


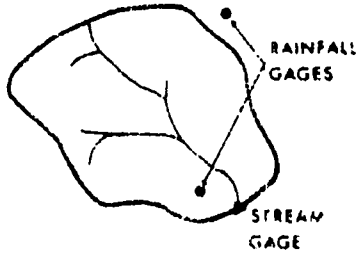
Figure 1. Unit hydrograph approach.

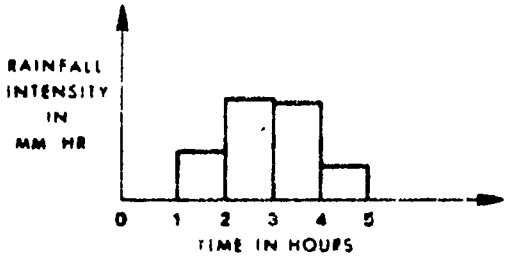
1 DETERMINE VOLUME OF DIRECT RUNOFF FROM ISOLATED STORM



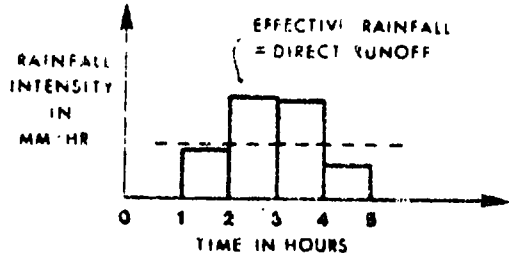
$$\frac{\text{CUBIC METERS/SEC} \times \text{SEC}}{\text{AREA IN SQUARE METERS}} = \text{MM OF DIRECT RUNOFF}$$

2 DETERMINE RAINFALL FOR THE WATERSHED

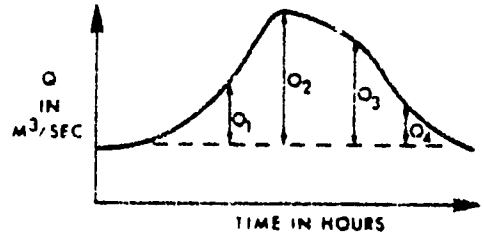




3 ESTIMATE LOSSES = TOTAL RAINFALL − DIRECT RUNOFF



4 UNIT HYDROGRAPH = HYDROGRAPHIC ORDINATES CORRESPONDING TO 1 UNIT (1MM) OF DIRECT RUNOFF



$$= (O_1 \div \text{MM DR}) + (O_2 - \text{MM DR}) + \ldots (O_n \div \text{MM DR})$$

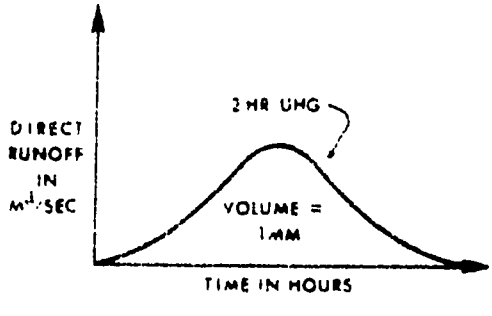


Figure 2. Development of a unit hydrograph by the isolated storm approach.

In order to apply a unit hydrograph, the average watershed rainfall must first be estimated. Next, loss rates are subtracted from total rainfall to obtain effective rainfall. The quantity of effective rainfall is then multiplied by the UHG ordinates corresponding to the same duration of effective rainfall (Table 2). A 1-hour UHG, in this case, is directly applied to 1-hour increments of effective rainfall. Unit hydrograph models are linear; 20 millimeters of effective rainfall yields a direct runoff hydrograph with ordinates 20 times that of the UHG. The resulting direct runoff hydrograph is then added to the base flow, if any, to obtain the total runoff hydrograph. It must be emphasized that the UHG developed from a specified duration of effective rainfall can be applied to effective rainfall which fell over the *same* duration. Thus, a 6-hour UHG cannot be applied directly to an effective rainfall which occurred over 2 hours. Several methods are available to convert a unit hydrograph from one duration to another and are discussed in most hydrology texts.

Table 2. Application of a Unit Hydrograph.

Time hr	1-hr UHG Ordinates m^3/sec	Effective Rainfall mm	Direct Runoff a m^3/sec	Direct Runoff b m^3/sec	Direct Runoff subtotal m^3/sec	Base Flow m^3/sec	Total Discharge m^3/sec
0	0.0	0	0.0	0.0	0.0	12	12
1	0.5	20	10.0	0.0	10.0	12	22
2	5.0	30	100.0	15.0	115.0	12	127
3	10.0	0	200.0	150.0	350.0	12	362
4	7.5	0	150.0	300.0	450.0	12	462
5	5.0	0	100.0	225.0	325.0	12	337
6	2.5	0	50.0	150.0	200.0	12	212
7	0.0	0	0.0	75.0	75.0	12	87
8	0.0	0	0.0	0.0	0.0	12	12

The above unit hydrograph method is of limited value for most watershed studies because both rainfall and streamflow data must be available. Since streamflow data are seldom available at locations of interest, synthetic unit hydrograph models have been developed. These models consist of mathematical expressions that relate measurable

watershed characteristics to unit hydrograph characteristics. Runoff hydrographs for ungauged watersheds can be estimated with synthetic UHG models if loss rates can be approximated.

Unit hydrograph models have been used extensively for flood analyses and the design of spillways and flood control storage. These include the Snyder, the Clark, and the Soil Conservation Service (SCS) methods. The SCS method will be discussed in greater detail because runoff can be estimated directly from soil-vegetation characteristics of a watershed.

The SCS method, used in the TR-20 computer model, incorporates generalized loss-rate and runoff relationships developed from watershed studies in the United States. Soil-vegetation-land use characteristics are related to curve numbers (CN) which indicate the runoff potential for a given rainfall (Table 3). Soils are classified hydrologically into four groups:

A = high infiltration rates usually deep, well-drained sands and gravels;

B = moderate infiltration rates, fine to moderate texture;

C = slow infiltration rates, moderate to fine textured;

D = very slow rates usually clay soils or shallow soils with a hardpan near the surface.

Three antecedent moisture conditions (AMC) are also considered:

AMC I = dry;

AMC II = near field capacity;

AMC III = near saturation

After the CN is determined, rainfall is converted to direct runoff graphically (Figure 3).

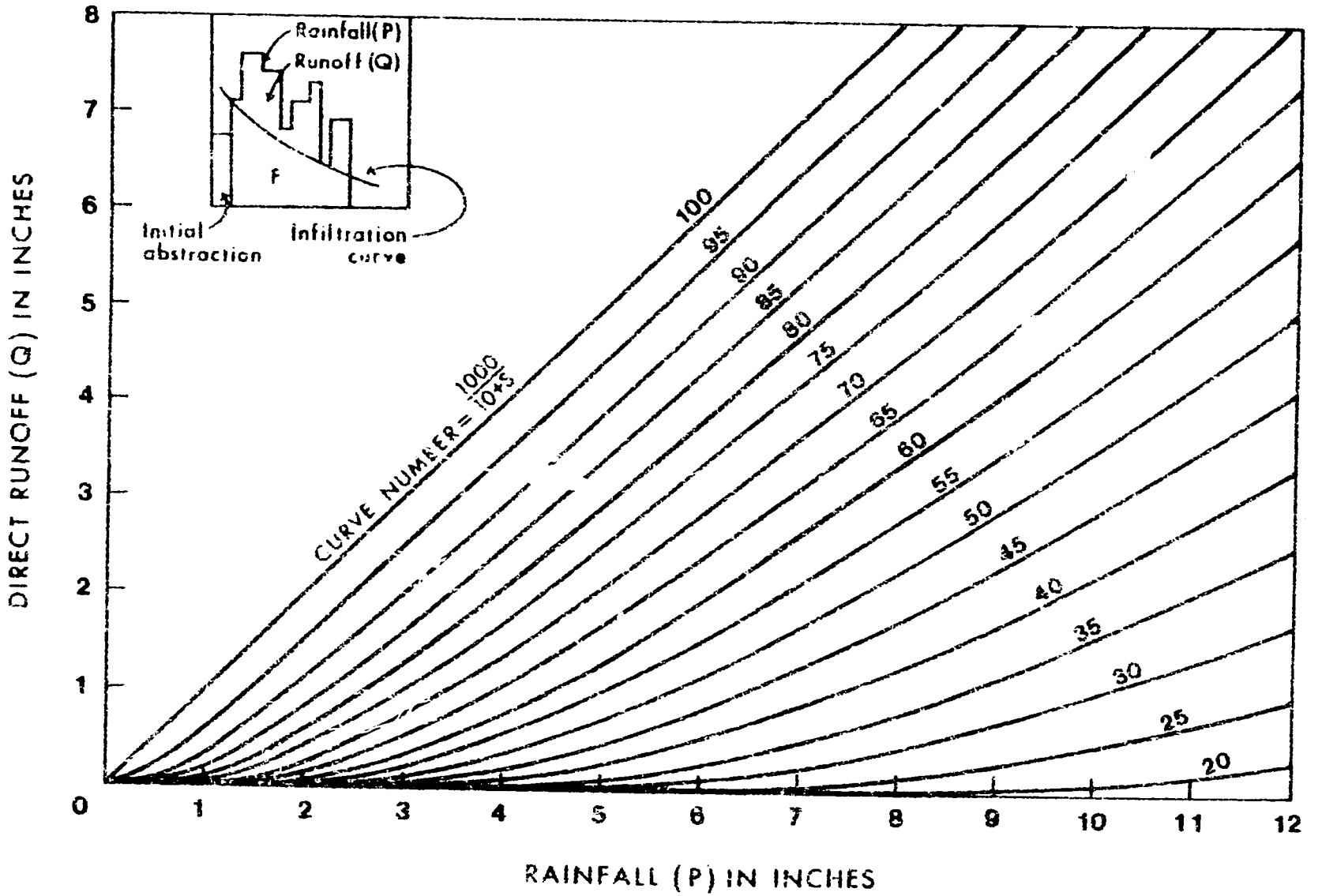


Figure 3. United States Soil Conservation Service rainfall-runoff relationships for curve numbers. $Q = \frac{(P-0.2S)^2}{P+0.8S}$ P=0-12 inches; Q=0-8 inches.

Table 3. United States Soil Conservation Service Relationships Between Soil-Cover Complexes and Curve Numbers (CN) for Antecedent Moisture Condition (AMC) II in Puerto Rico.

Cover and condition	Hydrologic soil group			
	A	B	C	D
Fallow	77	86	91	93
Grass (Bunch grass, or poor stand of sod)	51	70	80	84
Coffee (no ground cover, no terraces)	48	68	79	83
Coffee (with ground cover and terraces)	22	52	68	75
Minor crops (garden or truck crops)	45	66	77	83
Tropical kudzu	19	50	67	74
Sugarcane (trash burned; straight-row)	43	65	77	82
Sugarcane (trash mulch; straight-row)	45	66	77	83
Sugarcane (in holes; on contour)	24	53	69	76
Sugarcane (in furrow; on contour)	32	58	72	79

For the SCS model to be valid, curve number relationships should be determined for each hydrographically different region. The relationships developed in the United States are generally applicable to small watersheds less than 13 square kilometers with average slopes less than 30 percent.

Once effective rainfall is determined, a hydrograph can be produced. Peak flow (q_p) is determined by the triangular hydrograph method:

$$q_p = \frac{KAQ}{T_p}$$

Where:

K = constant

A = area in square kilometers

Q = flow volume in millimeters

T_p = time to peak in hours, where $T_p = \frac{\Delta D}{2} + .6T_c$

ΔD = duration of unit excess rainfall in hours = $0.133\ T_c$

T_c = estimated time of concentration in hours

Example

A 102 millimeter rain fell over an 11.9 square kilometer watershed with a grass cover, soils in group C, and an AMC II. The duration of rainfall was 6 hours. Estimate the direct runoff volume and the corresponding peak flow.

(1) from Table 1, CN = 80.

(2) Enter Figure 5 with 102 millimeters of rain and CN = 80. The direct runoff is approximately 52 millimeters.

(3) Peak flow discharge for the watershed with a time of concentration (T_c) of 2.3 hours, is determined as follows:

$$T_p = \frac{\Delta D}{2} + .6\ T_c$$

$$= \frac{0.31}{2} + (.6 \times 2.3) = 1.53 \text{ hours}$$

$$q_p = \frac{484 \times 4.6 \times 2.06}{1.53} = 2998 \text{ cfs } (83.9\ m^3/\text{sec})$$

Changes in direct runoff associated with changes in the soil-vegetation complex are determined largely by the CN relationships. For example, converting from tropical kudzu, hydrologic soil group C, AMC = II, to a grass cover, changes the CN from 67 to 80. This in turn, would result in an increase in direct runoff from 14 millimeters to 32 millimeters for a 76 millimeter rain. In some instances, the time of concentration could also be altered which would affect the peak and general shape of the stormflow hydrograph.

Generalized Watershed Models

The previous section dealt with single-event methods or models which allow estimates of peaks or stormflow volumes with limited data. Sometimes an estimate of continuous streamflow response is needed. Such information is useful for determining reservoir-conservation storage requirements, for water quality investigations, and for estimating

differences in annual streamflow or low-flow before and after watershed modifications. Models with greater complexity and more extensive data requirements are then needed.

Most generalized watershed models are continuous simulation programs which use a water budget approach. Hydrologic processes such as interception, evaporation, transpiration and infiltration are simulated to varying degrees. Some processes may be simulated conceptually, based on a relationship with some measurable watershed characteristic. More rarely, components are calculated directly from physical measurements (physically based). For either case, processes must be linked together mathematically so that the conservation of mass principle is not violated. To be manageable, most such models are "lumped" (*i.e.*, spatial variability of processes and characteristics over the watershed unit is ignored). Modeling units should, therefore, be relatively homogenous in terms of hydrologic characteristics.

The generalized watershed models developed in recent years differ in terms of concepts, level of complexity, and input requirements. For general application, models should be conceptually sound, flexible in design, and physically relevant. Input data requirements should not be unreasonable and output should be of a type which can be conveniently used. The utility of such models depends on input-output capabilities and on the transferability of parameters to ungauged or altered watersheds. (Typical components of a continuous simulation model are illustrated in Figure 4.)

REGIONAL ANALYSIS

A regional analysis is a statistical approach in which generalized equation, graphical relationships, or maps are developed for the purpose of estimating hydrologic information at ungauged sites. Runoff factors, unit hydrograph coefficients, and streamflow frequency characteristics can be estimated for ungauged watersheds that are within the same climatic region as gauged watersheds. Any pertinent information within the region should be used to relate watershed characteristics with hydrologic characteristics. In one extreme, a regional analysis may be used to estimate runoff coefficients or peak flow in cubic meters per second per square kilometer associated with a specified recurrence interval. At the other extreme, a regional analysis may be used to estimate parameter values needed to execute a complex hydrologic model.

Regional streamflow frequency analysis is the most commonly applied regional analysis. Equations and maps are developed which allow the derivation of exceedence frequency curves for ungauged areas in the following manner:

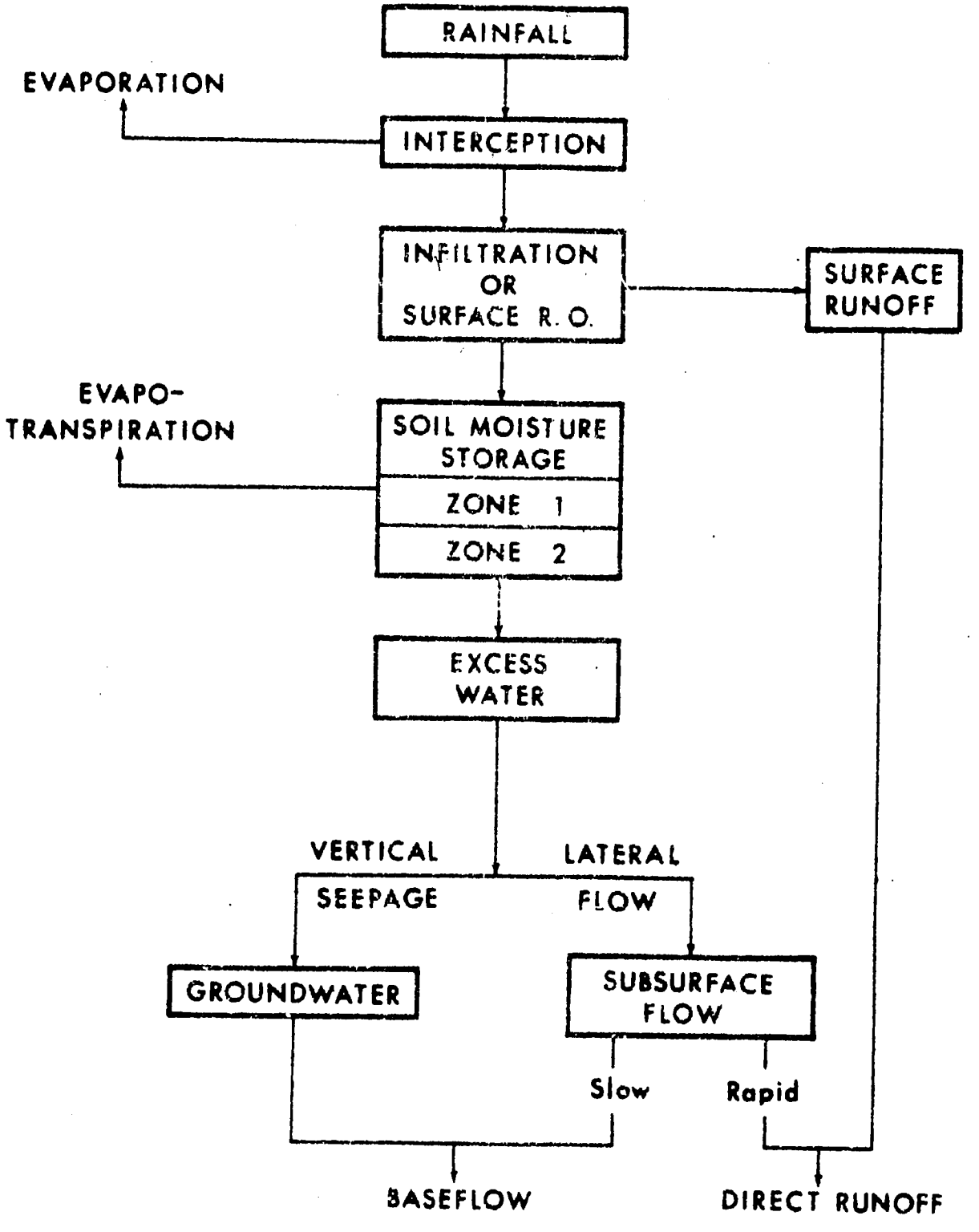


Figure 4. Hydrologic processes and runoff relationships.

(1) Select components of interest such as the mean annual peak flow, 100-year recurrence interval peak flow *etc.*

(2) Select explanatory variables (characteristics) of gauged watersheds such as drainage area, watershed slope, percentage of area covered by lakes, *etc.* Prediction variables are determined by regression analysis, as previously discussed.

(3) Derive prediction equations with single or multiple linear regression analysis.

(4) Map and explain the residual errors, which are the differences between calculated and observed values at gauged sites. The residuals constitute unexplained variance in the statistical analysis. Since it is impossible to include all variables which influence a particular hydrologic response, the mapping of unexplained variances can sometimes indicate other factors which are important. Sometimes mapped residuals will indicate a relationship between the magnitude of the residual error and watershed characteristics such as vegetative type or soils.

(5) Determine frequency characteristics for ungauged locations by applying the regression equation with adjustments as indicated by the mapped residual errors.

Regional analysis has been widely applied in the United States where streamflow or other hydrologic information is available, within different climatic regions. The method must be used with care, however, since only one or, perhaps, a few components of the hydrologic system are included in the analysis. The results should always be considered a rough estimate of the true hydrologic characteristics.

CHAPTER VI

VEGETATIVE MANAGEMENT AND WATER YIELD

INTRODUCTION

To meet world demands for surface and ground water, several approaches to water augmentation and methods for better water management have been explored. Water harvesting, reuse, salvage (by removal of riparian plant communities), and vegetation management on upstream catchments are some of these approaches.

The management of vegetation on upstream catchments to increase the yield of usable water is of special interest. Water yield can be increased by vegetative treatments that benefit, or are at least compatible with, other natural resource objectives. Concepts of vegetation management for water yield improvement will be presented, along with a brief summary of several worldwide studies on the effects of altering vegetative cover on water yield.

VEGETATION MANAGEMENT FOR WATER YIELD--CONCEPTS

Many studies conducted throughout the world have demonstrated that annual water yields can be increased following the implementation of vegetation management practices. In general, the increased runoff is attributed to decreased evapotranspiration on the watersheds. That is, following treatment, less precipitation input is converted to vapor as a result of rainfall and snowfall interception and transpiration, and more is made available for streamflow runoff. Presumably, the reduced evapotranspiration is due to changes in the structure and composition of vegetation on the watershed.

Evaporation processes generally account for a significant proportion of the annual precipitation input on most watersheds. Consequently, the potential to increase water yield by decreasing evapotranspiration is attractive. For example, 85 to 95 percent of the annual precipitation is evaporated or used by plants on many watersheds in arid and semiarid regions, leaving only 5 to 15 percent available for streamflow runoff. On

high elevation mountain watersheds in the snow zones of the world, the annual water yield may be as high as 50 percent of the precipitation input, but the evapotranspiration component is still significant and potentially subject to reduction through vegetation management.

Perhaps the above concepts may best be illustrated with a hypothetical, but realistic, water budget for a forested watershed (Table 1). Prior to treatment, average annual precipitation and evapotranspiration were 635 and 560 millimeters (mm), respectively, leaving 75 mm for streamflow runoff. After the implementation of a vegetation management practice, perhaps a partial harvesting of the forest overstory in a timber management operation, the annual streamflow runoff was increased by 25 mm (from 75 to 100 mm) due to a reduction in evapotranspiration of 25 mm (from 560 to 535 mm). The annual precipitation input of 635 mm remained the same, as basic precipitation patterns are usually not affected by modifications in the structure and composition of vegetation cover.

In the case illustrated, annual water yield increased by 33 per cent, while annual evapotranspiration decreased by 5 percent. It should be noted that, no matter what vegetation management practice is imposed on watersheds, the annual evapotranspiration may only slightly change. However, as demonstrated above, even a small reduction in evapotranspiration may cause significantly increased streamflow runoff.

Indications are that, for appropriate conditions and situations, water yields can be augmented by vegetation management practices without denuding watersheds of plant cover and without unacceptable changes in erosion and sedimentation. Evidence also suggests that vegetation management designed for water yield improvement can be developed to be compatible with other natural resource uses and values.

If the structure and composition of vegetation at the interface of earth and atmosphere can be modified by management practices,

Table 1. Average annual precipitation, evapotranspiration, and runoff for a hypothetical watershed in a treated and untreated condition.

Water Budget Component	Untreated (mm)	Treated (mm)
Precipitation	635	635
Evapotranspiration	560	535
Runoff	75	100

evapotranspiration may be reduced with the result that more of the annual precipitation input will be released from watersheds as usable water. This concept is the primary basis for the belief that vegetation can be managed for water yield improvement as well as for other natural resource products and amenities.

SUMMARY OF WATER YIELD IMPROVEMENT EXPERIMENTS

Experimental catchments, often supplemented by plot studies and computer modeling, have been used on numerous occasions to demonstrate that the hydrologic relationships of a river basin may be significantly affected by the implementation of a vegetation management practice on upstream catchments. These management practices, often imposed as a water yield improvement practice, include various types of forest cutting or removal, changes of forest cover from one tree type to another, or more drastic changes in which a forest cover is replaced by another type of vegetation.

As an overview of the potentials for water yield improvement through vegetation management, a brief summary of several worldwide studies on the effects of altering vegetative cover on water yield and the significance of the resulting conclusions are presented.

Emmenthal Mountains

In 1900, an early study of the effects of forest treatments on water yield was carried out in the Emmenthal Mountains of Switzerland. Here, measurements of climate, precipitation, and streamflow were made on two small catchments, one forested and the other pastureland, to determine the influence of forests on water production. Despite attention to detail, there was no way to ascertain that the observed differences in streamflow between the two catchments were caused only by differences in vegetation cover.

Wagon Wheel Gap

A second attempt to quantitatively analyze the influence of forests on water yield was made in the Wagon Wheel Gap investigation of 1911. The control watershed approach (in which streamflow from two similar catchments are compared during a period of "calibration," and then treating one catchment while leaving the other untreated as a control) was first used in this study of two forested catchments in the Colorado Rockies of the western United States. After eight years of calibration, one of the catchments was denuded by removing the scrub aspen and coniferous vegetation. Then, for seven additional years, streamflow from the denuded areas was compared with flow from the control catchment. This investigation conclusively demonstrated that clearing forest cover did increase streamflow. This study also demonstrated that changes in water yield could be quantitatively assessed.

Coweeta Hydrologic Laboratory

In 1934, the Coweeta Hydrologic Laboratory was established by the USDA Forest Service to analyze the effects of various forest cutting and vegetative conversion treatments on water yield in the humid mountains of the eastern United States. Mixed hardwoods with basal area densities of 20 to 25 square meters per hectare characterized the original forest conditions on the twelve experimental catchments at Coweeta. Treatments implemented and then evaluated included clearcutting with and without control of regrowth, poisoning of forest overstories on portions of catchments with regrowth restricted, and thinning above and below by selective logging.

With the exception of limited thinning (25 percent of the basal area removed), the treatments evaluated increased water yield by varying amounts. In general, these increases were greatest immediately after treatment and the duration of effect was dependent, in part, upon the severity of treatment. One of the catchment studies is the site of the only cutting experiment replicated in time.

Kamabuti

Coniferous and deciduous forest overstories on a small mountainous catchment in Kamabuti, Japan were cleared in 1948, with subsequent annual recutting of sprouts. Significant water yield increases were observed following treatment, although these increases were restricted to the growing season.

Fernow Experimental Forest

In 1951, the USDA Forest Service began gauging on several small catchments at the Fernow Experimental Forest in the Allegheny Mountains of West Virginia in the eastern United States. Original forest conditions on these catchments were mixed hardwoods at 20 to 25 square meters of basal area per hectare. After calibration, water yield improvement studies were designed and implemented to determine effects of logging on streamflow. Treatments evaluated consisted, for the most part, of thinning by alternative silvicultural practices.

As was found at Coweeta, with the exception of limited thinning (in this case, approximately 15 percent of the basal area removed), the treatments evaluated increased water yield by varying amounts. Also, these increases were greatest immediately after treatment.

Fraser Experimental Forest

To assess effects of forest cutting on snow pack dynamics and subsequent streamflow, the USDA Forest Service logged mature lodgepole pine and spruce-fir in strips and blocks on an experimental catchment in the

Colorado Rockies of the western United States. As a result of this treatment in which about 40 percent of the catchment was clearcut from 1954 to 1956, streamflow increased during the snowmelt period (essentially May and June). This increase in water yield was attributed, primarily, to redistributions in snowpacks brought about by a restructuring of the forest overstories.

Kimakia

In 1956, the high montane and bamboo forests on an experimental catchment at Kimakia in Kenya, East Africa, was cleared and planted to patula pine. Vegetables were grown among the pines until the third post-treatment year (when the pines were 3 to 5 meters high). A large increase in water yield was observed following cutting, with the greatest increases immediately after treatment. No change in seasonal patterns of streamflow occurred.

San Dimas Experimental Forest

At San Dimas, located in the semiarid region of California in the western United States, the USDA Forest Service selectively treated chaparral vegetation thought to use proportionally large quantities of water. In 1958 and 1959 riparian vegetation was cut and regrowth controlled on one experimental catchment (less than 2 percent of the area treated), while chaparral on moist sites with deep soils was sprayed with herbicides on another catchment (about 40 percent of the area treated). Both treatments increased water yield, with dry-season streamflow affected more significantly.

A disastrous wildfire swept San Dimas in 1960, destroying all existing vegetation. Dry-season streamflow increased appreciably following the wildfire on the two catchments treated, while streamflow from untreated (control) but burned catchments did not.

H. J. Andrews Experimental Forest

To determine how logging activities affect streamflow on the western slope of the Cascade Range in Oregon, United States, two experimental catchments were subjected to staged treatments (road construction, cutting of the coniferous overstories, and burning) during the period of 1959 to 1963. Significant increases in water yield occurred in the low flow season after each treatment, but they were small in actual volume (less than 0.1 mm per day).

Jonkershoek Forest Reserve

Analysis of streamflow from an experimental catchment on the Jonkershoek Forest Reserve, South Africa, has shown a 50 percent increase in water yield after one third of the radiata pine forest cover was removed 16 years following planting. Presumably, most of the increase in flow was due to less transpiration losses. This effect of increased streamflow was maintained for three years after the thinning treatment.

Junquillar Basin

To evaluate effects of established land use patterns on the western slope of Chile's coastal mountains, three experimental catchments (two burned and an unburned control) were gauged in the Junquillar Basin during 1970. Native vegetation on the area included small trees (roble maulino, white boldo, and litre), shrubs, and a few grasses. Radiata pine had been planted on the burned catchments, a common practice in the region.

While still exploratory, preliminary results have indicated that streamflow from the catchments did not differ noticeably. However, peak flows, which are more sensitive to treatment and may be more important in a region of high rainfall, were higher on the burned areas.

North Maroondah

Measurements of effects of thinning radiata pine plantations and regrowth mountain ash on streamflow volumes were the subject of major experimental catchment studies conducted by the Melbourne and Metropolitan Board of Works in the North Maroondah area of Australia. Preliminary results suggest that forest manipulations involving thinning of these forest cover types may be a feasible approach to increasing Melbourne's water supplies.

Arizona Watershed Program

Watershed managers in the southwestern United States, a semiarid region with short water supplies, have been particularly interested in evaluating possibilities of water yield improvement by vegetation management. As a result, the Arizona Watershed Program (involving federal, state, and private interests) was formulated to study the influence of vegetation management practices on the hydrologic processes affecting water yield improvement. While many vegetation types have been investigated, results of experimental catchment studies to date indicate that the greatest opportunities for water yield improvement by vegetation management are found in chaparral shrub communities, pinyon-juniper woodlands, ponderosa pine forests, and mixed conifer (including aspen) forests.

It appears that water yield from chaparral shrub communities can be increased by removing shrub overstories and establishing a cover of grasses and forbs. Although experimental catchments have been established by the USDA Forest Service at several locations in chaparral, only the Three Bar Watersheds, located in east-central Arizona, will be considered here.

In 1956, four small catchments (B, C, D, and F) were established on Three Bar. All were burned over by wildfire three years later. With the exception of Catchment C, all of the catchments were seeded with grass shortly after the fire; Catchment B was reseeded; and Catchment C seeded for the first time in 1960. After calibration, control of chaparral shrub regrowth with herbicides was attempted on Catchments C and B and changes in water yield were observed. On Catchment C, the shrubs were controlled through aerial applications and hand treatments with herbicides. Annual water yield following treatment increased over 325 percent. Hand application of herbicides to the shrubs on the north-facing slopes, comprising 40 percent of Catchment B, increased annual water yield by 320 percent. Complete conversion on Catchment F resulted in an annual water yield increase of approximately 700 percent.

Originally thought to have potential, improving water yield by manipulating pinyon-juniper woodlands does not appear promising at this time. On Beaver Creek and Corduroy Creek, experimental catchments located in north-central and east-central Arizona, respectively, removal of pinyon-juniper overstories by mechanical techniques (chaining, cabling, and hand clearing) has not increased water yield. However, water yield was improved on one experimental catchment by killing pinyon and juniper trees with herbicides and leaving them stand. The increase on Beaver Creek Catchment 3 after aerial spraying of herbicides was 65 percent annually. However, this study was too limited to make general statements about chemical conversion treatments for increasing water yield.

Opportunities for and estimates of water yield improvement through vegetation management in ponderosa pine forests are synthesized from the results of experiments on Castle Creek, located in east-central Arizona, and Beaver Creek. For purposes of discussion, vegetation management options in ponderosa pine forests may be placed into two categories: clearing of forest overstories and thinning of forest overstories. Various alternatives are possible within these categories, however. For instance, clearings can be arranged and oriented in various patterns, and intensity of thinning can be varied.

Clearing of ponderosa pine from one sixth of the West Fork of Castle Creek and thinning the remaining five sixths increased annual water yield by over 25 percent. On Beaver Creek Catchment 12, an increase of approximately 30 percent has occurred annually since the complete clearing of the forest overstory. Clearing forest overstories from 20 meter side strips and leaving alternating uncut strips 60 meters wide increased annual water yield by nearly 15 percent on Beaver Creek Catchment 9. Thinning the forest overstory by group selection on Beaver Creek Catchment 17 increased annual water yield by about 20 percent.

Estimates of water yield improvement through the manipulation of mixed conifer forest overstories are based, in part, upon partial conversion experiments on the Workman Creek Watershed in east-central Arizona. On the North Fork of Workman Creek, deciduous riparian vegetation was removed, and two thirds of the moist-site and dry-site forests were converted to grass. The resulting increase in water yield was approximately 85 percent. On the South Fork of Workman Creek, annual water yield increased nearly 115 percent after an individual tree selection cut was followed by a conversion cut.

DISCUSSION OF WATER YIELD IMPROVEMENT EXPERIMENTS

A review of worldwide studies of the effects of altering vegetative cover on water yield suggests that several generalizations can be made:

(1) reduction in densities of forest overstories increases water yield;

(2) establishment of forest overstories on sparsely vegetated land decreases water yield; and

(3) response of water yield to treatment is highly variable and, for the most part, unpredictable.

The above generalizations must be qualified when specific experiments are considered but, in most instances, they are accurate. With few exceptions, the worldwide studies have shown a definite response to vegetative cover alteration. However, the magnitude of treatment response has varied considerably. For example, removal of scrub aspen and coniferous vegetation in the Colorado Rockies of the western United States caused streamflow to increase only 35 millimeters during the first year after treatment, while complete cutting and removal of high montane and bamboo forests in the mountains of East Africa increased water yield in excess of 450 millimeters during the first year. These extremes reflect the diverse nature of the results and suggest the complexity of the causative factors.

To summarize, the results of experimental catchment studies suggest that vegetation management may have potential for increasing water yield on many drainages throughout the world. Furthermore, if desired, many of these management practices can be designed to maintain or enhance the production and use of associated natural resources, including timber, domestic livestock, wildlife, aesthetics, and soils. Such possibilities are not surprising, as many of the vegetation management practices tested in various parts of the world are employed to benefit other natural resources. Therefore, it seems possible that vegetation management can satisfy increasing demands for other natural resources while it is increasing water yield.

The results presented in this overview are based, for the most part, on research tests and not operational programs. Hopefully, these research findings can be coupled with economic and social considerations to develop operational practices that will provide multiple benefits.

It must be emphasized, however, that total areas potentially suited to vegetation management practices aimed at increasing water yield must be reduced to account for all of the possible constraints in implementing an operational water yield improvement practice on a particular watershed. Generally, the total areas must be adjusted downward by considering the constraints to implementation (Figure 1). Only after these constraints have been taken into account can treatable area be estimated.

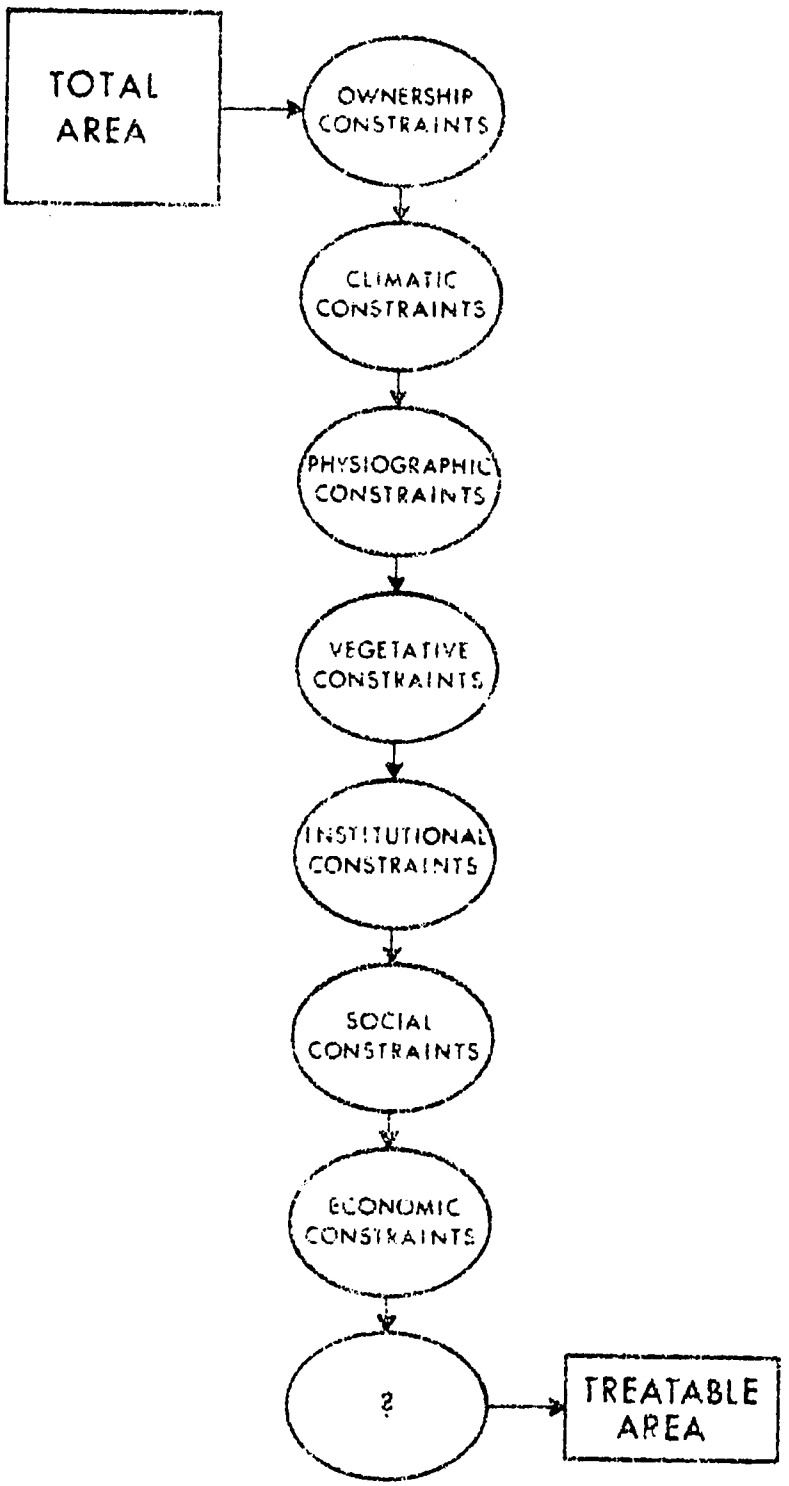


Figure 1. Constraints encountered by watershed managers when estimating treatable area for water yield improvement practices.

CHAPTER VII

EROSION PROCESSES AND CONTROL

INTRODUCTION

This chapter attempts to summarize the available body of knowledge and hypotheses on erosion processes, gully formation, and control. Included are: fundamental erosion processes, classification of gullies, objectives in gully control, types of control structures, cost relations, and recommendations.

EROSION PROCESSES

In general, there are three basic erosion processes on upland watersheds: surface erosion, mass wasting, and channel or gully erosion.

Surface erosion involves the detachment and subsequent removal of soil particles and small aggregates from land surfaces. This type of erosion is caused by the action of raindrops, thin film flows, and concentrated overland flows. It results in sheet erosion, rills, small gullies, *etc*. While seldom serious in forested areas, surface erosion can be an important source of sediment from rangelands and cultivated lands.

Mass wasting (or mass movement) is an important type of erosion in steep, mountainous country. Mass wasting includes erosion in which cohesive masses of soil are displaced. Movement can be rapid, as with landslides, or it may be quite slow, as with slumps and soil creeps. Man's activities can greatly accelerate the process of mass wasting.

Channel or gully erosion is the detachment and movement of material, either individual soil particles or large aggregates, from a stream channel. This kind of erosion is a major form of geologic erosion which, under poor land management, can be greatly accelerated.

All of the above erosion processes can occur singly or in combination. At times, it is difficult to distinguish or separate between the basic types of erosion because, in reality, there is a continuum of forms.

The control of channel or gully erosion is a particularly important responsibility of watershed resources managers. To develop effective control measures, an understanding of gully formation and control structures is necessary.

CLASSIFICATION OF GULLIES

Discontinuous Gullies

Gullies may be classified as *discontinuous* or *continuous*. Discontinuous gullies may be found at any location on a hillslope. Their start is signified by an abrupt headcut. Normally, gully depth decreases rapidly downstream. A fan forms where the gully intersects the valley. Discontinuous gullies may occur singly or in a system of chains in which one gully follows the next downslope. These gullies may be incorporated into a continuous system either by fusion with a tributary, or may become a tributary to the continuous stream net themselves by a process similar to stream "capture." In the latter case, shifts on the alluvial fan cause the flow from a discontinuous gully to be diverted into a gully, falling over the gully bank. At this point, a headcut will develop that proceeds upstream into the discontinuous channel where it will form a nickpoint. Headward advance of the nickpoint will lead to gully deepening.

Continuous Gullies

The continuous gully begins with many fingerlike extensions into the headwater area. It gains depth rapidly in the downstream direction and maintains approximately this depth to the gully mouth. Continuous gullies nearly always form systems (stream nets). They are found in different vegetation types, but are prominent in the semiarid and arid regions. It appears that localized or regional depletion of any vegetative

cover can lead to gully formation and gully stream nets, if other factors such as topography and soils are conducive to gully initiation.

During the youthful stage, gully processes proceed toward the attainment of dynamic equilibrium; while, in the old age stage, a gully loses the characteristics for which it is named and resembles a river or "normal" stream. Gully development may not end with old age, however. Environmental changes, such as induced by new land use and climatic fluctuation or uplift, may lead to rejuvenation, throwing the gully back into the youthful stage. We must also recognize that gully development is not necessarily an "orderly" process, proceeding from one condition to the next "advanced" one.

OBJECTIVES IN GULLY CONTROL

Main Processes of Gully Erosion as Related to Control

The mechanics of gully erosion can be reduced to two main processes: *downcutting* and *headcutting*. Downcutting of the gully bottom leads to gully deepening and widening. Headcutting extends the channel into ungullied headwater areas and increases the stream net and its density by developing tributaries. Thus, effective gully control must stabilize both the channel gradient and channel headcuts.

Long-Term Objective of Controls--Vegetation

In gully control, it is of benefit to recognize long- and short-term objectives because often it is very difficult or impossible to reach the long-term goal (vegetation) directly; gully conditions must be first altered. Required alterations are the immediate objectives.

Where an effective vegetation cover will grow, gradients may be controlled by the establishment of plants without supplemental mechanical measures. Only rarely can vegetation alone stabilize headcuts, however, because of the concentrated forces of flow at these locations. The most effective cover in gullies is characterized by great plant density, deep and dense root systems, and low plant height. Long, flexible plants (such as certain tall grasses), on the other hand, lie down on the gully bottom under impact of flow. They provide a smooth interface between flow and original bed, and may substantially increase flow velocities. These higher velocities may endanger meandering gully banks and, in spite of bottom protection, widen the gully. Trees, especially if grown beyond sapling stage, may restrict the flow and cause diversion against the bank. Where such restrictions are concentrated, the flows may leave the gully. This is very undesirable because, in many cases, new gullies develop and new headcuts form where the flow reenters the original channel.

Engineers' Measures--An Aid to Vegetation Recovery

If growing conditions do not permit the direct establishment of vegetation (due to climatic or site restrictions, or to severity of gully erosion), engineering measures will be required. These measures are nearly always required at the critical locations where channel changes invariably take place. Examples are nickpoints on the gully bed, headcuts, and gully reaches close to the gully mouth where deepening, widening, and deposition alternate frequently with different flows. Nickpoints signify longitudinal gradient changes; a gentler gradient is being extended toward headwaters by headcutting on the bed. Normally, critical locations are easily definable.

An effective engineering design must help establish and rehabilitate vegetation. Revegetation of a site can be aided in different ways. If the gully gradient is stabilized, vegetation can become established on the bed. Stabilized gully bottoms will make possible the stabilization of banks, since the toe of the gully side slopes is at rest. This process can be speeded up mechanically by sloughing gully banks where steep banks would prevent vegetation establishment. Banks should be sloughed only after the bottom is stable, however,

Vegetation rehabilitation is also speeded if large and deep deposits of sediment accumulate in the gully above engineering works. Such alluvial deposits make excellent aquifers, increase channel storage capacity, decrease channel gradients, and thus, decrease peak flows. Channel deposits may also raise the water table on the land outside the gully. They may reactivate dried-up springs or may convert ephemeral springs to perennial flow. All these results create conditions much more favorable to plant growth than those existing before control.

Watershed Restoration Aids Gully Control Measures

Measures taken outside the channel can also aid revegetation processes in the gully. Improvements on the watershed that: increase infiltration and decrease overland flow, and spread, instead of concentrate, this flow, will benefit gully healing processes. A study on sediment control measures showed that sediment yields were reduced 25 to 60 percent by land treatment and land use adjustments, as surveyed at 15 to 20 year old flood water retarding structures in the southern Great Plains. But when combined land treatment and structural measures were applied, sediment yields were reduced 60 to 75 percent. Normally, however, gully improvements can be attained quicker within the gully than outside, because of concentration of treatment and availability of higher soil moisture in the defined channel.

Since watershed restoration measures are only supplemental to gully control, some examples will suffice here: seeding and planting with and without land preparation and fertilization; vegetative cover conversions; and engineering works such as reservoirs, water diversions, benches, terraces, trenches, and furrows.

Immediate Objectives of Control

Different types of measures benefit plants in different ways. It is therefore important to clarify the type of help vegetation establishment requires most. Questions should be answered such as: Is the present moisture regime of the gully bottom sufficient to support plants, or should the bottom be raised to increase moisture availability? One must recognize that a continuous, even raising of the bottom is not possible.

The immediate objectives of a gully treatment must consider other aspects in addition to plant cover. Usually, these considerations involve hydraulics, sedimentations, soils, and sometimes the logistics required for the management of the watershed For instance, management may call for deposits of maximum possible depth at strategic locations to provide shallow gully crossings. Thus, if sediment catch is a desirable objective, large dams should be built. But if aesthetic considerations make check dams undesirable (and watershed logistics and revegetation offer no problems), the gully bottom may be stabilized with dams submerged into the bed, and thus invisible to the casual observer.

These examples illustrate how important it is to clarify the immediate and overall objectives of a planned treatment before deciding on approaches and measures. The objectives determine the measures; the measures determine the type of result.

GULLY CONTROL STRUCTURES AND SYSTEMS

Types of Porous Check Dams

The most commonly applied engineering measure is the check dam. Forces acting on a check dam depend on design and type of construction material. Nonporous dams with no weep holes, such as those built from concrete, sheet steel, wet masonry, and fiberglass, receive a strong impact from the dynamic and hydrostatic forces of the flow. These forces require strong anchoring of the dam into the gully banks, to which most of the pressure is transmitted. In contrast, porous dams release part of the flow through the structure, and thereby decrease the head of flow over the spillway and the dynamic and hydrostatic forces against the dam. Much less pressure is received at the banks than with nonporous dams. Since gullies generally are eroded from relatively soft soils, it is easier to design effective porous check dams than nonporous ones. Once the catch basin of either porous or nonporous dams is filled by sediment deposits, however, structural stability is less critical because the dam crest has become a new level of the upstream gully floor.

Loose rock can be used in different types of check dams. Dams may be built of loose rock only, or the rock may be reinforced by wire mesh, steel posts, or other materials. The reinforcements may influence

rock size requirements. If wire mesh with small openings is used, rocks may be smaller than otherwise required by the design flow.

Some different types of check dams will be described, but the field of check dam design is wide open. Many variations are possible. The torrent control engineers of Europe have been especially successful with filter or open dams. Most of their designs are for large torrents where stresses on the structures are much greater than those in gullies, generally. Other types of filter dams have vertical grids, or grids installed at an angle to the vertical.

All the torrent control dams are quite sophisticated and costly. Such high costs are often justified in Europe, however, since population densities require the most effective and lasting control measures. These qualities are especially important if the basic geologic instability of the alpine torrents is considered. In contrast, most gullies in the western United States are caused by soil failure. Life and high-cost property are not usually endangered. Simpler, less expensive structures will therefore be preferable. Some of the most effective and inexpensive dams are built mainly from loose rock. They will, therefore, be emphasized in the descriptions that follow.

Loose Rock

Since loose-rock dams (Figure 1) are not reinforced, the angle of rest of the rock should determine the slope of the dam sides. This angle depends on the type of rock, the weight, size, and shape of the individual rocks, and their size distribution. If the dam sides are constructed at an angle steeper than that of rest, the structure will be unstable and may lose its shape during the first heavy runoff. For the design of check dams, the following rule of thumb can be used: the angle of rest for angular rock corresponds to a slope ratio of 1.25 to 1.00; for round rock, 1.50 to 1.00.

Wire-Bound Loose Rock

A wire-bound check dam is identical in shape to that of a loose-rock dam, but the loose rock is enclosed in wire mesh to reinforce the structure. The flexibility within the wire mesh is sufficient to permit adjustments in the structural shape, if the dam sides are not initially sloped to the angle of rest. Therefore, the same rock design criteria are required for a wire-bound dam as for a loose-rock structure.

The wire mesh should: be resistant to corrosion, be of sufficient strength to withstand the pressure exerted by flow and rocks, and have openings not larger than the average rock size in the dam. Wire mesh may not be effective in boulder-strewn gullies supporting flows with heavy, coarse loads.

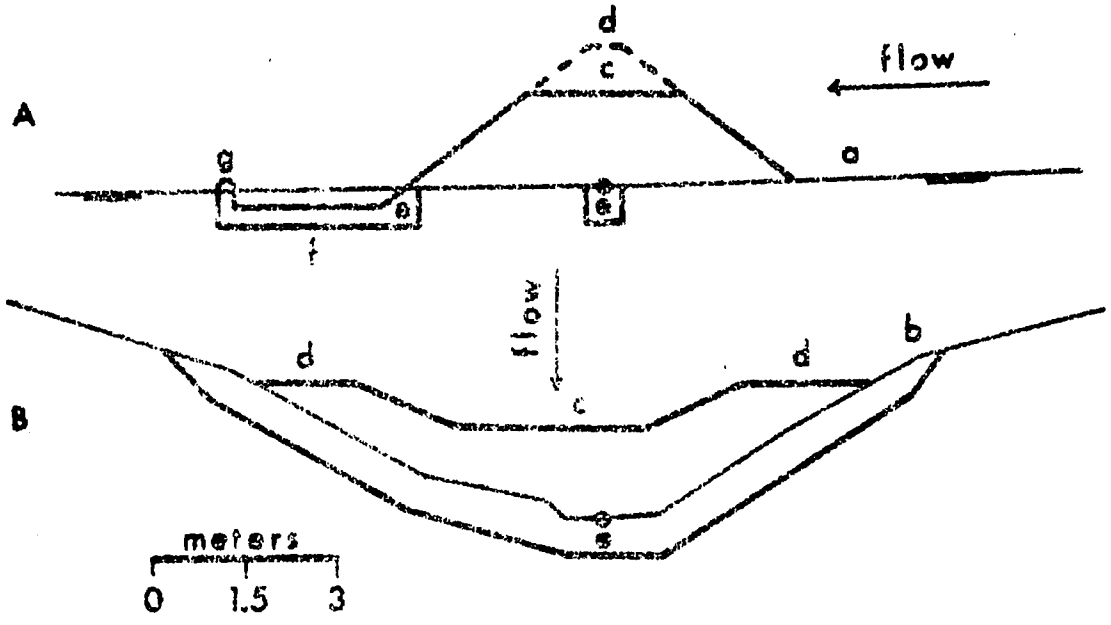


Figure 1. Construction plans for a loose-rock check dam.
A = section of the dam parallel to the centerline of the gully.
B = section of the dam at the cross section of the gully.
a = original gully bottom. b = original gully cross section.
c = spillway. d = crest of freeboard. e = excavation for key.
f = excavation for apron. g = end sill.

Single Fence

Single-fence rock check dams (Figure 2) differ greatly in shape and requirements of construction materials from the loose-rock and wire-bound dams. These structures consist of: a wire-mesh fence, fastened to steel fenceposts and strung at right angles across the gully, and a loose-rock fill, piled from upstream against the fence. The rock fill can be constructed at an angle steeper than that of rest for two reasons: (1) The impact of flows will tend to push the individual rock into the fill and against the dam, and (2) Sediment deposits will add stability to the fill and will eventually cover it.

The design of this type of check dam should emphasize specifications for the wire mesh, and the setting, spacing, and securing of the steel fenceposts. The wire mesh specifications will be the same as those for the wire-bound dams.

The steel fenceposts should be sufficiently strong toresist the pressure of the rock fill and the flows, and must be driven into the gully bottom and side slopes to a depth that insures their stability in saturated soil. If it is impractical to drive posts to sufficient depths, the stability of the posts should be enhanced by guys. These guys should be anchored to other posts that will be covered and thus held in place by the rock fill.

In general, spacing between the fenceposts should not be more than 1.2 meters to prevent excessive pouching (stretching) of the wire mesh. Where conditions do not allow this spacing, a maximum of 1.5 meters can be used, but the fence must be reinforced by steel posts fastened horizontally between the vertical posts. Excessive pouching of the wire mesh reduces the structural height and impairs the stability of the dam.

Double Fence

The double-fence rock check dam has two wire mesh fences, strung at a distance from each other across the channel (Figure 3). In this type of dam, a well-graded supply of rocks is essential, otherwise the relative thinness of the structure would permit rapid throughflow, resulting in water jets. Double-fence dams should only be built if an effective rock gradation can be obtained.

When flows of large magnitude (2 meters^3/second, for example) or gullies on steep hillsides are encountered, the base of the double-fence dam should be wider than the crest. This will add structural stability and increase the length of the flow through the lower part of the dam.

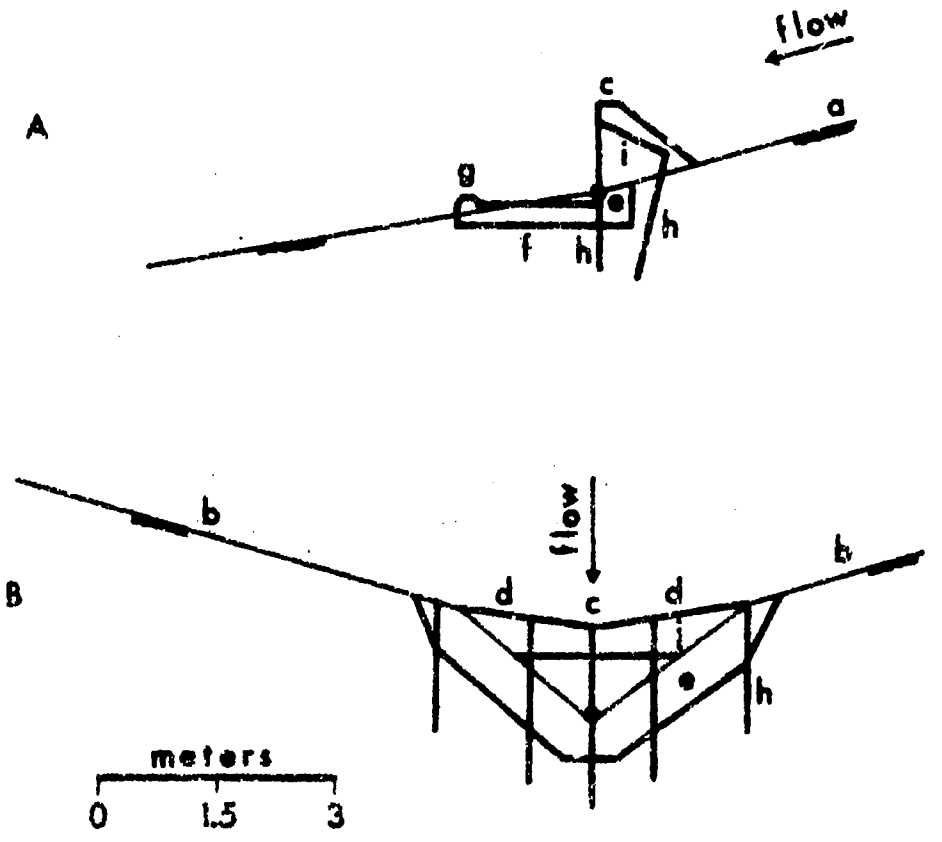


Figure 2. Construction plans for a single-fence rock check dam.
A = section of the dam parallel to the centerline of the gully.
B = section of the dam at the cross section of the gully.
a = original gully bottom. b = original gully cross section.
c = spillway. d = crest of freeboard. e = excavation for key.
f = excavation for apron. g = end sill. h = steel fencepost.
i = guys. j = rebar, 13 millimeters in diameter.

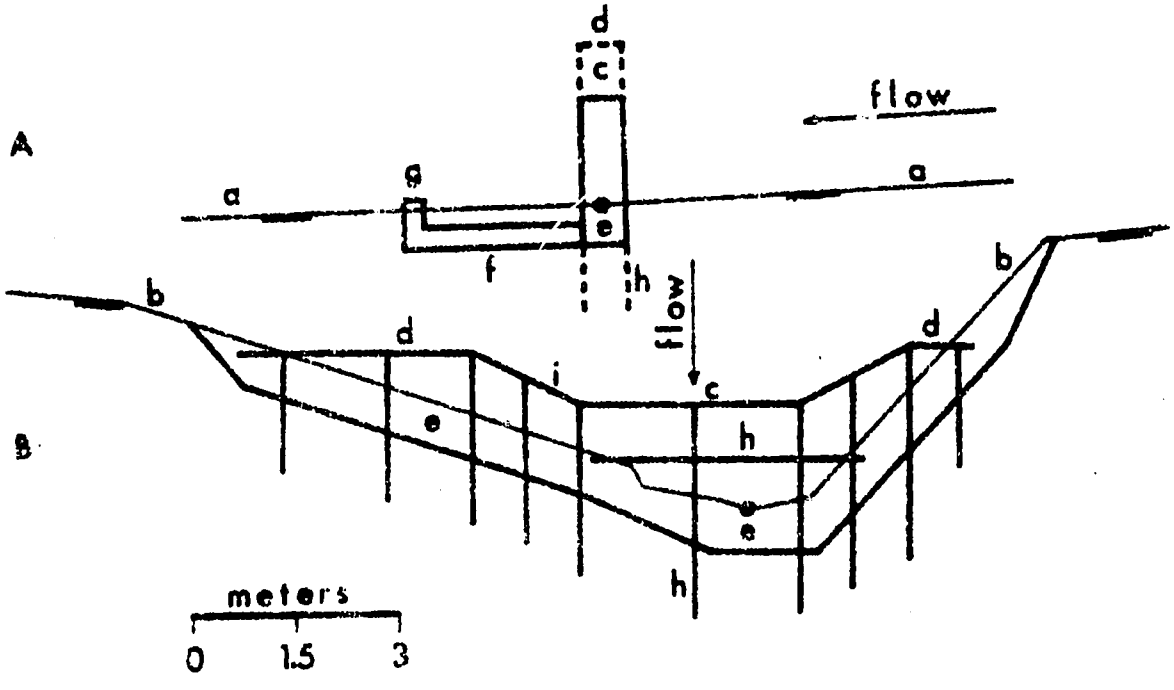


Figure 3. Construction plans for a double-fence rock check dam.
A = section of the dam parallel to the centerline of the gully.
B = section of the dam at the cross section of the gully.
a = original gully bottom. b = original gully cross section.
c = spillway. d = crest of freeboard. e = excavation for key.
f = excavation for apron. g = end sill. h = steel fencepost.
i = rebar, 13 millimeters in diameter.

Gabion

A gabion check dam consists of prefabricated wire cages that are filled with loose rock. Individual cages are placed beside and onto each other to obtain the dam shape. Normally, this dam is more aesthetically pleasing, but it is more costly than loose-rock or wire-bound rock check dams.

Headcut Control

Headcuts can be stabilized by different types of structures, but all have two important requirements: porosity in order to avoid excessive pressures and thus eliminate the need for large, heavy structural foundations; and some type of inverted filter that leads the seepage gradually from smaller to larger openings in the structure. (Otherwise, the soils will be carried through the control, resulting in erosion.) An inverted filter can be obtained if the headcut wall is sloughed to such an angle that material can be placed in layers of increasing particle size, from fine to coarse sand and on to fine and coarse gravel. Good results may also be obtained by use of erosion cloth, a plastic sheet available in two degrees of porosity.

If rock walls reinforced by wire mesh and steel posts are used, site preparation can be minimized. Loose rock can be an effective headcut control if the flow through the structure is controlled also. As in loose-rock check dams, the size, shape, and size distribution of the rock are of special importance to the success of the structure. The wall of the headcut must be sloped back so the rock can be placed against it.

If the toe of the rock fill should be eroded away, the fill would be lost. Therefore, stabilization of this toe must be emphasized in the design. A loose-rock dam can be designed to dissipate energy from the chuting flows, and to catch sediment (Figure 4). Sediment depositions will further stabilize the toe of the rock fill by encouraging vegetation during periods with no or low channel flow.

General Design Criteria

Loose Rock

Loose rock has proved to be a very suitable construction material if used correctly. Often it is found on the land and thus eliminates expenditures for long hauls. Machine and/or hand labor may be used. The quality, shape, size, and size distribution of the rock used in construction of a check dam affect the success and lifespan of the structure.

Obviously, rock that disintegrates rapidly when exposed to water and atmosphere will have a short structural life. Further, if only

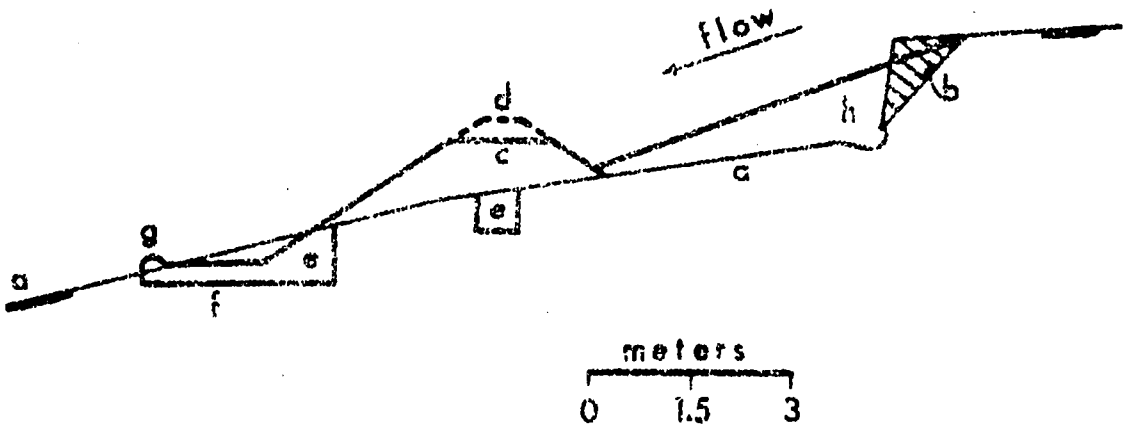


Figure 4. Construction plan for a gully headcut control with a loose-rock check dam. The section of the structure is parallel to the centerline of the gully. a = original gully bottom. b = excavated area of headcut wall. c = spillway. d = crest of freeboard. e = excavation for key. f = excavation for apron. g = end sill. h = rock fill.

small rocks are used in a dam, they may be moved by the impact of the first large water flow, and the dam quickly destroyed. In contrast, a check dam constructed of only large rocks that leave large voids in the structure will offer resistance to the flow, but may create water jets through the voids. These jets can be highly destructive if directed toward openings in the bank protection work or other unprotected parts of the channel. Large voids in check dams also prevent the accumulation of sediment above the structures. In general, this accumulation is desirable because it increases the stability of structures and enhances stabilization of the gully.

Large voids will be avoided if the rock is well graded. Well-graded rock will permit some flow through the structure. The majority of the rock should be large enough to resist the flow.

Since required size and gradation of rock depend on size of dam and magnitude of flow, strict rules for effective rock gradation cannot be given. The recommendations given below are empirical values derived from gully treatments in the Colorado Rocky Mountains, and should be evaluated accordingly. The designer should use these values only as a guide for his decision.

As a general rule, rock diameters should not be less than 10 centimeters, and 25 percent of all rocks should fall into the 10 to 14 centimeter size class. The upper size limit will be determined by the size of the dam; large dams can include larger rock than smaller ones. Flat and round rock, such as river material, should be avoided. Both types slip out of a structure more easily than broken rocks, which anchor well with each other.

In general, large design peak flows will require larger rock sizes than small flows. As an example, assume that the designed total dam height ranges between 1 and 2 meters, where total height is measured from the bottom of the dam to the crest of the freeboard. Type of dam is loose rock without reinforcement. Design peak flow is estimated not to exceed 1 meter^3/second. An effective rock gradation would call for a distribution of size classes as follows:

Size	Percent
10-14 cm	25
15-19 cm	20
20-30 cm	25
31-45 cm	30

If, on the other hand, dam height would be increased to 3 meters, rock up to 1 meter diameter, constituting 15 percent of the volume, could be placed into the base of the dam and the second size class decreased by this portion. If peak flow was estimated not to exceed 0.75 meter^3/second, the 31 to 45 cm size class could be eliminated and 55 percent of the volume could be in the 20 to 30 centimeter class.

Spacing

The location of a check dam will be determined primarily by the required spacing of the structures. Requirements for spacing depend on the gradients of the sediment deposits expected to accumulate above the dams, the effective heights of the dams, the available funds, and the objective of the gully treatment. If, for instance, the objective is to achieve the greatest possible deposition of sediment, high, widely spaced dams would be constructed. On the other hand, if the objective is mainly to stabilize the gully gradient, the spacing would be relatively close and the dams low.

In general, the most efficient and most economical spacing is obtained if a check dam is placed at the upstream toe of the final sediment deposits of the next dam downstream. This ideal spacing can only be estimated, of course, to obtain guidelines for construction plans.

Normally, objectives of gully control require spacings of check dams great enough to allow the full utilization of the sediment-holding capacity of the structures. Determination of this spacing requires definite knowledge of the relationship between the original gradient of the gully channel and that of sediment deposits above check dams placed in the gully.

Keys

Keying a check dam into the side slopes and bottom of the gully greatly enhances the stability of the structure. Such keying is important in gullies where expected peak flow is large and where soils are highly erosive (such as soils with high sand content). Loose-rock check dams without keys were successfully installed in soils derived from Pikes Peak granite, but estimated peak flows did not exceed 0.2 meters^3/second.

The objective of extending the key into the gully side slopes is to prevent destructive flows of water around the dam and consequent scouring of the banks. Scouring could lead to gaps between dam and bank that would render the structure ineffective. The keys minimize the danger of scouring and tunneling around check dams because the route of seepage is considerably lengthened as voids in the keys become plugged, the length of the seepage route increases. This increase causes a decrease in the flow velocity of the seepage water and, in turn, a decrease in the erosion energy.

The part of the key placed into the gully bottom is designed to safeguard the check dam against undercutting at the downstream side. Therefore, the base of the key, which constitutes the footing of the dam, must be designed to be below the surface of the apron. This is of particular importance for fence-type and impervious structures because of the greater danger of scouring at the foot of these dams. The water flowing over the spillway forms a chute that creates a main critical area of impact where the hydraulic jump strikes the gully bottom. This

location is away from the structure. The sides of loose-rock and wire-bound check dams slope onto the apron, on the other hand, and no freefall of water occurs.

The design of the keys calls for a trench, usually 0.6 meters deep and wide, dug across the channel. Where excessive instability is demonstrated by large amounts of loose materials on the lower part of the channel side slopes or by large cracks and fissures in the bank walls, the depth of the trench should be increased to 1.2 or 1.8 meters.

Dam construction starts with the filling of the key with loose rock. Then the dam is erected on the rock fill. Rock size distribution in the key should be watched carefully. If voids in the key are large, velocities of flow within the key may lead to washouts of the bank materials. Since the rock of the keys is embedded in the trench and therefore cannot be easily moved, it is advantageous to use smaller materials, such as a mixture with 80 percent smaller than 14 centimeters.

Height

The effective height of a check dam is the elevation of the crest of the spillway above the original gully bottom. The height not only influences structural spacing but also volume of sediment deposits. In most cases, dam height will be restricted by one or all of the following criteria: costs, stability, and channel geometry in relation to spillway requirements. Cost relations between different types of rock check dams will be discussed later. Stability of impervious check dams should be calculated where life and/or property would be endangered by failure.

Severely tested check dams in Colorado had maximum heights as follows: loose-rock and wire-bound dams, 2.2 meters; and fence-type dams (thickness of 0.6 meter), 1.8 meters.

In gullies with small widths and depths but large magnitudes of flow, the effective height of dams may be greatly restricted by the spillway requirements. This restriction may result from the spillway depth necessary to accommodate expected debris-laden flows.

Spillway

Most gullies have either trapezoidal, rectangular, or V-shaped cross sections. For structural gully control, design storms should be of 25 years magnitude and, as a minimum, spillways should accommodate the expected peak flow from such a storm. In mountainous watersheds, however, where forests and brushlands often contribute large amounts of debris to the flow, the size and the shape of spillways should be determined by this expected organic material. As a result, required spillway sizes will be much larger than if the flow could be considered alone. Spillways designed with great lengths relative to their depths

are very important here. Yet, spillway length can be extended only within limits because a sufficient contraction of the flow over the spillway is needed to form larger depths of flows to float larger loads over the crest. The obstruction of a spillway by debris is undesirable since it may cause the flow to overtop the freeboard of the check dam and lead to its destruction.

The characteristics of the sides of a spillway are also important for the release of debris over the structure. Spillways with perpendicular sides will retain debris much easier than those with sloping sides; in other words, trapezoidal cross sections are preferable to rectangular ones. A trapezoidal shape introduces another benefit by increasing the effective length of the spillway with increasing magnitudes of flow.

The length of the spillway relative to the width of the gully bottom is important for the protection of the channel and the structure. Normally, it is desirable to design spillways with a length not greater than the available gully bottom width so that the waterfall from the dam will strike the gully bottom. There, due to the stilling-basin effects of the dam apron, the turbulence of the flow is better controlled than if the water first strikes against the banks. Splashing of water against the channel side slopes should be kept at a minimum to prevent new erosion. Generally, spillway length will exceed gully bottom width in gullies with V-shaped cross sections, or where large flows of water and debris are expected relative to the available bottom width. In such cases, intensive protection of the gully side slopes below the structure is required.

Apron

Aprons must be installed on the gully bottom and protective works on the gully side slopes below the check dams, otherwise flows may easily undercut the structures from downstream and destroy them.

Apron length below a loose-rock check dam cannot be calculated without field and laboratory investigations on prototypes. Different structures may have have different roughness coefficients of the dam side slope that forms a chute to the flow if tailwater depth is low. Differences in rock gradation may be mainly responsible for the different roughness values.

The design procedures for the loose-rock aprons were therefore simplified and a rule of thumb adopted: the length of the apron was taken as 1.5 times the height of the structure in channels where the gradient did not exceed 15 percent, and 1.75 times where the gradient was steeper than 15 percent. The resulting apron lengths included a sufficient margin of safety to prevent the waterfall from hitting the unprotected gully bottom. The design provided for embedding the apron into the channel floor so that its surface would be roughly level and about 0.3 meters below the original bottom elevation.

At the downstream end of the apron, a loose-rock sill should be built 0.15 meter high, measured from channel bottom elevation to the crest of the sill. This end sill creates a pool in which the water will cushion the impact of the waterfall.

The installation of an end sill provides another benefit for the structure. Generally, aprons are endangered by the so-called ground roller that develops where the hydraulic jump of the water hits the gully bottom. These vertical ground rollers of the flow rotate upstream and, where they strike the gully floor, scouring takes place. Thus, if the hydraulic jump is close to the apron, the ground roller may undermine the apron and destroy it. The end sill will shift the hydraulic jump farther downstream, and with it the dangerous ground roller. The higher the end sill, the farther downstream the jump will occur. Since data on sediment and flow are not usually available, a uniform height of sill may be used for all structures.

Ephemeral gullies carry frequent flows of small magnitudes. Therefore, it is advisable not to raise the crest of the end sills more than 0.15 to 0.25 meter above the gully bottom. End sills, if not submerged by the water, are dams and create waterfalls that may scour the ground below the sill. At higher flows, some tailwater usually exists below a sill and cushions, to some extent, the impact from the waterfall over the sill.

Where the downstream nature of the gully is such that appreciable depth of tailwater is expected, the installation of end sills is not critically important. The hydraulic jump will strike the water surface and ground rollers will be weak.

Bank Protection

Investigations have shown that check dams may be destroyed if flows scour the gully side slopes below the structures and produce a gap between the dam and the bank. Since water below a check dam is turbulent, eddies develop that flow upstream along each gully side slope. These eddies are the cutting forces.

Several types of material are suitable for bank protection. Loose rock is effective, but should be reinforced with wire-mesh fence, secured to steel posts, on all slopes steeper than 1.25 to 1.00. The design should provide for excavation of the side slopes to a depth of about 0.3 meter so that the rock can be placed flush with the surrounding side slope surface to increase stability of the protection. Excavation of surface materials also assures that the rock would not be set on vegetation. Banks should be protected for the full length of the apron.

The height of the bank protection depends on the characteristics of channel, flow, and structure. Where gullies have wide bottoms and spillways are designed to shed the water only on the channel floor, the

height should equal total dam height at the structure, but can rapidly decrease with distance from the structure. In contrast, where the waterfall from a check dam will strike against the gully banks, the height of the bank protection should not decrease with distance from dam to prevent the water from splashing against unprotected banks.

In gullies with V-shaped cross sections, the height of the bank protection should be equal to the elevation of the upper edges of the freeboards of the dam. In general, the height of the bank protection can decrease with increasing distance from the dam.

CONSTRUCTION PROCEDURES

Before construction starts, the following design features should be staked and flagged conspicuously:

(1) Mark the centerline of the dam and the key trenches, respectively, on each bank. Set the stakes away from the gully edge to protect them during construction.

(2) Designate the crest of the spillway by a temporary bench mark in the gully side slope sufficiently close to be of value for the installation of the dam.

(3) Mark the downstream end of the apron.

(4) For loose-rock and wire-bound dams, flag the upstream and downstream toes of the dam proper.

Caution is required during excavation to avoid destroying the stakes before the main work of installation begins.

The construction of all dams should start with the excavation for the structural key, the apron, and the bank protection. This very important work can be performed by a backhoe or hand labor. Vegetation and loose material should be cleaned from the site at the same time.

The trenches for the structural keys will usually have a width of 0.6 meter, therefore a 0.5 meter wide bucket can be used on the backhoe. If the construction plan calls for motorized equipment, two types of backhoes can be used. One, mounted on a rubber-wheeled vehicle and operating from a turntable, permits the backhoe to rotate 360 degrees. This machine travels rapidly between locations where the ground surfaces are not rough and works very efficiently in gullies whose side slopes and bottoms can be excavated from one or both channel banks. The other type can be attached to a crawler tractor. This type proves to be advantageous at gullies that are difficult to reach, and at ones with widths and depths so large that the backhoe has to descend into the channel to excavate. In deep gullies with V-shaped cross sections, temporary benches on the side slopes may be necessary. Often, the bench can be constructed by a tractor with blade before the backhoe arrives.

The excavated material should be placed upstream from the dam site in the gully. The excavated trench and apron should then be filled with rock. Since a special graded rock is required for the keys, rock piles for keys must be separate from those used in the apron and dam proper. Excavations can be filled by dumping from a dump truck or by hand labor. During dumping operations, the fill must be checked for voids, which should be eliminated.

If dump trucks are loaded by a bucket loader, some soil may be scooped up along with the rock. Soil is undesirable in a rock structure because of the danger of washouts. To avoid soil additions, use a bucket with a grilled bottom that can be shaken before the truck is loaded. Other devices such as a grilled loading chute would also be appropriate.

Dumping rock into the dam proper has two advantages: The structure will attain greater density, and rocks will be closer to their angle of repose than if placed by hand. Hand labor can never be completely avoided, however, since plugging larger voids and the final dam shape require hand placement. Where gullies are deep and dumping is impractical, rock chutes may be used.

Often, gully control projects are planned to provide employment for numbers of people. This objective can easily be accomplished if sufficient supervision is available for the individual steps in the construction. Special attention is needed at the spillway and freeboard. In loose-rock and wire-bound structures, where the shape of the dam is not outlined by a fence as in the other types, experience shows there is a tendency to construct the spillways smaller than designed.

In wire-bound dams, a commercial, galvanized stock fence, usually about 1.2 meters wide, can be used. The stay and line wires should not be less than 12-1/2 gage low-carbon steel, the top and bottom wires 10 gage low-carbon steel, and the openings in the mesh 0.15 meter. To connect ends of the fence or to attach the fence to steel posts, a galvanized 12-1/2 gage coil wire is sufficiently strong.

The wire mesh of required length and width should be placed over the gully bottom and side slopes after the trench and apron have been filled with rock. Generally, several widths of mesh will be needed to cover the surface from bank to bank. If several widths are required, they should be wired together with coil wire where they will be covered with rocks. The part not to be covered should be left unattached to facilitate the fence stringing operations around the structure.

Before the rock is placed on the wire mesh for the installation of the dam proper, the mesh should be temporarily attached to the gully banks. Otherwise, the wire mesh lying on the gully side slopes will be pushed into the gully bottom by the falling rock and buried. Usually, stakes are used to hold the wire mesh on the banks.

After the dam proper is placed and shaped, the fence can be bound around the structure. Fence stretchers should be applied to pull

the upstream ends of the fence material down tightly over the downstream ends, where they will be fastened together with coil wire. Then the bank protection below the dam should be installed.

The installation of single- and double-fence dams begins with the construction of the fences after excavation is completed. Construction drawings should be followed closely here because the final shape of the dams will be determined by the fences. Conventional steel fenceposts can be used. In some locations, the great height of posts may offer difficulties for the operator of the driving equipment, and scaffolds should be improvised. A pneumatically driven pavement breaker with an attachment can be used to ease the job of driving. Since relatively great lengths of hose may be attached this tool may be used in deep gullies and on sites with difficult access.

At single-fence dams, dumping of rock is practical if the gully is not excessively deep or wide. At double-fence structures, hand labor, a backhoe, or a clamshell will be required. The rock should be placed in layers and each layer inspected for large voids, which should be closed manually by rearranging rocks.

Much time and effort can be saved during construction if a realistic equipment plan is established beforehand. Such a plan requires an intimate knowledge of the cross sectional dimensions of the gullies and their accessibility to motorized equipment. Pioneer roads that might be needed because of lack of access are not only important for equipment considerations, but will also enter into the cost of the construction.

If equipment is to be used, as a general rule, it appears to be advantageous to use heavier and larger machines if their mobility is adequate. Although hourly costs for heavier machines are usually greater, the total cost for a job is reduced.

With few exceptions, conventional construction equipment is not sufficiently mobile to operate in rough topography without pioneer roads. In watershed rehabilitation projects such as gully control, road construction is undesirable because it disturbs the ground surface and may lead to new erosion. It is therefore desirable to consider crawler-type equipment only.

COST RELATIONS

Relationships between the installation costs of the four different types of rock check dams described here are based on research in Colorado. The relationships are expressed by ratios (Figure 5) to avoid specific dollar comparisons. When considering the cost ratio, one must keep in mind that differential inflation may have offset some finer differences in cost. It is advisable, therefore, to test the cost of individual structures by using material and volume requirements as given by the equations. The cost ratios (Figure 5) can then be adjusted, if necessary.

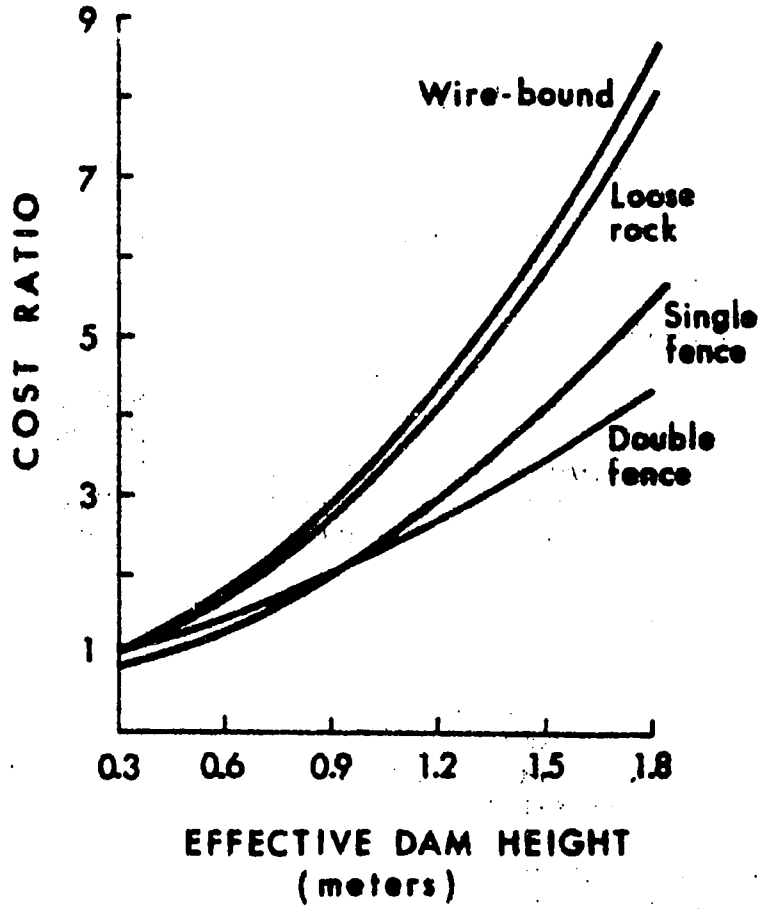


Figure 5. Installation cost of four different types of check dams as a function of effective dam height. The cost ratio is the cost of a dam related to the cost of a loose-rock dam, 0.3 meter high, built with angular rock.

It is obvious that the cost of installing a complete gully treatment increases with gully gradient because the required number of dams increases. However, there is one effective dam height at which the cost is lowest (Figure 6). In the sample gully, this optimum height for loose-rock dams is about 0.6 meter, for single-fence dams 0.7 meter, and for double-fence dams 1.1 meters. A constant gully cross section was assumed. In reality, of course, gully cross sections usually change between dam sites. The optimum height for lowest treatment costs is not a constant, but changes between gullies, depending on shape and magnitude of the gully cross sections at the dam sites.

Since the cost of the dam is directly proportional to the rock volume, rock requirement will be dependent upon dam height (Figure 6). This means that, in a given gully, there is one dam height at which rock requirements for a treatment are smallest.

A treatment cannot be evaluated on the basis of cost of installation alone, because recognition of benefits is part of the decision making process. Sediment deposits retained by check dams can be incorporated into a cost ratio that brings one tangible benefit into perspective. Sediment has been cited as the nation's most serious pollutant. The sediment-cost ratio increases (treatment is increasingly beneficial) with dam height and decreases with increasing gradient.

Since single-fence and double-fence dams cost less than loose-rock and wire-bound loose-rock dams for an effective height greater than 0.3 meter, the sediment-cost ratio is more favorable for the fence-type structure. The ratios remain smaller than 1.0 in all gradients larger than 5 percent for treatments with loose-rock and wire-bound loose-rock dams, and on gradients larger than 7 and 9 percent for treatments with single-fence and double-fence dams, respectively.

The importance of sediment-cost ratios in relation to gully gradient and effective dam height becomes apparent in situations where not all gullies of a watershed can be treated. Gullies with the smallest gradient and largest depth, and highest possible fence-type dams should be chosen if other aspects, such as access or aesthetic value, are not dominant.

OTHER GULLY CONTROL STRUCTURES AND SYSTEMS

Nonporous Check Dams

Rock can be used for the construction of wet masonry dams. Limitations in available masonry skills, however, may not permit this approach. A prefabricated concrete dam was designed and a prototype installed in Colorado. It required very little time and no special skills for installation. The capital investment for this dam is larger than for a rock structure, however. A prestressed concrete manufacturer

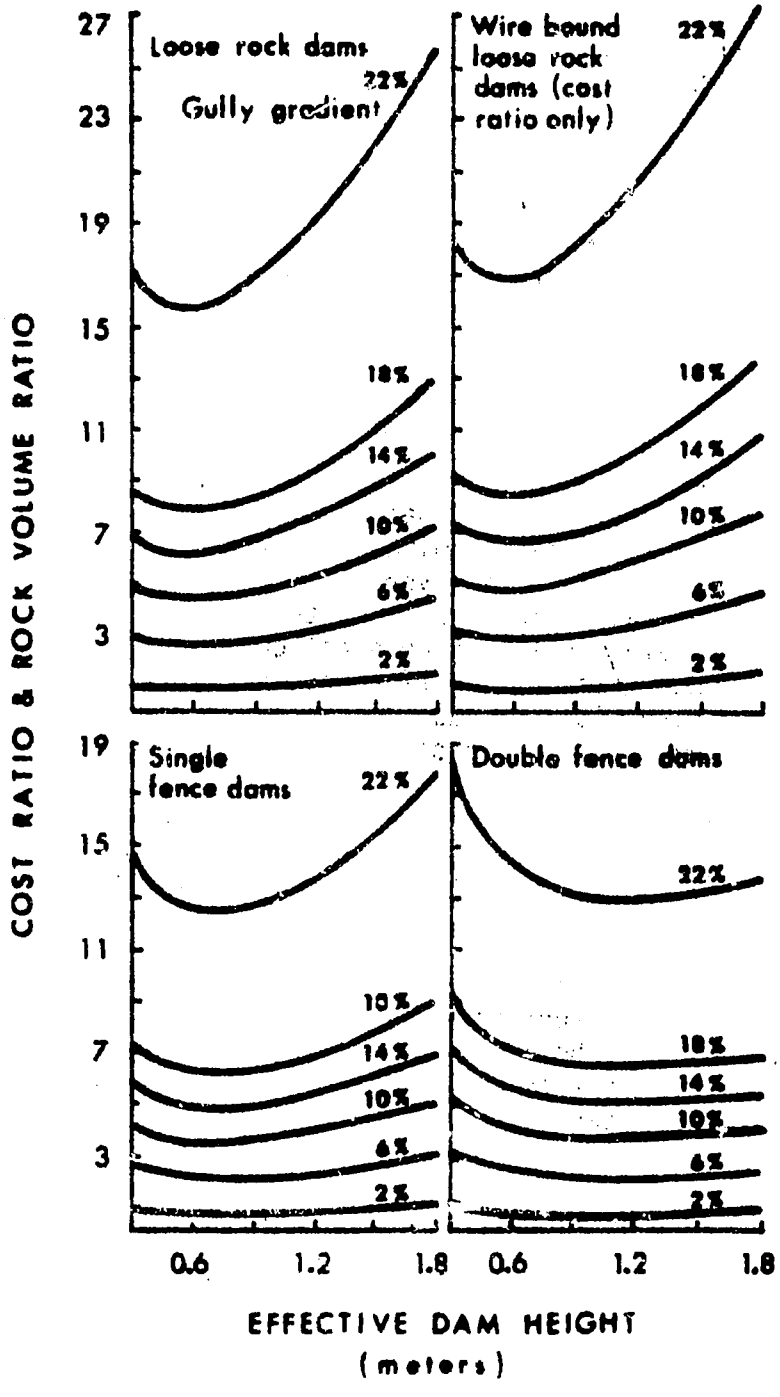


Figure 6. Relative cost of installation of check-dam treatments and relative angular rock volume requirements in gullies with different gradients as a function of effective dam height. The cost and rock volume ratios relate the cost and rock volume of a treatment to those of a treatment with loose-rock dams 0.3 meter high installed on a 2 percent gradient.

must be available reasonably close to the project area and the construction sites must be accessible to motorized equipment. Where aesthetic considerations and land values are high (recreational sites and parks, for example), a prestressed, prefabricated concrete check dam may be the answer.

Check dams may also be built from corrugated sheet steel. For successful application, a pile driver is required to assure proper fit of the sheets. Excavating trenches for the sheets jeopardizes dam stability if the refill is not compacted sufficiently. Quite often, insufficient depth of soil above the bedrock does not permit this dam type.

Earth Check Dams

Earth check dams should be used for gully control only in exceptional cases. Basically, it was the failure of the construction material, soil (in combination with concentrated surface runoff), that caused the gully. Gullies with very little flow may be an exception if the emergency spillway safely releases the flow onto the land outside the gully. The released flow should not concentrate, but should spread out on an area stabilized by an effective vegetation cover or by some other type of protection such as a gravel field. Most gullied watersheds do not support areas for safe water discharge.

Standpipes or culverts in earth check dams generally create problems, because of the danger of clogging the pipe or culvert inlet, and the difficulty in estimating peak flows. Therefore, additional spillways are required.

If soil is the only dam material available, additional watershed restoration measures (such as vegetation cover improvement work and contour trenches) should be installed to improve soil infiltration rates, to enhance water retention and storage, and thus to decrease magnitude and peak of gully flows.

Vegetation-Lined Waterways

With the exception of earth check dams, gully control measures described previously treat the flow where it is--in the gully. In contrast, treatments by waterways take the water out of the gully by changing the topography. Check dams and waterways both modify the regime of the flow by decreasing the erosive forces of the flow to a level that permits vegetation to grow. In waterways, however, flow is modified compared with the original gully, in two ways: lengthening the watercourse, resulting in a gentler bed gradient; and widening the cross section of flow, providing very gentle channel side slopes. This latter measure leads to shallow flows with a large wetted perimeter (increase in roughness parameter). Both measures substantially decrease flow velocities, which in turn decrease the erosive forces.

Contrasted with check dam control, waterway projects strive to establish a vegetative cover when land reshaping is finished. Indeed, a quick establishment of an effective vegetation lining is the key to successful waterways. It follows that the prime requisites for a successful application are precipitation, temperature, and fertility of soils, all favorable to plant growth. Other requisites are:

(1) Size of gully should not be larger than the available fill volumes;

(2) Width of valley bottom must be sufficient for the placement of a waterway with greater length than that of the gully;

(3) Depth of soil mantle must be adequate to permit shaping of the topography; and

(4) Depth of topsoil must be sufficient to permit later spreading on all disturbed areas.

Design criteria or prerequisites in terms of hydraulic geometry are not yet available.

Vegetation-lined waterways require exact construction (therefore, close construction supervision) and frequent inspections during the first treatment years. The risk, inherent to nearly all types of erosion control work, is greater for waterways at the beginning of treatment than for check dam systems. To offset this risk, in Colorado, 19 percent of the original cost of installation was expended for maintenance, while for the same period of time, only 4 percent was required at check dams.

Eight percent less funds were expended per linear meter of gully for construction and maintenance of grassed waterways than for check dams. This cost difference is not significant, especially if the greater involvement in waterway maintenance is recognized. In deciding on the type of gully control, one should consider not only construction costs but also risk of the prerequisites for vegetation-lined waterways.

SUMMARY OF DESIGN CRITERIA AND RECOMMENDATIONS

Spacing decreases with increasing gully gradient and increases with effective dam height. Number of check dams increases with gully gradient and decreases with increasing effective dam height. Expected volumes of sediment deposits increase with effective height.

For practical purposes, gully gradients ranging from 1 to 30 percent do not influence volumes of sediment deposits in a treatment. On gradients larger than 30 percent, sediment catch decreases more distinctly with increasing gradient.

Rock volume requirements are much larger for loose-rock and wire-bound loose-rock dams than for fence-type dams. At effective dam

heights larger than 0.6 meter, treatments with double-fence dams require the smallest amounts of rock.

At effective dam heights larger than about 0.5 meter, loose-rock and wire-bound loose-rock dams are more expensive than fence-type dams. The difference in cost increases with height. Single-fence dams are less expensive than double-fence dams at effective heights up to 1.0 meter.

Regardless of gradient, in a given gully, there is one effective dam height for each type of structure at which the cost of treatment is lowest (Figure 6). For each type of treatment, rock requirements are smallest at the optimum effective dam heights for least costs (Figure 6). The sediment-cost ratio (the value of expected sediment deposits divided by the cost of treatment) increases with effective dam height and decreases with increasing gully gradient. At effective dam heights of about 0.6 meter and larger, single-fence dams have a more pronounced beneficial sediment-cost ratio than loose-rock or wire-bound loose-rock dams. At effective dam heights of 1.1 meters and larger, treatments with double-fence dams have the largest sediment-cost ratios.

CHAPTER VIII

WATER QUALITY

INTRODUCTION

The hydrologic cycle depicts the movement of water through a forest ecosystem. Water flow is a major component of the environment, linking together the atmospheric, soil, biotic and stream compartments of the system. Since water is the carrier of materials and energy between the atmospheric and terrestrial portion of the system and the stream, an understanding of the processes which affect water quality in forest streams has as its basis an understanding of the hydrologic process.

DISSOLVED CHEMICAL CONSTITUENTS

To understand various impacts, one must realize that forest streams are not separate and distinct from the area they drain, but are an integral part of the ecosystem. As water comes into contact with each part of the system, the chemical characteristics adjust accordingly. Chemical reactions and physical processes occur as the water contacts the atmosphere, soil and biota. It is these processes and the condition of each compartment that determine the amount and kind of chemical species in solution.

The major sources of dissolved constituents in water draining upland watersheds are: geologic weathering of parent rock, meteorological inputs, and biological inputs. Chemical and physical weathering converts rock minerals into soluble or transportable form. Dissolved matter, including organic compounds and mineral ions, are added to the forest ecosystem in precipitation, dust, and other aerosols. The biological inputs are mainly materials gathered elsewhere and deposited in the forest by animals (including man) and the photosynthetic production of organic material from inorganic substances, followed by the subsequent breakdown of the organic back to the inorganic compounds.

In undisturbed ecosystems, the rock substrate and soil generally control the relative concentrations of metallic ions (cations such as Ca^{+}, Mg^{++}, K^{+} and Na^{+}), while the relationship of biological and biochemical processes in the soil to precipitation rarely governs the anionic (HCO_3^{-}, NO_3^{-}, and $PO_4^{=}$) yield. Anions, such as chloride (Cl^{-}), nitrate (NO_3^{-}), and sulfate ($SO_4^{=}$), at least in the absence of abundant sulfide minerals, originate from the atmosphere; the output of these ions is regulated by soil processes.

Although appreciable quantities of nitrogen, sulfur, and other elements are often found in precipitation and in dust and dry fallout between rains, the soil under natural forest conditions is considered the greatest contributor of dissolved elements to runoff. Other components of the ecosystem (biologic, atmospheric, rock substrate), through their influence on soil processes and properties, play an important role in determining the chemistry of outflow.

Such dissolved compounds can leave a system by water transport over and through the soil or forest floor to either groundwater or surface flow.

The above processes are often lumped under the term nutrient cycling, which consists of inputs, outputs and the movement of dissolved solids within the system. This is chiefly concerned with outputs, that is, the streamflow from upland basins and the various factors influencing the chemical components in this runoff.

The movement of water through the soil, along with biological activity, controls the ionic composition of water leaving upland watersheds as streamflow. The most chemically active components of a forest soil are the clay and organic colloids. Soil colloids have a large capacity to exchange ions in solution for those adsorbed on their surfaces. Clays have high exchange capacities compared with most other minerals because of their large surface area per unit volume and their negative electrical charge.

A simplified picture of the exchange process would be that cations absorbed on soil colloids are selectively exchanged for hydrogen ions from the soil water. The hydrogen ions come principally from the solution of carbon dioxide in water and dissociation of the resulting H_2CO_3 molecule into a hydrogen ion and bicarbonate ion. The dissolved carbon dioxide originates chiefly in the metabolism of microorganisms and plant roots in the soil. Based on the above assumptions, only the water remaining for some time in interstices between soil particles is likely to pick up an appreciable load of dissolved carbon dioxide and consequently be effective in leaching mineral ions.

Studies have shown that the ionic concentrations and their relationships to discharge are quite variable. For example, a direct relationship exists between H^{+}, NO_3^{-} concentrations and discharge, but no relationship between discharge and the concentrations of Mg^{++}, Ca^{++},

$SO_4^{=}$, and K^+ has been found in streams on an experimental forest in New Hampshire. Elsewhere, individual cation concentrations, when considered throughout the year, appeared to be independent of discharge rate on four experimental watersheds in the Appalacian mountains of the eastern United States. An inverse relationship to cation concentrations and discharge of selected streams has been reported in the Rocky Mountains. Also, an inverse relationship between ion concentrations and discharge was observed from a stream in California. In large streams, general ionic concentrations are commonly lower at times of high flow than at low flow due to the long residence time of water in the soil during the dry weather, which gives more opportunity for chemical reactions.

Land management practices can significantly influence ionic balances. For example, if the cation-anion balance of the soil solution is changed temporarily by the addition or subtraction of an ionic species due to logging or fire, the equilibrium is restored by an equivalent change in the concentrations of oppositely charged ions.

Once water has reached an effluent stream, it is often considered to consist of a base flow fraction made up of ground water that infiltrates into the channel and a direct runoff fraction, which in turn enters the drainage system during and soon after precipitation periods. The direct runoff presumably has no residence time in the ground water reservoir and only a short contact with soil or vegetation. As mentioned earlier, reactions in the soil zone are commonly extensive enough that the direct runoff has a considerably higher dissolved-solids content than the original rain or snow. Sometimes, the base flow has a still greater dissolved load. Based on the assumptions outlined above, the solute concentration of river water would be inversely related to flow rate. This would not necessarily be the case if the stream were influent with base flow nonexistent.

Other natural factors in the stream itself that influence ionic composition include: reactions of water with mineral solids in the streambed and in suspension, reactions among solutes, losses by evaporation and by transpiration from plants growing in and near the stream, and effects of organic matter and aquatic organisms. This latter set of natural factors results in fluctuations of composition that bear little relation to discharge rates.

Chemical equilibria probably control a few properties of water in flowing streams. For example, the ion-exchange reactions of solutes with suspended sediment probably are rapid enough that they usually are at equilibrium. Certain oxidations, such as ferrous to ferric ion, also normally reach equilibrium. For biological processes such as the utilization and production of carbon dioxide and oxygen, the equilibrium approach is not necessarily appropriate. If the stream is to be considered a dynamic system, which it is, kinetics would better describe its chemistry rather than using a steady-state equilibrium approach. For example, the processes whereby biological organisms consume organic

loads of the stream can often be better studied and understood by applying rates of reactions and processes.

When a forest is harvested (especially clearcut), trees no longer take up nutrients and the nonmerchantable parts of trees increase forest litter. The removal of the forest canopy changes the microclimate, making it warmer and reducing evapotranspiration, resulting in an increased soil water content. This increased temperature and water content of the soil accelerates the activity of microorganisms that break down organic matter. The greatly increased respiration of these organisms raises the carbon dioxide partial pressure of the soil atmosphere, which in turn increases the bicarbonate anion level and leaching loss of cations from the system. Nitrogen losses as nitrate may also occur, when it is produced by the oxidation of organic matter (nitrification) and not utilized by the forest vegetation which has been removed.

Recent studies throughout the United States do show that following clearcutting, there is an increased loss of nutrients (cations and nitrate) from the logged area along with an increased runoff volume. This increased ionic loss along with increased runoff would possibly tend to give concentrations of ions a less noticeable increase, but total losses should be quite outstanding.

Studies have also shown that slash burning following logging produces an even greater increase in the release of ions from the forest floor litter and mineral soil. This increase in the release of ions is due to the breakdown of the organic debris to a soluble form, making it easily removed from the soil by leaching water. Generally, this process can lead to an increase in the total loss of nutrients in streamflow. However, the above may not always happen. For example, a moderately severe fire in a conifer stand had no specific effect on the concentrations of Ca^{++}, Mg^{++}, Na^{+}, K^{+}, or HO_3^{-} in the stream. It was postulated in this study that ash constituents were dissolved by light rainfall and leached into the permeable forest soil before the first snow. Because of the acidic nature of the soil, the dissolved cations were absorbed on the exchange complex instead of being washed directly into the stream. Of course, rains of high intensity following a severe fire could move large quantities of soluble ash compound into flowing streams. As the forest regenerates following a perturbation, the dissolved load of the stream also returns to levels experienced before the disturbance.

In summary, the dissolved load of streams after various forest activities, such as clearcutting or burning, is a function of the several soil, vegetative and climatic characteristics that describe a forest ecosystem. Soil characteristics, such as porosity and texture, determine the pathway and rate of water movement in or over soil, soil erodibility, and how strongly nutrients will be held within the soil matrix. Vegetative characteristics, such as species composition, influence the rate of nutrient uptake. The rate of revegetation controls the rapidity with which recycling begins after system disruption. The

leaching rate is influenced by form, chemistry, amount and intensity of precipitation. Generalization of effects of forest management in widely differing upland ecosystems is precluded by the intricate interaction among these many variables.

SUSPENDED SEDIMENT

In some instances, undisturbed upland watersheds generally have low suspended sediment concentrations (10 to 20 ppm average concentration). Higher concentrations are often the result of a perturbation to the drainage area such as roads, logging, or natural catastrophes which can cause accelerated erosion.

Erosion of soils produces sediment in waters draining forest lands. Three major erosion processes are of concern: surface erosion, mass soil movement, and channel erosion. Surface erosion is the direct result of rain striking unprotected soil surfaces. Soil particles are detached and transported by overland flow across the soil surface. This process is relatively nonexistent in the nondisturbed, well protected forest floor which has a high infiltration rate. Accelerated erosion can be expected in cases where the protective forest floor litter has been removed exposing mineral soil along with soil compaction.

Mass soil movement is the process by which large volumes of soil and rock materials move downslope under the influence of gravity. This movement is usually prevalent in areas where the geologic substrate is naturally unstable.

Channel erosion is the result of abrasion by water or debris on the stream bank and bed. This erosion process can contribute heavily to suspended sediment. It was found, for instance, that 25 percent of the sediment yields in the western United States could be attributed to logging activity, 25 percent to agriculture and 50 percent to bank cutting in the main river.

In general, increased velocity of streamflow will give an increased concentration of suspended sediment. Also, any practice that reduces the stability of the streambank or other watershed surfaces will cause suspended sediment to increase.

Roads and road building are considered to be the principle sources of suspended sediment. Studies and observations have shown that as much as 90 percent of the sediment produced from timber sale areas in the northern regions of the United States comes from roads.

There have been numerous studies relating forestry activities to accelerated erosion and sedimentation. Generally, it has been found that watershed damage from felling, limbing and bucking of trees during timber harvesting is probably negligible.

Skidding and yarding activities can cause accelerated erosion; however, the great variety of techniques and machines used in this operation provide alternatives for minimizing damage on many sites. A major rule here is: the less compacting and disturbing the contact with the forest floor, the less watershed damage will result from skidding and yarding.

Balloon logging probably results in the least compaction and disturbance because the logs are transported free in the air over most of the cut area. Grapple and yarding systems are intermediate between skyline and high lead, as they combine features of each. The most destructive technique of all is tractor logging.

Harvest areas on upland watersheds are subject to erosion until new vegetative cover is established, since it is the exposed mineral soil that is a major source of suspended sediment. Furthermore, varying degrees of damage to the forest floor result from the several combinations of harvesting and log transport systems.

In a study, clearcutting and removal of trees by the balloon system resulted in the lowest soil sediment deposited in streams and had the smallest exposure of bare soil. Clearcutting by tractor, as expected, exposed the most mineral soil (over 30 percent).

Once an area is logged, slash is frequently eliminated by controlled burning. Intense fires often lead to accelerated erosion. Extremely hot fires consume vegetation, litter and duff materials and leave the soil unprotected. Such fires may also reduce the organic content of the soil and alter the stability of surface soil aggregates. Infiltration rates are often reduced and surface runoff can be increased by the production of a nonwettable surface layer. Controlled burns are usually not intense enough to cause erosion problems.

Fire can also be a contributor to accelerated mass wasting, due largely to the destruction of the natural mechanical supports of soils. In the western United States, logging and burning produced increases in mass soil movements due to the loss of mechanical support of the root systems of trees and plants. Many other studies support the relationship of fire, logging and road building to accelerated mass movements and resulting stream sedimentation.

BACTERIOLOGICAL QUALITY

Quite often, bacteriological indicators are employed to gain knowledge of the biological quality of streamflow. An estimate of these organisms is a relatively simple, fast and inexpensive index of pollution, especially when the membrane filter technique is used. Knowledge of cycles and variability of bacteria in natural waters and the relationships of bacteria to physical environmental factors is sparse.

There have been some studies of relatively undisturbed watersheds describing bacteria-environment relationships.

Seasonal coliform trends have been studied and evidence of relationships between coliform counts and certain physical environmental factors (streamflow and air temperature) have been found. Great increases in logging and stream turbidity over a period of years did not affect coliform densities, but it should be noted that the logging was on municipal watersheds and disturbance was probably minimal.

An assessment of the causes of variation in bacterial numbers of a small, unpolluted stream in the Rocky Mountains of the United States indicated that the most important cause of bacteria population fluctuations was summer rainstorms of short duration, producing overland flow. When streamflow is stable during periods of no precipitation, bacterial numbers can be related to the size of the water-streambed contact surface. As streamflow increases after precipitation, bacteria are deposited in the ground water associated with the stream and are later released into the stream as it recedes. Bacterial numbers fluctuate during the winter even when temperatures are as low as 0° to 5.5°C. It has also been found that when cattle graze in marshy areas adjacent to the stream, the bacterial density of the stream rises. The bacteria counted were coliform and total bacteria.

In a measurement of bacterial groups in streamflow from mountain watersheds in the Rocky Mountains of the western United States, total coliform, fecal streptococcus, and fecal coliform bacterial groups were closely related to the physical parameters of the stream, and they were especially dependent on the "flushing effect" of runoff from snowmelt and rain, summer storms, or irrigation. The seasonal trend for all bacterial groups was similar: low counts prevailed while the water was at 0°C; high counts appeared during rising and peak flows caused by June snowmelt and rain; a short "post-flush" decrease in bacterial counts took place as the runoff receded in early July; high bacterial counts were again found in the July-August period of warmer temperatures and low flows; and counts declined in September.

Concerning evidence that the forest floor can act as a bacterial filter, it has been found that snowmelt water that had percolated through a strip of forest on the bank of a reservoir contained fewer bacteria than water that had not passed through the forested strip.

The major sources of fluctuations in bacterial content (especially fecal coliform) that can lead to pollution levels in stream water are concentrations of any warm blooded animals on the watershed including man, livestock, or big game animals. If bacterial content of stream water is to be kept below pollutional levels, strict attention must be given to all sources of potential contamination by living organisms.

THERMAL QUALITY

Water temperature may or may not be critical to the survival of the flora and fauna residing in a given stream. However, the composition of these communities will change when there is a change in stream temperature. An elevation of the water temperature will cause increased biological activity which will place a greater demand on the dissolved oxygen in the stream. In addition, increased biological activity may be detrimental to the health of the fauna and even replace existing fish with warm water species. The population dynamics and the type, quantity, and quality of the food of the fauna living within the stream will also change with variations in water temperature.

Clearing the timber overstory adjacent to a stream is one way the water temperature will be increased. Removal of the trees increases the area of the stream exposed to radiation from the sun. That increased exposure is associated with a rise in temperature is logically predicted if one considers an energy budget of the water in a stream. If the trees are removed from the banks of a stream having a certain average temperature, the only change in the energy budget is an increase in solar energy entering the system from the additional area of illuminated stream surface. The temperature will rise as there are no new outlets of energy from the system. Increases in stream temperature may range from fractions of a degree centigrade for a slight opening to over ten degrees centigrade for a clearing of the watershed.

A mathematical model developed in the western United States has been used to predict stream temperatures following modifications of the vegetation shading the stream. This model states that the change in stream temperature is a function of the surface area of the stream exposed to direct solar radiation, the net solar radiation load of the exposed water surface, and the discharge of the stream. The model is operated using variables which describe the physical situation of a stream with vegetation bordering it. For application to a specific case, the existing exposed surface area of the stream, the stream discharge, and the amount of incoming solar radiation is determined. The density and thickness of the vegetative strip bordering the stream and the height of the trees are used to compute the effective unshaded area of the stream surface. The orientation of the stream, time of year, and physiography of the site are required to determine the effective radiation loading.

The model may be operated several times to determine the effects of various methods of forest cutting on the stream temperature. Such predictions of changes in stream temperature may also be used as input to other models whose outputs are the amount of dissolved oxygen in the stream or the impacts on plant and animal communities associated with the water. Due to interrelationships of plants and animals, there may be an effect in several populations due to a change in the stream temperature. Changes in stream temperatures may have severe consequences in certain ecosystems. Thus, one should examine possible effects and choose appropriately before implementing a vegetative treatment.

CHAPTER IX

WATER HARVESTING

INTRODUCTION

Water harvesting systems may be defined as artificial methods whereby precipitation can be collected and stored until it is beneficially used. The system consists of a catchment, which is made more impervious by artificial means than it was in its natural state, and a storage facility for the harvested water.

The elements of the water harvesting system and the development of modern techniques will be presented. In addition, various methods of treating catchments and storing harvested water and the economics of water harvesting systems will be discussed.

ELEMENTS OF WATER HARVESTING SYSTEM

Water Collection

There is no single method of treating catchments to increase runoff that is universally applicable. Each site must be individually evaluated in order to determine the optimum treatment that will produce water from a given site for a particular use.

In the design of a water harvesting system, numerous factors must be considered. They include: the amount of runoff to be expected from storms of various magnitudes, the ratio of runoff to precipitation or runoff efficiency, and the effect of the selected treatment on the quality of the water. The runoff efficiency is highly variable, depending upon storm intensity, the permeability of the surface of the watershed, the degree of saturation of soil of the watershed, *etc.* Precipitation is a random variable; the selection of a particular treatment to induce runoff and the size of the catchment should reflect the undertainty of precipitation and runoff.

For almost all treatments, there is a minimum threshold amount of precipitation required to saturate the catchment surface; below this amount, virtually no runoff occurs. However, once this threshold has been exceeded, the relationship between storm precipitation and runoff will be essentially linear.

A catchment can be made more impervious using the following methods: land surface alteration, chemical treatments, soil cementation treatments, and ground cover modification. In land alteration, runoff can be increased by: clearing and smoothing, shaping and compacting. The two basic types of chemical treatment are the use of water repellents (such as silicones) and clay dispersants (such as sodium salts). Soil cementation treatments include the mixing of asphalt, cement, resins and polymers into the soil. Ground covers that have been used for catchment construction can be classified as: exposed membranes (including butyl, plastic and asphalt), covered membranes, generally utilizing gravel to cover plastic sheeting, reinforced cement-mortar coated plastic, sheet metal, concrete, reinforced asphalt and asphalt planking.

Water Storage

Various methods of storage have been used with the above methods of catchment construction. These methods include: above-ground tanks and lined reservoirs.

The above-ground tanks have been constructed from: steel, reinforced concrete, metal grain bins with flexible liners, butyl bags, wire reinforced stucco and railroad tank cars and other types of surplus tanks.

The earth reservoirs have been sealed with various types of membrane liners and by mechanical and chemical treatment. The membranes that have been used include: plastic and butyl rubber sheeting, unreinforced and reinforced asphalt membranes, and reinforced cement-mortar coated plastic. Mechanical and chemical treatments include: mechanical compaction with and without the use of a compacting agent such as enzymes, clay dispersants which are also sometimes compacted, water repellants, polymers such as SS-13, and betonite.

Evaporation and Seepage Control

Evaporation and seepage control are needed in order to successfully store harvested water. The methods used in achieving this control are generally dependent on the size and function of the storage facility. Frequently, the same materials are used for both the catchment and the reservoir because seepage control and runoff inducement must both function so as to reduce the entry of water into the soil. Like the catchment, the size of the reservoir must anticipate the precipitation and runoff variability of the particular site. In some instances,

evaporation has been controlled by use of chemicals such as long chain alcohols, by use of floating and suspended covers of butyl rubber and plastic sheeting on small tanks, and by completely filling the tank with rock.

DEVELOPMENT OF MODERN WATER HARVESTING TECHNIQUES

Since the 1950s, the technology of water harvesting has developed variety and sophistication. In Australia, "roaded" catchments, based upon the concept of compacted earth, were constructed over thousands of hectares in order to collect water for agricultural purposes. In a roaded catchment, the soil is graded into a series of parallel ridges, having gentle slopes that permit water flow into the ditches that separate them. The ditches then channel the water to storage areas, or the water may be used directly at the site.

In the United States, catchments were built in the 1950's out of sheet metal for watering livestock. Also during this period, experimentation was undertaken with plastic and artificial rubber membranes, for the construction of both catchments and of reservoirs. Since then, butyl rubber catchments have been installed in many areas. More than 300 catchments in the state of Hawaii have been constructed of this material.

A number of experiments have been attempted on Indian reservations in the western United States. Not all the techniques have been successful, but some have worked well. One catchment at Shongopovi, on the Hopi reservation, has provided supplemental domestic water since the early 1930's; this catchment was constructed with very little disruption of the natural topography. On the Navajo reservation, butyl rubber catchments and storage bags are successfully used by stockmen. A concrete catchment is being constructed on coal mine spoils on the Black Mesa to test the feasibility of water harvesting for agricultural purposes on the spoils.

In 1961, waterproofing the soil itself to serve as a catchment structure was attempted. Materials that imparted hydrophobic properties to the soil, thus decreasing its permeability to water were tested. These materials included sprayable asphaltic compounds, plastic and metal films bonded to the soil, soil compaction and dispersion, and field fabricated asphalt and fiberglass membranes.

Water harvesting techniques for the growing of shrubs on coal strip mine soils in New Mexico have been explored. It was found that treatment of the ground with paraffin increased water runoff and the growth of two month old saltbush and Siberian peashrub transplants; the soil moisture content of treated plots was increased by about twenty percent.

There is considerable variation in the cost longevity and efficiency of the above methods of catchment and storage construction.

These systems would need to be evaluated for each site in order to select the best system. Some of the systems to be discussed in the following section have been developed and/or tested at the University of Arizona in the United States over the past fifteen years. In general, these systems are among the most economical of those mentioned above. These water harvesting systems were designed to: provide a dependable supply of stock water, provide a high quality water for domestic and industrial supplies, and extend agriculture into lands presently uncultivated due to lack of water.

WATER HARVESTING CATCHMENTS TESTED AT THE UNIVERSITY OF ARIZONA

Some of the more economical materials mentioned in earlier sections of this chapter have been tested in the Water Harvesting Program at the University of Arizona; the most expensive materials, such as sheet metal, concrete, asphalt panels and asphaltic pavements, were not tested. The results from small plots using exposed unreinforced asphalt membranes have shown that, although relatively inexpensive, this method is undesirable due to cracking caused by oxidation, plant germination and swelling and shrinking of the soil subgrade. Based on the results of small plot tests, economics and experience of other researchers, large scale testing at the University of Arizona has been limited to the following treatments: compacted earth, sodium, gravel covered plastic and reinforced chip-coated asphalt catchments. A discussion of these catchments follows. *(Note: All cost estimations presented in the following section are in 1972 U.S. dollars, and unless otherwise noted, are based upon construction methods used in Arizona.)*

Compacted Earth Catchments (CE)

The Public Works Department of Western Australia initiated in 1948 a program of construction of Roaded Catchments. These catchments consisted of clearing, shaping and contouring to control length and degree of slope and compacting with the aid of pneumatic rollers. An estimated 2500 roaded catchments have been installed principally to supply water for livestock use. These averaged approximately 1 hectare in size. There are also 21 roaded catchments totalling 706 hectares and ranging in size from 12.1 to 70.8 hectares presently being used to furnish domestic water for small towns in Western Australia.

This relatively large scale use in Australia of the compacted earth catchment attests to their utility. A 0.4 hectare compacted earth catchment was constructed in the spring of 1970 at Atterbury Experimental Watershed located near Tucson, Arizona, USA. A design similar to those in Australia was used. Two 121.9 meter long drains spaced 15.2 meters apart collected water from 7.6 meter long slopes. The drainage channels were covered with plastic and gravel to prevent erosion and water loss. The catchment was shaped by a grader following a 1.27 centimeter rainfall. The plot was then smoothed using a tractor-drawn rotary rock rake. This

proved to be an excellent method of smoothing. Following an additional 1.27 centimeters of precipitation, the plot was compacted using a 23.6 metric ton vibratory drum roller. The drainage channels were also lined at this time. The total cost of the catchment was approximately $250 including wages at $3.50 per hour. The cost would be more if the catchment site were more remote, unless several catchments were installed at one time. For large catchments, the cost should be less than $370.60 per hectare, the cost being primarily dependent on the cost of clearing and shaping. The smoothing and compaction costs on a large plot would be relatively low. There has been little maintenance since the plot was installed. Maintenance would consist primarily of weed control. If care were taken not to disturb the surface while controlling weeds, the road surface should improve with age.

During the 18-month project period, a total rainfall of 50.11 centimeters occurred. The compacted plot yielded 17.68 centimeters or 35.3 percent of the total rainfall. This represented an increase of 12.34 centimeters over the water yield from a control plot. The amount of precipitation required to initiate runoff was about 0.51 centimeter.

Assuming a life of 20 years, an interest rate of six percent, and an efficiency of 35 percent in a 30.48 centimeter rainfall area, the cost of water harvested from the compacted plot would be approximately $0.48 per cubic meter. This price does not include weed control costs. Economy of scale would reduce this cost even further on larger catchments.

Sodium Treated Catchments

Results from previous research indicate that small amounts of sodium, when applied to the surface of desert soils where there is little or no vegetation, will cause a dramatic reduction in infiltration rate. The effect, however, has been found to be temporary. Sodium does cause a clay migration from the surface. Clay lenses have been created in the laboratory and the field through the use of a relatively heavy treatment of sodium chloride. These clay lenses have been found to be migratory in the sandy loam soil (clay content = 11 percent) at Atterbury Experimental Watershed. When the lenses are close to the surface, they have a large effect on runoff. As the lenses move down in the soil profile, the effect becomes negligible.

The application of a relatively light treatment of sodium to a grass-covered soil does not result in a significant change in infiltration rate. The maintenance of a grass cover seems to be incompatible with the use of a light treatment of sodium chloride to increase runoff.

Results have indicated that sodium chloride can be used in increasing runoff where the soil is bare. Periodic disking and smoothing of the soil surface may be needed along with retreatment of sodium chloride in order to maintain a low infiltration rate. The disking may also be required to return the clays to the surface. This method of

treatment would require shaped catchment areas to minimize the length and degree of slopes so that erosion would not be excessive.

Perhaps the most effective use of sodium chloride is in conjunction with the compacted earth catchment. The sodium not only renders the catchment more impervious but is an effective way to control weeds. Weeds are the major maintenance problem in compacted earth catchments. The Compacted-Earth Sodium-Treated (CEST) Catchment has been field tested on a 0.4 hectare site at Page Experimental Ranch in Arizona. The catchment was prepared in the spring of 1971 in the same way as the CE Catchment at Atterbury Experimental Watershed. After shaping, the plot was rototilled to destroy soil structure. Four and one half metric tons of granulated salt were then added using a fertilizer spreader. The granulated salt was mixed into the upper 5 centimeters of soil and the soil surface smoothed using the rotating tractor-drawn rock rake. Following a 1.01 centimeter rainfall, the catchment was compacted with a drum roller. The total cost of the CEST Catchment was approximately $450. This catchment was constructed to serve a dual purpose. Grapes and deciduous fruit trees have been planted in the drainageways. Water is stored both in the soil and in a 56,850,000 liter storage tank where it is available for use during dry periods. Thus, the catchment can produce both food and water. This type of dual system should be more acceptable to the general public than bare catchment areas. The efficiency of this system neglecting soil-stored water has been greater than 50 percent of the total rainfall.

Gravel Covered Plastic (GCP)

The use of exposed plastic for water harvesting has been unsuccessful due to ultra-violet induced oxidation, wind, and mechanical damage. The use of gravel protects the plastic from sunlight and wind. Gravel covered plastic catchments were first installed at the University of Arizona in December of 1965. The 0.015 millimeter polyethylene plastic in early installations is still in excellent shape.

In order to reduce costs of the gravel covered plastic catchment, two different types of automated installation were developed. One type was a plastic laying gravel chute that fits on the back of a dump truck. By means of the chute, plastic could be laid down and covered in one installation.

A more controlled method of installation of GCP catchments can be attained through the use of a modified self-propelled chip spreader. Where specialized gravel spreading equipment is not available, the catchment has been installed at a rate of 185.8 square meters per hour using a front-end loader and a crew of five.

Large areas of the world have sufficient gravel in the upper soil profile to cover the plastic. Because of this, a machine was developed that would extract the gravel from the soil, lay plastic and cover the

plastic with the extracted rock. Considerable research effort was expended in the successful testing of this type of machine which was called the Gravel Extracting Soil Sifter (GESS).

A catchment is properly constructed if the plastic is covered with the minimum size and depth of gravel needed to provide a complete cover and resist erosion (Figure 1). On a 10 percent slope 30.48 meters long, a 1.27 centimeter cover of 0.48 to 0.95 centimeter gravel will withstand a 45.7 centimeter per hour intensity rainfall. In contrast with the CE and CEST catchments, the GCP Catchment produces sediment free water, a primary consideration in domestic supplies. The cost depends on the method of installation. In general, it would be approximately $2475 per hectare for large catchments installed with an improved version of the GESS using 0.0254 millimeter polyethylene plastic. The use of imported gravel would increase the cost to over $3713 per hectare. The projected life of a properly constructed and maintained GCP catchment is twenty-five years. With a 70 percent efficiency and a 6 percent amortization rate, the cost of water would be 0.089 per cubic meter in a 30.48 centimeter rainfall zone.

Chip-coated Reinforced-asphalt Catchments

Another type of catchment is the fiberglass reinforced asphalt catchment. Several of these catchments have been field tested in Arizona. Work at the University of Arizona in the area of reinforced asphalt catchments have centered around the use of plastic, both polyethylene and polypropylene, as the reinforcement material. The treatment consists of a prime coat of emulsified asphalt followed by a layer of 0.0102 millimeter polyethylene sheeting or polypropylene matting, which is then immediately covered with a top coat of emulsified asphalt and 0.32 to 0.48 centimeter chips. This Asphalt-Plastic Asphalt-Chip coated (APAC) catchment has many good features. It requires approximately one third the amount of gravel as a GCP Catchment. The treatment should work on any soil type since the plastic reinforcement prevents cracking. Treatment can be completed at one time. No curing time is needed during construction. The plastic should last at least 25 to 30 years if the catchment is properly maintained. Retreatment would be made by sweeping loose chips from the surface and laying down a new asphalt and chip protective coating. Based on the use of similar treatments in the roofing industry, retreatment would probably be needed every 10 to 15 years. Results from small plots indicate the catchment will cost at least twice as much as the GCP Catchment but will have an efficiency of 90 to 95 percent. This treatment has sufficient merit; large scale testing is planned.

WATER STORAGE METHODS COMPATIBLE WITH WATER HARVESTING

In general, the water storage techniques tested at the University of Arizona have been related to stock water supplies and consequently are

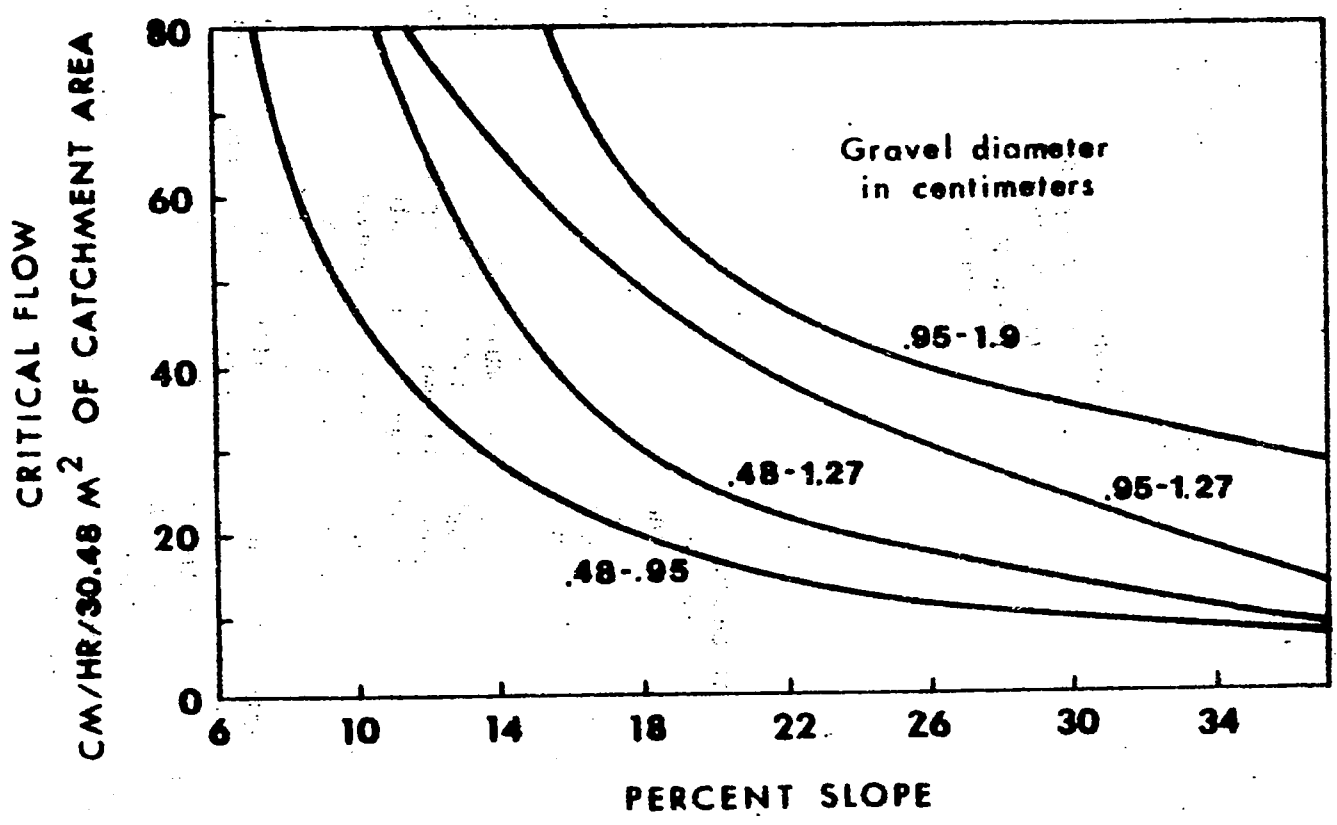


Figure 1. Critical flow versus slope for selected size of gravel cover.

limited in size. The basic treatment would also be suitable for larger reservoirs, with the possible exception of the rock-filled tank or those tanks utilizing the suspended cover for evaporation control. The seepage and evaporation control methods outlined here can also be used on existing or new reservoirs that are filled from other sources of water.

Plastic-lined Rock-filled Reservoir

The construction of this tank was prompted by the availability of commercial rock pickers which make the collection of rock for small tanks economical. Although decreasing storage by over 50 percent, the rock greatly reduces evaporation loss and practically eliminates any chance of mechanical damage including vandalism.

The tank is first excavated, then the surface is raked smooth. Two or three layers of 0.0254 millimeter polyethylene plastic is then laid down and covered with used rubber tires. The tires are filled with silty clay cover material to reduce the significance of any holes that may inadvertently occur in the plastic. The tires protect the plastic liner as rocks are added to the tank. In the United States, used rubber tires can be easily obtained at no cost. In areas where used tires are difficult to obtain, a 30.48 to 45.72 centimeter layer of soil on slopes less than 1:3 or a reinforced coat of cement-mortar could be used on the tank to protect the plastic. Three rock-filled tanks have been constructed in Arizona using a rotary drum commercial rock picker in areas containing sufficient rock to make the system economical. The cost is dependent upon the site and method of collection of the rock. The tanks were constructed for a cost of approximately $2300 for 94.6 cubic meters net storage with $1600 expended for the filling of the tank with rock. A reel-type rock picker was tested in connection with the construction of the above tanks. These tests indicated that the use of this type of picker should reduce costs by 50 percent.

Plastic-lined Concrete-coated or Earth-covered

The various methods of seepage control were outlined in the introduction. Plastic lining, if properly covered, offers a positive method of seepage control that is very competitive with other methods. Tests have indicated that a layer of silty soil, or a 1.90 centimeter layer of wire mesh reinforced cement-mortar will greatly reduce the seepage loss through holes that may inadvertently be placed in the plastic liner. The reinforced mortar coating is placed directly on the plastic and has proven to be an effective cover to use on steep slopes. This coating may either be placed using gunnite equipment or can be hand plastered. The cost of this cover is less than $2.15 per square meter.

In order to reduce the cost of installation on larger reservoirs, the same equipment developed for laying graveled plastic catchments can be used for laying and covering of plastic liners with soil. On smaller

tanks, of the size used for stock purposes, the soil covering is generally installed using hand labor. The economy and strength of a reinforced mortar covered plastic tank makes it practical to construct a walk-through cattle trough that is directly connected to the tank. This design avoids the need for a float valve which is subject to malfunction and vandalism. The use of the mortar covering also makes it possible to run water directly from the catchment into the tank, thus avoiding any chance of stoppage.

A Coupled-Expanded Polystyrene Asphalt-Chipcoated (CEPAC) Raft can be used for evaporation control. This system, first tested in the spring of 1972, is essentially 100 percent effective in preventing evaporation loss for the area covered. Any size of polystyrene sheets can be coupled together. Those tested at the University of Arizona have been primarily 2.54 centimeters thick, 1.62 x 1.62 meter sheets. These sheets are coated with emulsified asphalt and immediately covered with 0.16 to 0.32 centimeter chips. The sheets are coupled together using a coupler made out of two short lengths of slotted 3.81 centimeter PVC pipe. An outer frame of 3.17 centimeter PVC pipe filled with water provides a protective bumper for the rafts which have been constructed up to 148.6 square meters. These rafts can be coupled together to cover as large a body of water as desired. The cost of this system is less than $1.07 per square meter.

A suspended cover of butyl or reinforced plastic would be recommended for smaller tanks used for domestic control in which it is desirable to keep out foreign material or eliminate algae growth.

Sodium Treated Reservoirs

When there is sufficient clay in the soil and the incoming water is higher in sodium than calcium, the use of sodium salt is the most economical treatment for seepage control. A 567.8 cubic meter tank at Page Ranch, constructed in connection with the salt treated catchment, was sealed in 1971 with sodium chloride at the rate of 11.20 metric tons per hectare. The seepage loss at the tank appears to be insignificant, and due to the fact that the incoming water has more sodium than calcium, the life of the seal is indefinite. Evaporation is controlled through the use of CEPAC Rafts.

DISCUSSION OF THE ECONOMICS OF WATER HARVESTING SYSTEMS

To determine the most feasible method of water harvesting, costs and estimated life of the catchments must be considered. In addition, each site and potential water use should be examined in order to determine which catchment and method of storage to use.

The use of the CE and CEST Catchments are limited to areas where soil conditions are favorable. Both the CE and CEST Catchments should not be built where soils are difficult to compact. Tests to date have

indicated that clay content should not be less than five nor greater than 35 percent. For soils with the higher clay content, it would also be important to have more sand than silt, otherwise erosion problems would be unsolvable.

Water produced from a CE or CEST Catchment contains considerable sediment. In the case of the CEST Catchment, this sediment is finely dispersed and will remain in suspension. Although salt treated, the water from a CEST Catchment has less than 500 parts per million total salinity and can be used for most purposes including agriculture. Although more expensive, the CEST Catchment is generally preferred over the CE Catchment since the sodium not only increases the efficiency of the catchment but also serves as an herbicide which reduces maintenance costs.

A sodium treated tank would probably be the best to use in conjunction with a CE or CEST Catchment. Periodic retreatment of the tank may be necessary with a CE Catchment.

A graveled plastic catchment should be considered where gravel is economically available, the soil condition is not suitable for a CE or CEST Catchment, and/or a sediment-free water is desired. Generally, a plastic-lined reservoir would be used in conjunction with the GCP Catchment. A rock filled tank should be considered with the GCP Catchment if there is sufficient rock in the area and vandalism is a problem. Otherwise, a CEPAC raft covering would be recommended for evaporation control, unless the water were to be used directly for domestic use. In the latter case, a suspended cover would be recommended.

The APAC system would be used in areas where: soil or gravel conditions are such as to make the CE, CEST or GCP Catchments impractical, and/or rainfall and/or storage considerations were such that a high efficiency would be needed to maintain a firm water supply. In general, the same type of storage system used for the GCP Catchment could be used for the APAC system. The size of the storage reservoir could be reduced due to the higher efficiency of the APAC system.

Although more research is needed, costs of installation of water harvesting systems have been greatly reduced through application of modern techniques and methods described in this paper. Water harvesting should be considered whenever new water supplies for domestic and livestock use in developing arid and semiarid lands are needed. If the cost is low enough or the value of the crop is high enough, the water harvesting systems described in this paper can also be used to develop new agricultural lands where water is presently unavailable.

CHAPTER X

RESERVOIR MANAGEMENT

INTRODUCTION

Reservoirs are often an integral part of most watershed resources management programs. Reservoirs can be used to store and release water to enhance the general well being of people; they can help provide sustained water supplies for irrigation, municipal and industrial use, hydroelectric power generation, dillution of pollutants, and navigation, or they may be used to reduce floods. In nearly all regions, streamflow may be excessive during some seasons and insufficient in others. Not only do water supplies vary with time, location, quantity, and quality; the demand for water is highly variable. In particular, regions with well defined wet and dry seasons usually experience the greatest demands for water at a time when supplies are the lowest. Reservoirs can often provide the principle means of controlling and managing water supplies for human needs downstream.

Although the focus of this syllabus has been watershed resources management, it should be evident that such management must often be coupled with reservoir management to achieve water resource goals. The linkages among water resource goals, watershed management, and reservoir operation are important (Table 1). In some instances, a reservoir must be constructed in a basin to achieve water resource goals. For example, some type of storage reservoir is needed to provide water supplies during dry periods, regardless of watershed management activities. Water yield can be increased in many areas by converting from deep rooted (trees) to shallow rooted (grass) vegetation. However, without a reservoir, much of the increased water yield would likely flow from the area during high runoff periods and would be unavailable when irrigation was needed. Conversely, sound erosion control practices should accompany any reservoir project to prevent the storage capacity from filling up with sediment before the design life of the project. Economics usually dictate that sedimentation be controlled.

Table 1. Watershed and reservoir management as they relate to several water resource management goals.

Water Resource Management Goals	Watershed Management Objectives/Activities	Reservoir Management Objectives/Activities
Increase available water supplies for irrigation, municiple, *etc.*	Manipulate vegetative cover to increase water yield, (convert from deep rooted to shallow rooted species on watershed) Minimize/control erosion and sedimentation to maintain storage space in reservoir for the duration of design life. Rehabilitate watersheds in poorly managed areas.	Provide storage to accommodate increased water yield and also to provide firm yield for demands.
Reduce flood hazard.	Maintain vegetation and soils in good condition through proper land management; maximize infiltration and minimize surface runoff. Rehabilitate where necessary. Minimize sedimentation of channels to maintain channel capacity.	Provide storage space which can be used to store runoff during flooding. Store during periods of high runoff and release during dry periods
Maintain surface water supplies with a high quality for human consumption or fisheries resources.	Restrict or carefully manage land use activities conducive to production of sediments, disease carrying organisms. Maintain vegetation and soils in good condition. Rehabilitate watersheds where needed.	Regulate outflow to enhance desirable downstream water quality characteristics (dissolved oxygen and temperature).
Provide hydroelectric power.	Manage watersheds to sustain life of reservoir project as above.	Maintain a dependable storage with sufficient head to generate enough electricity to meet demands

When flood control is a goal, watershed management practices designed to maintain high infiltration rates and low surface runoff are needed. Such practices can affect the magnitude of the average annual flood. When extremely large storms occur of a less frequent nature, studies have shown that the condition of soils and vegetation have a minimal effect. In such cases, a reservoir can provide considerably more flood control. Certain "people" management options are available, however, to reduce flood hazard. Flood plain management (*i.e.*, keeping people and buildings out of flood hazard areas), offers a viable alternative to reservoirs. Social and economic factors should be carefully considered when evaluating such alternatives.

Social and economic problems are often associated with the construction of reservoirs. Relocation of people, loss of productive bottomlands, and adverse environmental impacts must be weighed against the benefits of a reservoir. Planning for the sustained and wise use of the benefits of reservoirs is essential if the benefits are not to become liabilities. For example, a flood control reservoir may lend a false sense of security and create overdevelopment of the flood plain downstream. Since no flood control reservoir is 100 percent effective, the potential for flood losses may be increased.

RESERVOIR OPERATION AND STORAGE

Once the need for a reservoir has been established, the following questions must be answered: can more than one goal be achieved, that is, should a multipurpose rather than a single-purpose reservoir be considered? Are the demands for storage with a multipurpose project competitive with respect to time? And what storage volume is required to meet demands?

Reservoir Operation

Political and economic decisions usually dictate whether a single-purpose or multipurpose reservoir is to be constructed. The needs of a region (including water supply, irrigation, electrical power, navigation, and flood protection) should be considered. It is usually more economicalto construct a reservoir capable of meeting several requirements rather than one. Also, it is possible in many instances to meet more than one demand with a fixed storage. For example, a given volume of storage may provide flood control during the rainy season, but that same volume may provide water supply needs during the dry season. If hydroelectric power is being generated, there may be constraints placed on the operation of the reservoir pool to maintain the required head of water.

Sometimes the demands for water are competitive for the same time period. Storage volumes in the reservoir must then be allocated to meet these competitive demands. Typically, this is accomplished by comparing demands with storage volumes and partitioning total storage (Figure 1).

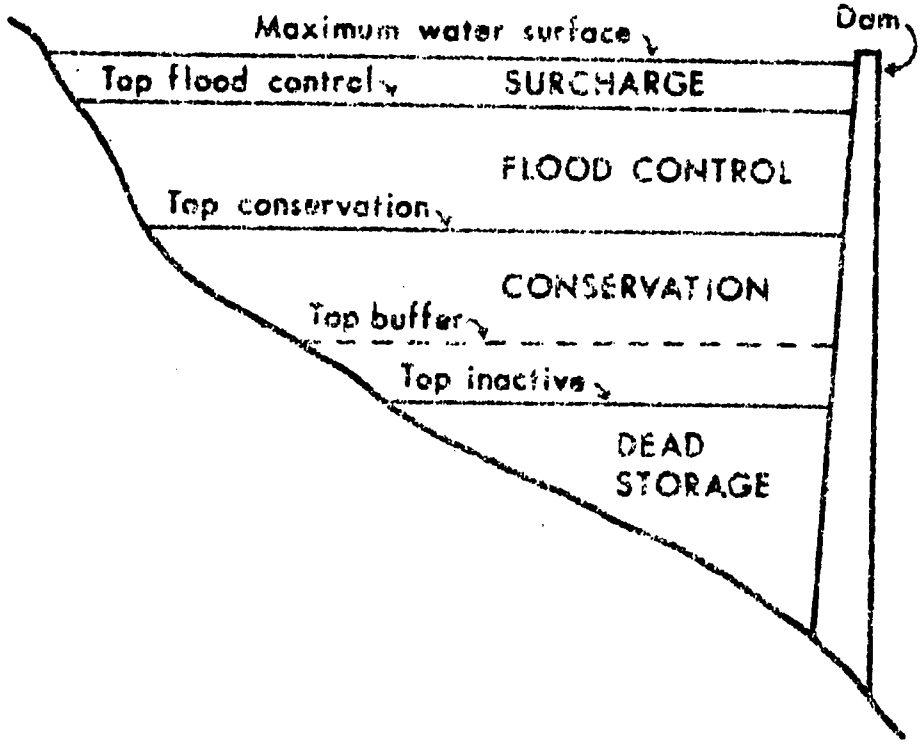


Figure 1. Allocation of storage for a multipurpose reservoir.

This partitioning process involves both the determination of required volumes, to be discussed later, and establishing operating rules to specify how the reservoir is to be managed.

The elevations of the various zones are used as guides for operation and can vary seasonally (Figure 2). The flood control zone would be evacuated of water at a time corresponding to the flood season (in this example, by the end of October). The reservoir would then be kept at the top of conservation space (bottom of flood control space) to provide sufficient storage to control flooding. The top of the flood control pool is used to maintain the integrity of the reservoir. Once the pool elevation rises above this level, as much flood water as possible is released to prevent the dam from collapsing. Once into Zone 1, the reservoir is operated to release the maximum amount of water without causing flooding. Ideally, this would coincide with bank-full conditions downstream. This operating rule would be in effect until the end of the flood season, April in this example. During the dry season, part of the flood control space is used for conservation storage (Zone 2). A system of priorities may be established within Zone 2 to insure that vital water needs will be met. In this example, a buffer space is provided for high priority use. An illustration would be a reservoir which provides for both irrigation and municipal water supplies. Zone 2 would be operated to satisfy irrigation demands until the pool dropped to the top of the buffer space. At this time, irrigation demands would not be met to meet higher priority municipal needs. Zone 3 represents the dead storage component of the reservoir which contains enough space to trap and retain sediment over the life of the project. Operating gates on the reservoir are above the top of Zone 3; therefore, the only time the pool elevation can drop below this zone is when the reservoir is evacuated as far as possible with control gates, and evaporation and seepage exceed reservoir inflow.

The development of *rule curves* (guidelines for reservoir operation, usually specifying target storages on a monthly basis) involves considerable knowledge of the variability of inflow to the reservoir and a clear understanding of seasonal water demands, priorities, and the downstream channel capacity. Historically high and low streamflow sequences are usually used to develop and test rule curves to insure that water requirements and all constraints are met. When historic records are limited, a regional analysis may be performed to extend data. Other options may be to synthesize streamflow records with either deterministic or stochastic models.

Rule curves serve as guides in the operation of a reservoir. Of course, the opportunity to adhere to these guides is improved by providing the reservoir manager with accurate, real-time forecasts of inflow. Many operating constraints must usually be considered along with the rule curves. For example, most reservoirs have restricted rates of change of outflow to prevent rapid surges of water downstream. In some cases, this may cause the reservoir pool elevation to deviate from the rule curve. Similarly, rule curves may occasionally be violated to accommodate

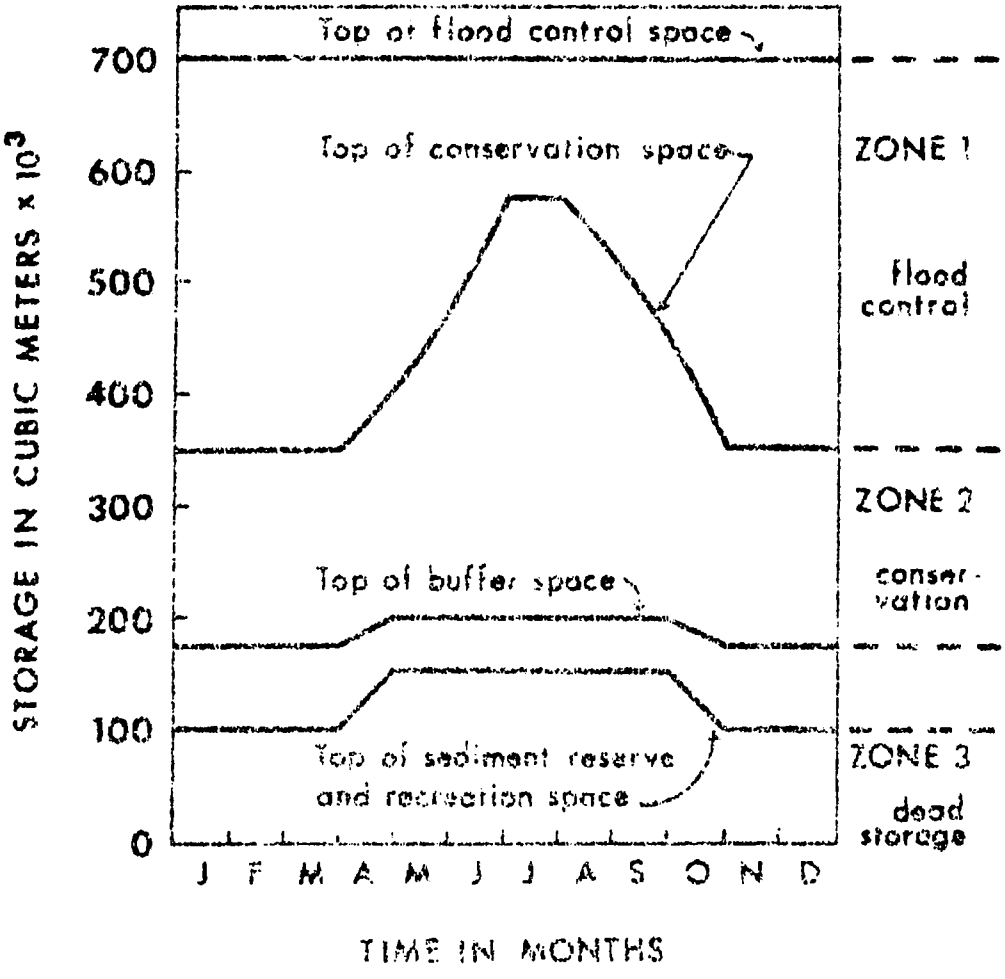


Figure 2. Operational rule curves illustrating seasonally varying storage requirements of a multipurpose reservoir.

temporary anomalies in this system. Examples would include changes in operation to accommodate the passage of migrating fish or to assist downstream efforts to remove a barge which has gone aground. However, such deviations in rule curve operating should not be allowed to adversely affect some other part of the system.

Reservoir Storage

Determining the storage volumes for a proposed reservoir, called *reservoir yield analysis* requires streamflow information at the reservoir site and all water demands (volumes) for the reservoir. Several methods can be used to determine these storage volumes. The method used depends upon: the type of study being performed (is the study preliminary or the final detailed storage determination?), whether a single-purpose or multipurpose reservoir is desired, the availability of streamflow data and other hydro-meteorological information, and the variability of demands to be placed on the reservoir. The type of reservoir yield analysis can be categorized as either simplified or detailed sequential analysis.

Simplified Analysis

Simplified methods of evaluating storage requirements are useful when it is desired to save time and resources, when approximate results are adequate, or when we wish to obtain a good initial estimate to a more detailed, sequential study. *Sequential mass curve* and *nonsequential mass curve* (depth duration analyses) are examples of simplified methods.

The *sequential mass curve*, or Ripple method, is probably the most common simplified procedure; it consists of graphically estimating the storage required to produce a given yield. To use the Ripple method, the demand must remain fairly constant, that is, seasonal variations in the demand for water from the reservoir cannot be analyzed. Also, the watershed characteristics which control streamflow must remain fairly uniform over the period of streamflow used in the analysis.

To apply the Ripple method, streamflow at the reservoir site must first be accumulated in a mass curve, construction in units of volume (Figure 3). The demand or desired yield can be represented by a straight line with a slope equal to the desired yield rate.

The *nonsequential mass curve analysis* is another simplified method of estimating reservoir storage. With this approach, the risk or the frequency of shortage associated with a given yield can be determined. The steps necessary to use the nonsequential method are demonstrated in the following:

(1) rank low flow events, designating the lowest as Number 1, the second lowest as Number 2, *etc.*

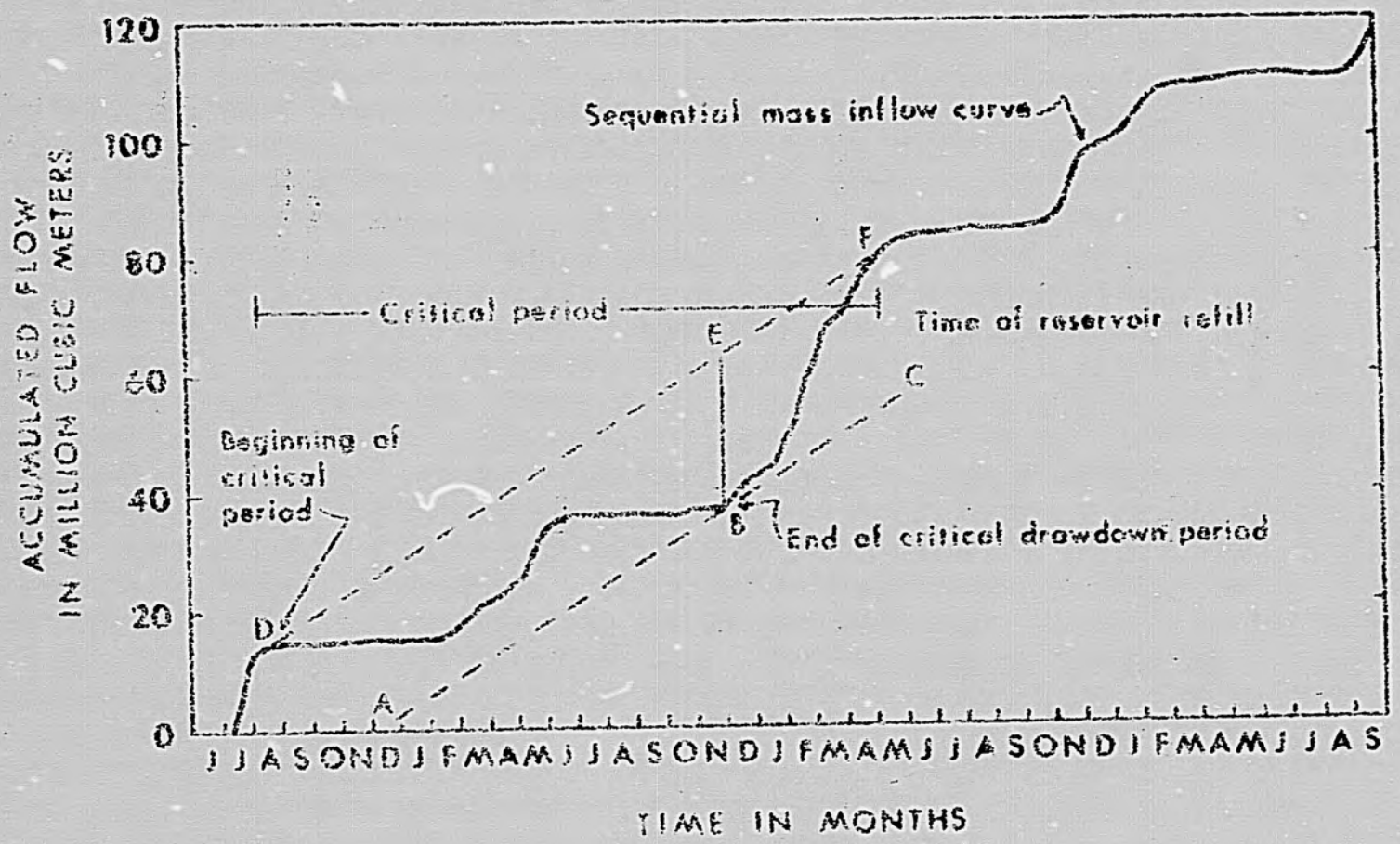


Figure 3. The sequential mass curve or Ripple method of determining reservoir storage. Given: desired yield = 39 million m^3/year. Construct line ABC with slope = 39 million m^3/year tangent to mass curve at B (lowest possible point of tangency). Construct line DEF parallel to ABC and tangent to mass curve at D (highest point of tangency prior to B). Line BE represents the maximum storage requirement to produce the desired yield (about 26 million m^3 is required).

(2) compute the median-plotting positions of nonexceedence frequency for ranked low flow events. For the 8 year period, the first 5 months could not be used to estimate 6 month low flow volumes. The effective record was, therefore, 8 years less than 5 months, or 7.58 years. The plotting position (PP) for the lowest 6 month volume was:

$$PP = 1 - (0.5)\ 1/N$$

$$= 1 - (0.5)^{1/7.58} = 1 - 0.9128 = 0.0872$$

Which means that the probability of a 6 month flow volume being less than 67.1 m3 x 10^6 would be 0.0872 or 8.7 percent. The formula for the plotting position of other volumes is

$$PP = 0.0872 + (\Delta R) \quad \left(\frac{\Delta P}{\Delta I} \right)$$

where:

$\Delta P = 0.9128 - 0.0872 = 0.8256$
$\Delta I = 7.58 - 1 = 6.58$
ΔR = Rank - 1

The number of events ranked is the smaller of N/n or R where:

N = number of months in the record
n = number of months in duration
R = rank of the last event with PP < 0.50
(In this example R = 4)

The ranked volumes were:

Rank	6 month Volume (m3 x 10^6)	Plotting Position (percent)
1	67.1	8.72
2	69.7	21.27
3	69.9	33.82
4	72.1	46.37

(3) plot the low flow events (Figure 4). These nonsequential mass curves are smoothed graphically to insure mutual consistency, that is, so curves do not cross.

(4) minimum runoff duration curves are then obtained by plotting points from the low flow frequency curves on logrithmic paper (Figure 5). The flow rates which are in cubic meters per second (Figure 2) are converted to volume (Figure 5).

(5) select the risks that are considered reasonable for the type of project being studied and, along with the required demand, evaluate the storage requirements (Figure 6). The nonsequential mass

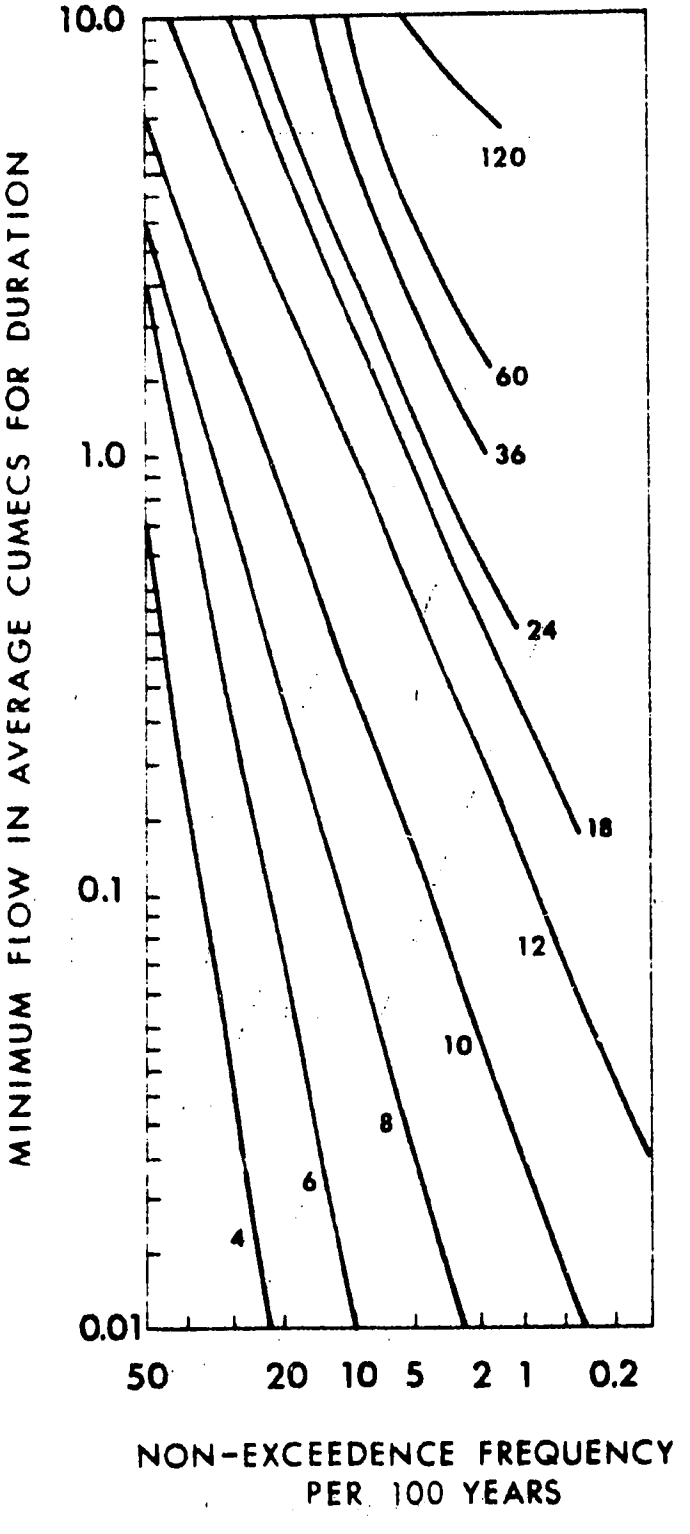


Figure 4. Low-flow frequency curves based on 35 years of historical flows. Parameter is duration in months. Values obtained from partial-duration analysis of independent (non-overlapping) events.

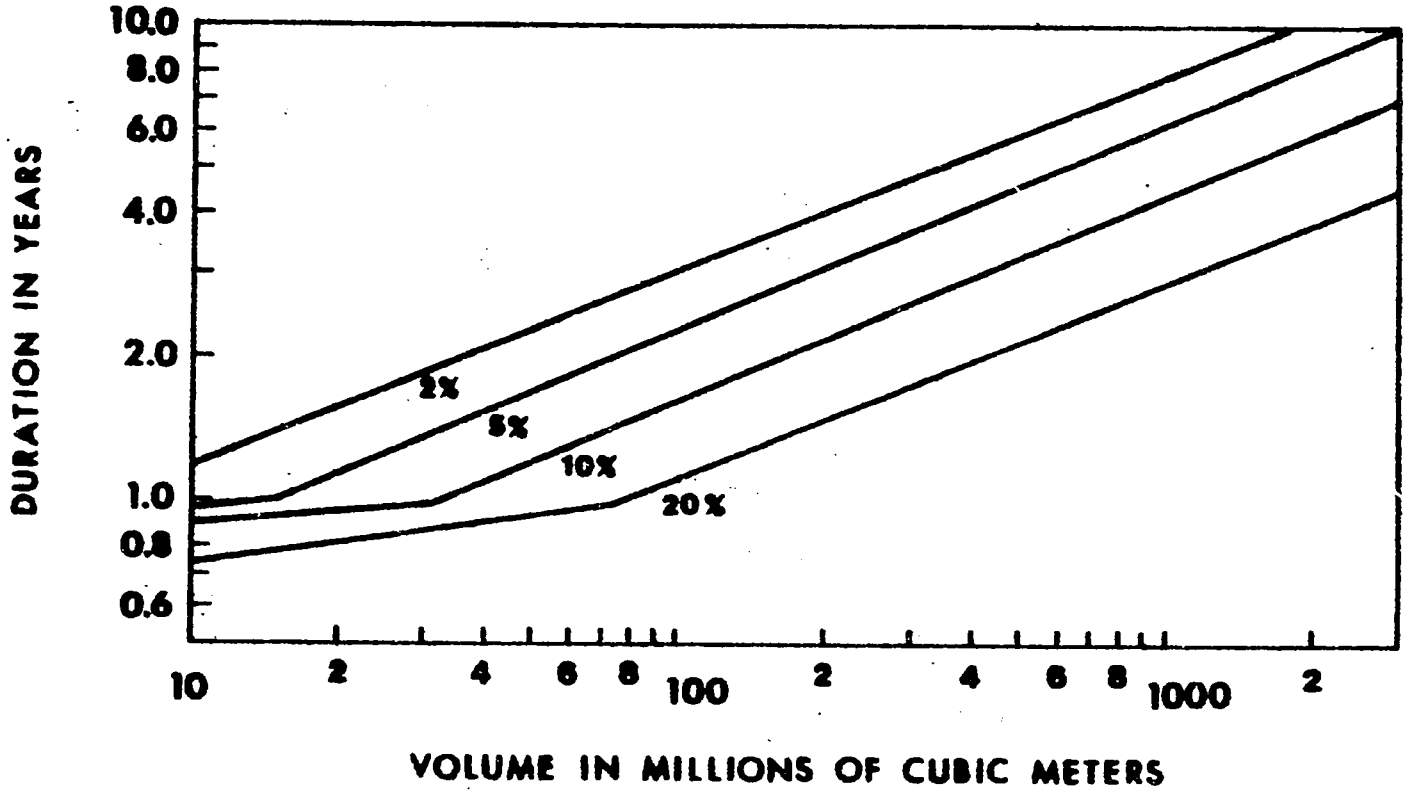


Figure 5. Minimum runoff-duration curves (based on Figure 4). Parameter is non-exceedence frequency in percent of years.

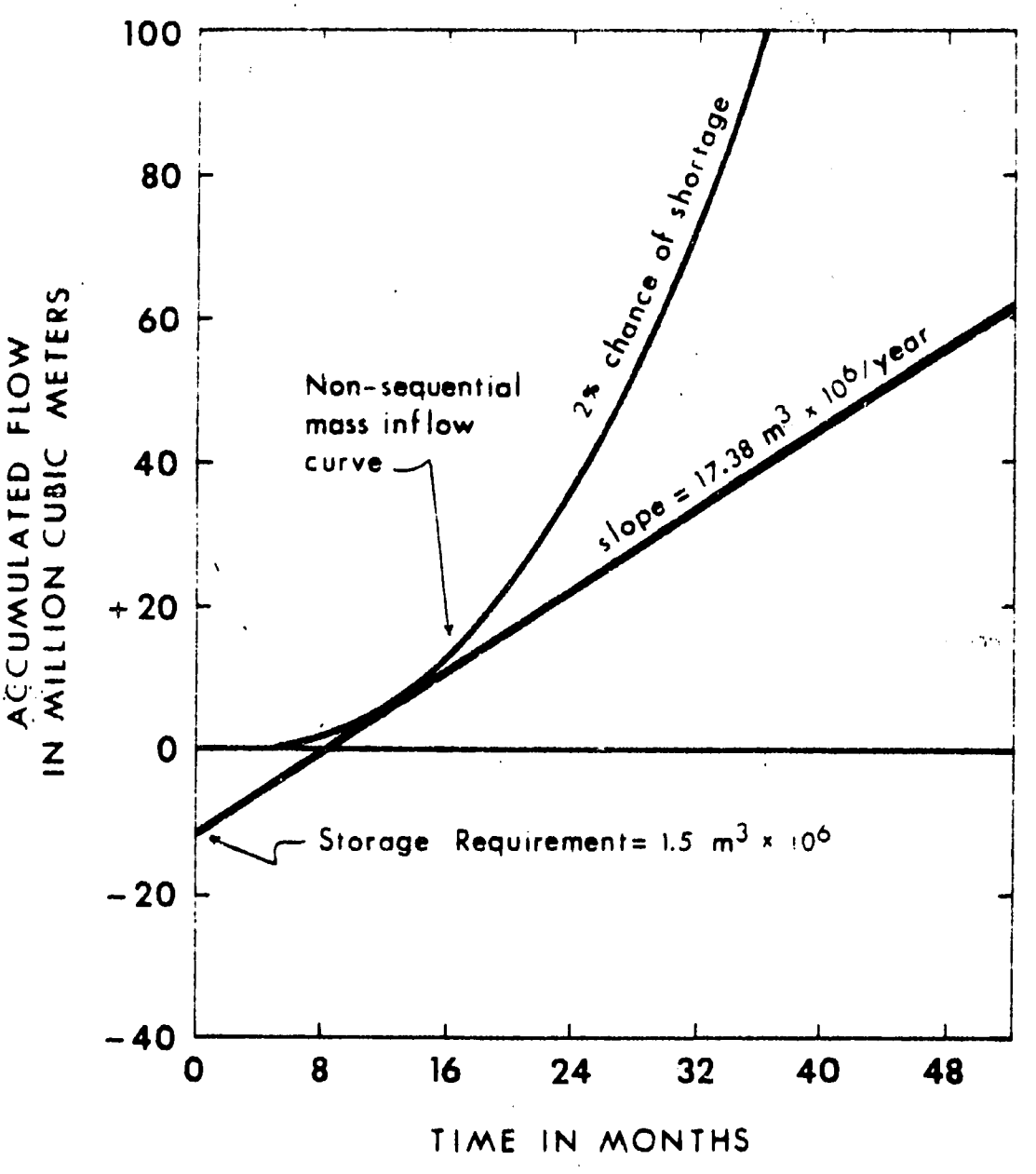


Figure 6. Non-sequential mass curve method of determining reservoir storage (from Figure 5).

curve is the selected volume duration curve plotted on arithmetic grid. This is used as the estimate of yiled. To determine the storage requirement, a straight line with a slope equivalent to the demand is plotted tangent to the mass curve. The absolute value of the negative vertical intercept represents the storage requirement (in this example, 11.5 $m^3 \times 10^6$).

The results from this example yield the storage required to meet the specified demand, in this case, 17.38 $m^3 \times 10^6$/year. Thus there would be a 2 percent change of having a shortage with the storage of 11.5 $m^3 \times 10^6$. Again, there are some constraints with the use of this method. The nonsequential mass curve does not reflect the seasonal variation of flows. Also, if demand varies seasonally, the procedure cannot be used. This method is only as good as the nonexceedence frequency curves from which it is based. Therefore, several years of record are needed. Typically, adequate streamflow data are not available to utilize either one of the two simplified approaches. In such cases, continuous simulation models may be used to generate streamflow for a particular area based upon precipitation records which are often more abundant.

Detailed Sequential Analysis

The most accurate method of determining reservoir storage requirements is by the detailed sequential analysis. This approach is usually considered more acceptable than the previously described techniques because all inflow and outflow to the reservoir site are examined during sequence of critical low flow events. Reservoir storage requirements then are evaluated with a procedure based on the principal of conservation of mass. The conservation of mass is expressed by the following continuity equation:

$$I - O = \Delta S$$

where:

I = total inflow volume to the reservoir during a specified time period
O = total outflow volume during the same time period
ΔS = change in storage volume in time period.

The change in storage can be expressed as follows:

$$S = S_t - S_{t-1}$$

where:

S_t = storage volume at end of time t
S_{t-1} = storage at end of time t-1

By substitution and rearrangement: $S_t = S_{t-1} + I_t - O_t$

A repetitive solution of the above equation together with an examination of constraints, storage boundaries and service priorities is called a *sequential routing study*.

Because of the detailed nature of a sequential analysis, computer programs are often used. Sequential routing can be performed by hand calculations, particularly when determining the storage capacity of a simple single reservoir, but the work is tedious.

Design Floods

Design floods or design storms are selected for reservoir studies as standards against which performance of the facility may be evaluated. The design flood is simply the runoff from a large storm and is defined by some selected criteria.

Design floods are typically referred to as spillway, reservoir, or project design floods. The spillway design flood is that flood which is selected to determine the size of the spillway of the reservoir. The reservoir design flood refers to the event selected for sizing the flood control storage of a reservoir. The project design flood is that which is used to determine the size of the project.

There are several approaches to determine design floods for one of the above purposes. The *probable maximum flood* (PMF) is that flood which may be expected from the most severe combination of hydro-meteorological conditions that are reasonably possible for an area. Typically, such a large event is used in the design of a spillway, particularly where failure would be disastrous in terms of loss of life. The *standard project flood* (SPF) is usually smaller than the probable maximum flood. Often a figure of 40 to 60 percent of the PMF rainfall is used to generate the standard project flood. It is usually used as an upper limit design flood for major reservoirs or local protection projects. In either case, the estimated flood events are based on sound knowledge of the meteorological conditions in the region. A certain amount of judgment is used in determining both of these floods. An alternative approach would be to determine floods with specific exceedence intervals such as the 20 year, 50 year, or 100 year event A risk is thus associated with these design floods. Reservoirs should probably not be designed on the basis of recurrence intervals except where loss of life is not a factor or where the economic impacts of failure are insignificant. It must be realized that a reservoir designed on the basis of, for example, a 100 year recurrence interval flood has associated with it a risk of failure of 67 percent over a 100 year period. In the case of multiple projects, the design on the basis of the 100 year event could be very misleading. If we have 100 reservoirs designed in this manner, there is a 67 percent chance that one of those reservoirs will fail in any given year.

As with low flow analyses used in conservation-storage studies, stochastic streamflow data may be generated for flood analyses. The concept of the design storm or design flood is simply that we can preselect the performance criteria which we wish to use for a particular water resource facility. Again, this performance criteria may be based on many factors other than hydrologic considerations. The economical, institutional, political, environmental, and social aspects may be determining factors in the selection of performance criteria.

Selection criteria for design floods are usually established by an agency which is responsible for designing and operating the reservoir. If a project has a very high dam with a large volume, and it is determined that the structure cannot be overtopped without disastrous consequences, a probable maximum flood would be likely chosen for spillway design. On the other hand, run of river hydroelectric power plants or diversion dams may be designed by means of a standard project flood in which case the structure could be overtopped without suffering serious damage. Small dams which impound one to two million cubic meters or less, or small recreational type lakes and farm ponds may be designed on the basis of floods with a specified recurrence interval. In such cases where a dam is low enough and the storage small enough so that no serious hazard exists to downstream inhabitants, an event such as the 50 year recurrence interval flood may be selected.

Methods of generating design floods have previously been discussed. In the case of standard project flood or the probable maximum flood generation, one would likely select a model such as the unit hydrograph and take meteorological (rainfall) data and generate streamflow. In the case of recurrence interval design floods, the study would involve a statistical analysis of existing streamflow records. Very often this requires a regional analysis to determine streamflow responses for ungauged sites.

CHAPTER XI

ECONOMIC ASPECTS

INTRODUCTION

For the hydrologist or watershed manager concerned with action programs and getting technically sound project proposals implemented, economics is of central concern--as are politics, social pressures, *etc.* This is the basic rationale for including an economic perspective in this course. While the academic hydrologist at times can quite justifiably ignore economics and politics in his search for the "best" technical approach to a watershed problem, the practitioner--who is of central concern to this course--cannot ignore the broader picture, *i.e.*, the conditions which determine the commitment and capacity to *implement* hydrology projects.

WATERSHED OBJECTIVES AND PROJECT PLANNING

Most land-use related projects involve implications in terms of changes in water quality and/or quantity. Thus, most such projects should include explicit consideration of water related impacts and of potential activities to achieve acceptable watershed protection standards. In some cases the major objectives of a project may be water related and constitute the reason why the project is being considered and proposed. In other cases, water related concerns may merely enter the project analysis in the form of constraints on other project activities.

Basically, project planning involves: definition of objectives, identification of alternatives to meet objectives, design of alternatives in terms of specific required inputs and outputs, analysis or appraisal of alternatives, and choice among alternatives. It is a dynamic and reiterative process which uses feedback from past and ongoing operations to improve future project planning activities.

The focus of this paper is on one of the elements in the overall planning process, namely analysis or appraisal. We limit ourselves to

the *economic* analysis and appraisal process, recognizing full well that most projects involve other appraisals, including: *technical appraisal* (a main subject covered in the present course), *commercial appraisal*, or the consideration of the availability of inputs when needed and the actual uses or requirements for outputs, *institutional and organizational appraisal*, which deals with the consistency of a given project alternative in terms of the institutional structure existing and the organizational capacity to undertake a project; *managerial appraisal*, or the consideration of whether or not in fact there is the managerial capacity available to implement and execute a given project; and *financial appraisal*, or the consideration of budget implications and financial profitability.

THE BASIC FRAMEWORK FOR AN ECONOMIC ANALYSIS

An economic analysis is carried out to provide information for decision making on the costs and benefits or economic impacts associated with a project and the relationship between costs and benefits, *e.g.*, whether the benefits exceed the costs for a given project alternative.

The emphasis here is on *economic* analysis from a national, public point of view, as distinct from the closely related *financial* analysis, which is of central concern to private entities. The public sector is also interested in financial considerations, since a project cannot be undertaken unless it is financially viable, *i.e.*, within the budget limits of the public sector or agency considering the project. A financial or budget analysis for a watershed project is fairly straightforward and involves consideration of financial (money) outflows and inflows for a given entity or group of entities.

There are two main applications of economics in project planning. First, we are interested in the economics of *alternative designs* (or project opportunities) to achieve the *same* objective(s). This involves analysis of "mutually exclusive" project alternatives. Second, once the "best" design for meeting a given objective has been chosen, *i.e.*, the economically "optimum" design, economics is relevant in terms of deciding whether or not in fact the project will be undertaken, when other known uses for scarce resources are considered.

Economic analyses of watershed projects are no different in principle or concept than economic analyses for any other type of project. Basically, in an economic analysis we are concerned with economic efficiency associated with alternative allocations of resources, *i.e.*, how to achieve the greatest benefits with given resources, or how to minimize the expenditure of resources in achieving given benefits. Some analytical issue and empirical problems are particularly important for watershed related projects. Some of these issues and problems relate to economic factors, and they are the main subject of this paper. Others relate primarily to technical factors and their treatment is properly the task of hydrologists; many of these have been discussed in earlier

sessions of the course. Thus, we do not discuss them further here, other than in terms of how the economist can interact with the hydrologist in determining what physical input-output information is needed in order to carry out an economic analysis. A basic point is that the physical relationships must be quantified *before* an economic analysis can be carried out. Thus, the present discussion proceeds under the assumption that such information can be generated. Given the fact that the lack of such information is in practice the major bottleneck encountered in most watershed project appraisals, it may seem that this assumption is made here to avoid a major problem. In fact, it is made to emphasize the point that the *economist cannot solve the information and data problems associated with watershed projects.* What he can do is to suggest a systematic approach to *identifying* direct and indirect negative and positive impacts associated with a project, and point out what information and data are needed for him to be able to *value* these various impacts.

STEPS IN AN ECONOMIC ANALYSIS

The nature and the amount of detail included in an economic analysis of a watershed project will vary from project to project and from institution to institution. However, some general guidelines can be mentioned. First, a meaningful economic analysis can be carried out only when objectives have been clearly specified and alternatives for meeting the objectives have been identified in terms of the physical input and output relationships involved.

Second, any economic analysis should include at least the following five steps:

(1) *Developing physical input-output relationships for alternatives and indirect effects in a form appropriate for the economic appraisal.* This means organizing input and output information in terms of basic physical units and in terms of the times when inputs are required and outputs will be forthcoming. The appropriate units are those with which values can be associated. The time element is critical, since the economist will eventually have to adjust costs and benefits that occur at different times to a common time basis.

(2) *Estimating appropriate unit values for inputs and outputs.* In a financial analysis, market prices are used; in an economic analysis, some market prices are adjusted to take into account differences between social value and market value and an attempt is made to derive monetary value (social values) for nonmarket inputs and outputs or impacts associated with a project. Again, economic unit values (usually called "shadow prices") are organized by time periods, recognizing the fact that they will likely change over time.

(3) *Combining the physical input and output information with the unit values to arrive at a total value flow for the project* (such as illustrated in Table 4). This is a basic table for the economic analysis,

since from it will be derived the various measures of economic project worth which will be used by decision makers in making their choices among project opportunities.

(4) *Calculating measures of project worth appropriate to the project and the institution undertaking the analysis.* The most common measures involve "adjusting" costs and benefits which occur at different times to a common point in time, generally the present. The process of adjustment is called discounting (and compounding) and the basis for the adjustment factor used is the relevant discount rate, generally determined at the national level and applied to all projects in all sectors, to insure consistency in results for diverse types of projects.

(5) *Testing the sensitivity of the calculated measures of project worth to changes in assumptions concerning input-output relationships, unit values, etc., for which some uncertainty exists.* Treatment of uncertainty is a critical step in the analysis process, since in most cases we will be quite uncertain abc ıany of the values assumed in the analysis.

PARTICULAR ISSUES OF CONCERN IN HYDROLOGY PROJECTS

Based on review of a number of hydrology/watershed management projects in developing countries, it appears that there are some specific analytical and empirical issues which are particularly common for watershed projects. These are discussed in the remainder of the paper.

The specific points selected for further treatment are the following:

(1) Consideration of alternative means for achieving goals.

(2) Determination of project scope and context.

(3) Identifying costs for watershed projects.

(4) Identifying benefits for watershed projects.

(5) Treatment of benefits and costs in multiple purpose projects.

(6) Presenting cost and benefit information in an appropriate form.

The fact that there are only six points does not mean that they are the only ones of concern to the analyst of a watershed related project.

EXAMPLES

The first of the examples is an economic analysis of alternative logging systems. The objective of the analysis is to find that system that maximizes net revenue subject to a constraint on maximum allowable sediment discharge. It is an example of an economic analysis to provide information for an operational decision where water related concerns are entered as a constraint.

The second example illustrates in summary form an economic analysis of a major watershed project designed to reduce the rate of sedimentation in a reservoir, thereby extending the useful life of the reservoir and producing additional downstream benefits. The project also involves several other elements, including wood production in combination with watershed protection, pasture improvement, and general improvement of upstream agriculture.

Example No. 1: Watershed Considerations as a Constraint in a Project

The growing worldwide concern for environmental protection makes this type of example relevant.

A 20 hectare woodlot is to be harvested. The lot occupies land along a river with an average slope of 20 to 30%. In order to prevent erosion and decrease resulting sediment flows, a clearcut will not be allowed by regulatory agencies. For this reason a selective cut will be made. However, it is anticipated that with standard logging techniques about 3.6 metric tons of sediment per hectare will enter the river the first year after the harvest. This amount of sediment is considered unacceptable by authorities and they will not issue the harvesting permit unless measures are taken to reduce sediment to no more than 1.8 metric tons per hectare. Thus, the forest manager must find an alternative that will reduce sedimentation of the river by at least 1.8 metric tons per hectare per year at the lowest cost possible, *i.e.*, he is searching for the least cost alternative for logging the area that will meet the constraint.

Harvestable volume on the woodlot is 300 cubic meters per hectare which can be sold for $10 per cubic meter.

If all 20 hectares had been harvested using standard methods, it is estimated that the following costs and returns would have then obtained:

Returns

300 cubic meters/ha x $10/cubic meter x 20 ha equals $50,000

Costs

labor: 1000 man hours x $2.00/hr equals 2,000
tractor: 250 hours x $25/hr equals 6,250
loading/transport: 120 hours x $20/hr equals $2,400
total cost: $10,650

Net revenue

$60,000 minus $10,650 equals $49,350

However, as mentioned the standard method is not acceptable because of the high sediment discharge associated with it. Two alternatives are proposed that would meet the maximum discharge restriction.

The *first* feasible alternative consists of leaving a 25 meter wide buffer strip (no cutting) along the river. The woodlot has a shoreline of 1600 meters, therefore, cutting would be reduced to a total of 16 hectares instead of 20 hectares. This means a loss of 4 hectares of timber or 300 cubic meters x 4 hectares x $10 per cubic meter which equals $12,000 of revenue foregone. This is considered a cost for this alternative. It is assumed that other costs would be reduced by 20 percent since only 16 hectares could be harvested. Thus, costs other than revenue foregone would decrease to $8,520 (20 percent less than $10,650). Total cost of this alternative would be $20,520 ($8,520 plus $12,000).

The *second* alternative which meets the sediment discharge requirements consists of establishment of 40 meter filter strip in which no machines are allowed. All commercial timber (*i.e.*, 300 cubic meters per hectare) on this 6.4 hectare filter strip can be cut but must be winched out at a higher cost. On the 6.4 hectares of the filter strip are estimated to be $8,094. For the remaining 13.6 hectares, costs will drop to an estimated $7,242 to reflect reduction in area logged. Thus, total cost of this alternative will be $15,336.

Assuming that these are the only two alternatives considered that meet the sediment discharge restriction, we would choose the lowest cost alternative or the filter strip approach. Revenue would be $60,000 as before and cost would be $15,336, for a net return of $44,664, which compares with a net return of $29,480 in the buffer strip alternative. The information generated in this analysis further indicates that the cost of the sediment discharge restriction would be $49,350 minus $44,664 or $4,686.

Example No. 2: Economic Analysis of a Watershed Protection and Management Project

Some years ago a reservoir was built along the Sierra River to provide storage of water for downstream use during periods of low flow. Downstream uses include irrigation on some 9,500 hectares and domestic

water use by the local population. It has been found after five years of operation that the reservoir is silting in at a much faster rate than initially anticipated, thus reducing effective capacity and ability to meet water requirements downstream. Siltation is occurring at a rate of 4 million cubic meters per year. Present reservoir capacity is down to 100 million cubic meters. At the present rate of siltation, it will only be four years before capacity is reduced to a point where it can no longer meet estimated water requirements of downstream users. (Domestic water use is increasing at a rate of about 6.19 percent per year, while irrigation use is fairly constant.)

Project Goal

To prevent the reduction (or loss) of water related downstream benefits (those that would be lost without the project include crop values and health and satisfaction associated with domestic water use), the project would extend the effective capacity and life of the reservoir by reducing the rate of siltation from 4 million cubic meters per year to 1 million cubic meters per year. Since there was apparently no problem of flood damage with or without the project, flood prevention was not included as a goal. It could be added in as a goal and treated in exactly the same way, if it was a problem.

Project Points of View

(1) Downstream users of water have a direct interest in maintaining the capacity of the reservoir so that they can continue to receive water during the dry periods when river flow is inadequate to meet requirements;

(2) Upstream users of the land which would be affected by the various conservation measures proposed for the project are interested in how such measures would affect them. If effects are negative, some form of compensation may be included in the project plan;

(3) The nation at large is concerned with increased crop consumption, improved welfare of domestic water users, and losses or gains incurred by upstream land users.

The point of view adopted in the analysis is primarily that of the nation, although the other two viewpoints are also considered.

Identification and Valuation of Project Costs

To accomplish the project goal, the following project components have been proposed in the technical design and analysis:

(1) Establish protection forest on the most critical areas where no other activity should take place because of slope or critical nature of soil protection.

(2) Establish protection/production forests on areas that need permanent protection but which are less critical so that some forest utilization can take place on a controlled basis.

(3) Build terraces on some of the most critical areas with very unstable soils.

(4) Manage and maintain pasture lands on a rotation, based on their carrying capacity and ability to regenerate. This will primarily involve control and policing activities together with technical assistance.

(5) Establish forest management on existing natural forest areas. This would include control of harvest and other activities, watershed protection inputs into access road establishment, inventory and other information gathering activities.

(6) Establish an overall watershed management and administration unit within the regional government to supervise and control implementation of an integrated watershed management program for the whole watershed, including the above elements. Include extension services for local farmers.

In the project documentation, appropriate technology, input requirements and timing for each of the project components were analyzed. Based on an initial survey of the total watershed of 17,500 hectares, the scale of each of the project components was determined, as shown in Table 1. Average input requirements per hectare were estimated and applied to the total areas to arrive at total labor, equipment and other input requirements. These input requirements together with unit value estimates were then used by the economist in valuing the project costs, which are summarized on lines 4 through 8 of Table 2.

In developing economic values for inputs, only unskilled labor was shadow priced. Other inputs were valued in the economic analysis at their financial or market price values.

A project period of 26 years was considered appropriate, considering the relevant social discount rate of 12 percent.

Identification of Benefits

Reservoir demand (*i.e.*, the demand on water from the reservoir which would not be available without it) is estimated at 86 million cubic meters in the first year (year 0) of the project as shown on the first line of columns 5 or 6 of Table 2. The capacity of the reservoir

Table 1. Areas associated with each project component

Component	Hectares
Protection plantings	760
Protection/production plantings	870
Terraces	320
Pasture use control	3,850
Natural forest management	3,160
Watershed planning & administration	(17,500) 1/

1/ Including the parts of the watershed not requiring direct action.

Table 2. Watershed project: identification of water benefits.

(millions of m3/yr)

(1) Year	(2) Reservoir Capacity without project	(3) Reservoir Capacity with project	(4) Difference with & without project	(5) Reservoir Use without project 1/	(6) Reservoir Use with project 2/	(7) Difference in use with & without
0	100	100	0	86.0	86.0	0
1	96	99	3	86.4	86.4	0
2	92	98	6	86.8	86.8	0
3	88	97	9	87.2	87.2	0
4	84	96	12	84	87.7	3.7
5	80	95	15	80	88.2	8.2
6	76	94	18	76	88.7	12.7
7	72	93	21	72	89.2	17.2
8	68	92	24	68	89.8	22.8
9	64	91	27	64	90.4	26.4
10	60	90	30	60	90	30.0
11	56	89	33	56	89	33
12	52	88	36	52	88	36
13	48	87	39	48	87	39
14	44	86	42	44	86	42
15	40	85	45	40	85	45
16	36	84	48	36	84	48
17	32	83	51	32	83	51
18	28	82	54	28	82	54
19	24	81	57	24	81	57
20	20	80	60	20	80	60
21	16	79	63	16	79	63
22	12	78	66	12	78	66
23	8	77	69	8	77	69
24	4	76	72	4	76	72
25	0	75	75	0	75	75

1/ Constrained by demand for water during first 4 years then constrained by capacity as demand outstrips supply

2/ Constrained by demand for first 10 years then constrained by capacity as demand outstrips capacity even with the project

3/ This is the measure due to the project, *i.e.*, the difference in use with and without the project

is 100 million cubic meters at present (start of project) and is decreasing by about 4 million cubic meters per year due to siltation. (See Col. 2 of Table 2) Thus, in about four years from the present the estimated capacity of the reservoir *without* the project would just be equal to demand. From then on, the reservoir would not meet the requirements for water from it.

with the project, it is estimated that the rate of siltation can be reduced to about 1 million cubic meters per year. Thus, the reservoir will be able to meet requirements for a longer period of time, although eventually, even with the project, demand for water will outstrip the capacity of the reservoir. This will occur in year 10 (compare Cols. 3 and 6).

A first reaction might be to use the difference between the without and with project capacities as shown in Col. 4 as a measure of benefits. However, this would overstate benefits, since even without the project, the reservoir could satisfy demand for four more years. With or without the project, the benefits would be the same during those first four years and, thus, the benefits due to the project would be zero during that period (years 0 through 3). For the next six years (years 4 through 9) capacity *with* the project would still be above demand. Thus, with the project, the benefits due to the project for this period would be the difference between estimated demand and supply *without* the project, or the demand deficit which would start to be felt in year 4 if the project were not undertaken. (This is the difference between raw items in Cols. 5 and 6) In year 10 demand would start to outstrip supply even *with* the project. Thus, from year 10 and on to the end of the project, the appropriate benefit figures would be the differences in capacity with and without the project (*i.e.*, the difference between Cols. 2 and 3). Using the above approach, the increased water use due to the project is identified and shown for each year (Col. 7 of Table 2).

The figures shown in Cols. 5 and 6 are gross figures which include evaporation from the reservoir, estimated to average about 54 million cubic meters per year. Since the evaporation would be approximately the same with and without the project, there is no need to adjust the figures shown in Col. 7. They represent net increases in *effective* water use.

In addition to the direct benefits associated with increased reservoir capacity, there will be some timber related benefits from the combined production/protection plantings (Table 3). In years 6 through 10 there will be some minor thinning volumes available and in years 17 through 21 there will be final harvest volumes available.

In addition to the water and timber related benefits, the following indirect benefits were identified but not quantified in the study:

(1) Eventual increases in livestock production due to regulation of grazing on watershed lands. (At present, many of the

Table 3. Inputs and outputs--production forest components.

	0	1	2	3	4	5	6	7	8	9	10	11-16	17	18	19	20	21
Hectares planted	174	174	174	174	174								174	174	174	174	174
Thinning harvest																	
ha							174	174	174	174	174						
m^3/ha							20	20	20	20	20						
Total m^3							3480	3480	3480	3480	3480						
Final Harvest																	
ha													174	174	174	174	174
m^3/ha													525	525	525	525	525
Total m^3(1000)													91.3	91.3	91.3	91.3	91.3

pastures are marginal due to overgrazing.) The project would restore these lands.

(2) Aesthetic values will increase as the land is rehabilitated.

(3) Access roads required for protection and other watershed management activities will permit faster and cheaper access by farmers to markets and increased mobility for extension personnel so they can reach more farmers.

(4) The project is expected to result in an increase in water quality in addition to quantity. A reduction in suspended loads carried over the reservoir dam will decrease the need for maintenance on individual irrigation installations.

Valuation of Benefits

Based on studies of crop increases made possible by irrigation, it was estimated that irrigation water flowing out of the reservoir would return a *net* of P2 per cubic meter of water. Since the major portion of the water is used for irrigation, there was no feasible way of placing a value on the water used for domestic purposes, and there is no feasible way of allocating the *increased* water made possible by the project to irrigation and domestic use, it was decided to value the domestic water at the rate used for irrigation, namely P2 per cubic meter. This was recognized to be a conservative estimate. Using this value per cubic meter and the water increase figures in Col. 7 of Table 2, the corresponding annual water related benefits from the project were determined (Row 1 of Table 4).

The wood production benefits were valued at P290 per cubic meter on the stump. This value was a parity price based on the value of imported wood. The parity price was adjusted down by 10 percent to reflect the lower quality of project wood. Total wood production benefits are shown on Line 2 of Table 4.

Other benefits were not valued due to inadequate data or to the inappropriateness of attempting to quantify values, *e.g.*, for the aesthetic benefits.

Comparing Costs and Benefits

As indicated (Line 9 of Table 4), there is a net cost involved in the project for the first four years, after which the value flow turns positive and increases steadily over the life of the project. Using a rate of discount of 12 percent, we arrive at a Net Present Worth (NPW) for the project of some P292 million. The rate of return (ERR) of the project would be well in excess of 50 percent.

Table 4. Value flow table.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
													million of pesos													
BENEFITS																										
1 Irrigation & domestic use	0	0	0	0	7.4	16.4	25.4	34.4	43.6	52.8	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144	150
2 Wood production							1.0	1.0	1.0	1.0	1.0							26	26	26	26	26				
3 Total	0	0	0	0	7.4	16.4	26.4	35.4	46.6	53.8	61	66	72	78	84	90	96	128	134	140	146	152	132	138	144	150
COSTS																										
4 Planting protection forest	3.4	4.5	1.1																							
5 Planting production forest	1.3	1.6	1.6	1.6	1.6	0.3												1.3	1.6	1.6	1.6	1.6	0.3			
6 Fence construction	0.8																									
7 Management costs 1/	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
8 Total	6.5	7.1	3.7	2.6	2.6	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.3	2.6	2.6	2.6	2.6	1.3	1.0	1.0	1.0
9 NET BENEFIT (COST)	(6.5	7.1	3.7	2.6)	4.8	15.1	25.4	34.4	45.6	52.8	60	65	71	77	83	89	95	125.4	131.4	137.4	143.4	149.4	130.7	137	143	149
10 Present Value at 12%	(6.5	6.3	2.9	1.8)	3.0	12.9	12.9	15.6	18.4	19.0	19.3	18.7	18.2	17.6	17	16.3	15.5	18.3	17.1	15.9	14.9	13.8	10.8	10.1	9.4	8.8
11 EPV at 12%	EPV at 12% P292 million																									

1/ Including protection and extension services, maintenance and administration.

The high returns to this project can be explained quite easily. Since the reservoir was already in place and its cost represented "sunk costs," they were not included in the analysis of the project. Thus, the small amount of additional expenditure required for the watershed protection activities (the project) were compared with the returns which actually include the total incremental benefits from the reservoir. Obviously, if one were analyzing a new reservoir project, the situation would be quite different, since the substantial expenditure for the reservoir would have to be added into the cost stream for the project, while the benefits would remain approximately the same.

DISCUSSION OF ISSUES

The two examples presented are representative of the types of economic analyses one encounters for watershed related projects. The following discussion outlines some of the major issues which arise concerning these examples.

Considering Alternative Means for Achieving Project Goals

Project planners should explore alternative means for achieving given project goals. If only one alternative is presented to the decision maker, his only decision is whether to accept or reject it. On the other hand, if information is presented which permits him to look at a range of alternative means for achieving a goal, then he can more thoroughly consider and weigh the implications of different courses of action.

In Example 1, two alternatives to the standard logging approach were considered explicitly in the analysis. If other known alternatives had been available then they should also have been considered. In this case, the objective was to find the lowest cost alternative that met the maximum allowable sediment discharge restriction or constraint. Thus, one should note that costs and benefits for the standard logging approach were used only as a basis for comparison since it was, by definition, an unacceptable alternative due to the fact that it did not meet the constraint. Thus, actually only two alternatives were compared, the buffer strip one and the filter strip one. If others had been available (technically defined) they could very easily be included in the analysis.

The appraisal did not consider alternatives in the case of Example 2. However, there appear to be two which might have been considered. The first is the use of dredging at some future date to maintain reservoir capacity equal to demand. The second is the expansion of the reservoir to increase capacity so it can meet demand even when siltation occurs. In addition, the report on which this example is based did not discuss alternative technologies and scales for project components,

nor did it go into the relative advantages of alternative timings of project activities to more efficiently achieve the goal of the project. Finally, although some of the project components were separable in terms of costs, the analysts did not have information on which to base a separation in terms of benefits. Thus components were not analyzed separately and it was not possible to evaluate alternative *combinations* of project activities to find a more efficient overall solution for meeting the goals.

Determining Project Scope and Context

A major question facing project planners is what to include and what not to include within the scope of a given project.

From a practical point of view, it boils down to a question of where to cut off the endless chain of effects or impacts associated with a given project. The theoretical answer is: "Include all the impacts." The practical answer is: "Include all those impacts which you can identify and which appear to be large enough relative to the direct and immediate impacts to make a difference in the cost and benefit flows." The object of a project evaluation is to generate the information needed to make a sound decision as to whether or not the project has benefits exceeding costs and, if so, whether the benefits exceed the costs by a large enough margin to make it worthwhile to commit scarce resources to the project rather than to some alternative use. If the direct benefits associated with a project are large enough relative to costs to make the project worth undertaking from an economic point of view, then spending a large amount of effort and funds on further analysis of all the various indirect impacts will not be worthwhile. However, if the project is marginally unacceptable, then there is a much stronger case for detailed analysis of indirect impacts. No general guidelines can be put forth here on how to determine the appropriate cutoff for considering indirect impacts. That will depend on each project situation, the knowledge of the project planners and staff specialists, the cost and time involved in generating information on indirect impacts, and the objectives of the institution sponsoring the analysis.

In the case of Example 1, the scope was very narrow, mainly due to the fact that the project involved a very small area and probably had insignificant indirect impacts. The example illustrates well the type of brief, uncomplicated analysis associated with operational decisions. Once this particular situation had been analyzed and the best logging method chosen (the lowest cost method that met the constraint) it is likely that that method was accepted and used for other similar logging situations without further analysis, *i.e.*, this simple analysis served as the basis for developing an operational guideline for logging that says: "In situations of riverside logging, a filter strip system is the cheapest alternative logging system which meets the specified maximum allowable sediment discharge constraint."

In the case of Example 2, the project scope included the major impact elements, with the exception that there was no consideration given to how the project would affect the farmers upstream on the watershed lands who would have to change their operations due to conversion of land to forest or due to curtailment of grazing on critical watershed lands. Similarly, there was no quantitative analysis of the positive impacts on farm economies associated with the improved road network and the increased mobility and availability of extension services. Ideally, these should have been included in the analysis, and one would expect--even without having information on the project background and area--that it would have been possible to provide some more explicit treatment of these impacts.

The question of project scope is closely related to other aspects of project definition. These are: project points of view, cost and benefit identification.

Concerning project points of view, Example 1 can be identified with two: the logging operator (or company involved with logging the area), and the public point of view concerning sediment discharge. In this case, the public point of view has been expressed in terms of the maximum allowable discharge regulation and thus does not need to receive further consideration in the analysis. The logging operator or company point of view (assuming that this is a private entity involved) is really the point of view from which the analysis is carried out, *i.e.*, the question is: "What is the minimum cost we have to incur to achieve the constraint?" If the public sector is doing the logging, the question remains the same from an economic efficiency point of view.

Example 2 is somewhat more complex in terms of points of view. As stated in the text, there are three points of view identified, namely the downstream water users, the upstream land users and the national point of view which incorporates the other two points of view within an overall objective function. The downstream users' point of view defines the scope of the project at that end: the project should be defined broadly enough to include the necessary downstream costs to achieve the benefits accruing to the downstream users. On the other hand, the upstream land users' point of view defines the scope of the project at that end: the project should be defined broadly enough to include those costs and benefits for that group that occur because of the project. As mentioned earlier, there did not appear to be adequate consideration given to this point of view and the associated costs and benefits.

Consideration of points of view helps the analyst in identifying the appropriate scope and in identifying relevant costs and benefits for use in the economic, financial and social analysis for the project. The following two sections discuss cost and benefit identification in terms of economic efficiency analysis.

Identifying Costs

One can specify three main categories of costs involved in watershed projects. These are.

Structures and Work Costs

These include costs of dams, gully plugs, construction of contour furrows or terraces, channel construction or improvement, road relocation, retainer walls, *etc.*, and maintenance of these structures and facilities.

Vegetation Manipulation Costs

These mainly include costs of removal of vegetation and planting and management costs associated with the establishment of new vegetation.

Value of Outputs Foregone

Even eroded or deteriorated lands may be producing values through grazing, subsistence farming, *etc.* These activities may have to be curtailed for a period of time in order to restore land to some higher level of productivity. The value of such production foregone should be included as a project cost. In the case of a protection project, timber harvested per unit area may be reduced due to the introduction of buffer strips along rivers, streams, roads, *etc.* Selective harvest may have to be imposed on steep hillsides which may in turn reduce the present value of harvests. This reduction is a cost.

The first two categories of costs are quite obvious, and both examples treated these in an adequate fashion. The third category--value of outputs foregone--is also relevant to both cases. In Example 1, it can be noted that the analyst treated the value of timber foregone through creation of a buffer strip as a cost. He could also have merely reduced the total benefit figure by this amount, thus treating this value foregone in terms of benefits. Either way would have produced the same result, since the objective was to arrive at the alternative with the highest net return.

In the second example, there were values of outputs foregone from changes in land use that should have been considered but were not, as explained in the previous section. This supports the point made earlier that project scope points of view and cost and benefit identification are closely interrelated. Since the upstream land users' point of view was not adequately defined, the analyst also missed identifying explicitly changes in value of output associated with upstream land use due to restriction of grazing on some lands and shift in land use from agriculture to forestry on other lands.

Identifying Benefits Using the "With and Without" Test

The basic approach suggested for identifying costs and benefits involves use of the "with and without" test. Basically, this means that the analyst asks and answers the question: "What would the situation likely be without the project over the period of years contemplated for the project and what would the situation likely be with the project?"

The particular point to emphasize here is that the "without" project situation is not the same as the present situation for most types of watershed projects. Thus, over time, without the proposed watershed project, soil conditions might deteriorate, erosion might increase, *etc.* The analyst has to make sure that these changes are taken into account (Figure 1). Without the project, conditions would deteriorate until in year n production would have decreased to Y. With the project, it is estimated that production will increase to Z. The point to note here is that *both* Z minus X *and* X minus Y are legitimate benefits to be attributed to the project. Thus, the analyst will not only need to estimate the increase in production which will be possible (*i.e.*, Z-X) but he will also have to make an estimate of the losses which will be avoided (*i.e.*, X-Y). Example 2 illustrates this point.

Application of the "with and without" test also brings out another point related to benefit identification and valuation (which is also illustrated by Example 2). The point is that merely because a project changes some physical dimension in a positive way, this does not necessarily mean that there is a benefit involved. In Example 2, the project starts immediately to reduce the level of siltation in the Sierra reservoir and thereby increases the effective capacity of the reservoir. However, even without the project the level of capacity of the reservoir is in excess of demand and will continue to be so for the next 4 years. Applying the "with and without" test, the analyst can see that consumption of water (the relevant benefit parameter) will remain the same with or without the project for this period. Thus, the benefit (losses avoided) due to the project will be zero during the first four years, or until the capacity of the reservoir *without* the project would have fallen below requirements for water. This point applies more broadly to many different types of watershed projects.

The above point relates to the fact that in an economic efficiency analysis, benefits should be measured in terms of human consumption. Thus, for example, the hydrologist may provide an estimate of metric tons or cubic meters of soil loss that can be avoided by undertaking a given project. But this information is not enough for an economic analysis. In order to value the benefits from the project, such losses avoided have to be translated into a schedule of crop or other consumption losses avoided. Thus, agricultural experts have to come up with a relationship between soil loss and crop production or soil loss and production of some other consumption item. This consumption loss can then be valued and used as the benefit in the economic efficiency analysis.

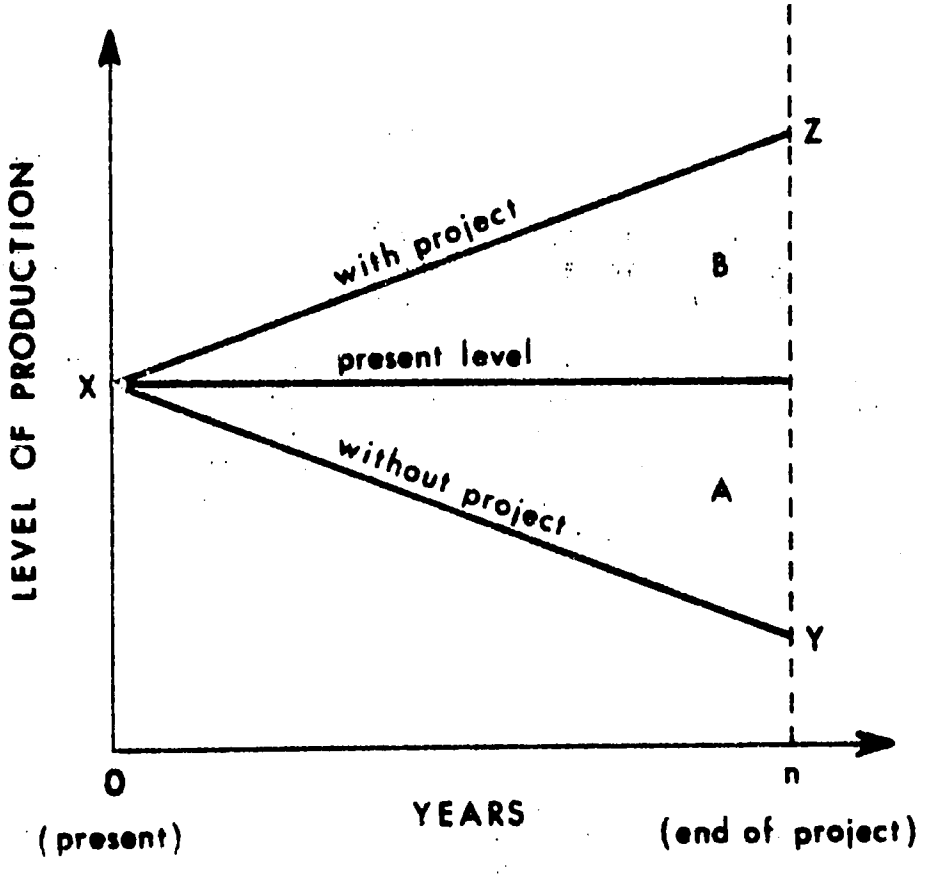


Figure 1. Identifying benefits using the with and without test. A = losses avoided. B = production increases over present level.

Treatment of Benefits and Costs in Multiple Purpose Projects

A point worth mentioning here is the need to use care and caution in identifying costs and benefits associated with multiple purpose projects which include a watershed management element. For exmaple, in some cases, trees planted on denuded lands as part of a watershed protection or restoration project will also be managed for controlled harvest for fuel or other products. In such cases, both types of benefits will have to be included in the analysis. Of course, any associated costs involved in harvest will have to be subtracted, if roadside value for the harvest is used instead of stumpage value. Proper allocation of tree planting costs to the watershed benefits and the wood output benefits is difficult. If timber production is the main objective of the project with watershed protection or restoration as a secondary purpose, then one practical approach would be to allocate the basic costs to the timber objective. Any *additional* costs of vegetation management to achieve the constraint or watershed objective would be allocated to the watershed component of the project. Similarly, in the case of logging road redesign to meet certain watershed constraints or objectives, the equivalent of the minimum road cost to get the timber out would be attributed to the timber element, while the additional costs associated with higher standards to meet the watershed objectives would be allocated to the watershed element.

In the case of a primary purpose watershed project, the cost of tree planting or other activities would be associated with the primary purpose and benefits, while timber benefits would be treated as secondary benefits. As mentioned earlier, it is important in such cases to remember to subtract any secondary *costs* associated with the timber production up to the point of valuation of the timber (*e.g.*, stumpage level, delivered log level, *etc.*).

Timing of Costs and Benefits--Presenting Cost and Benefit Information

Most watershed projects tend to be longer term projects in the sense that the inputs occur over a considerable period of time and the benefits accrue over an even longer period of time. Further, benefits and costs are constantly changing over time.

A main problem is to develop a sound estimate of the timing of the benefits. Restoration projects generally take time to implement. Full productivity is restored slowly in most cases. For example, if trees are planted on a deteriorated watershed, the full protective effect on erosion control will take some time to achieve.

In order to keep track of the project assumptions regarding the build-up to project benefits and costs over time, it is essential to use appropriate physical flow tables and, ultimately, properly designed value flow tables. (Such tables are shown as Tables 3 and 4 in Example 2 in this paper.)

Treatment of Uncertainty

Watershed related projects are particularly subject to great uncertainty in terms of the values of costs and benefits used. Thus, it is important that project appraisals include explicit treatment of uncertainty. Neither of the two examples presented earlier did so, and that is perhaps a typical situation found in most economic appraisals.

There are some simple techniques, such as sensitivity analysis and break-even analysis, which can be applied rather easily and cheaply in most cases. Basically, sensitivity analysis involves varying assumptions concerning the values of key parameters and then testing the sensitivity of the chosen measures of project worth to such changes. A break-even analysis is aimed at identifying values of key parameters which would switch the profitability of a project from acceptable to unacceptable levels.

SUMMARY AND CONCLUSIONS

The present paper presents an overview of some special problems associated with economic analyses of watershed projects. The paper presents some examples and case studies of economic analyses of watershed projects and provides insights into how the analyst can consider watershed elements when they are imposed as constraints on projects that have other goals (*e.g.*, wood production).

A question remains: What lessons and conclusions can be drawn in terms of how the economist can work more effectively with hydrologists, foresters, agronomists and other technical specialists in attempting to provide improved analyses of watershed projects? Based on the discussion in this paper and a review of a number of watershed project appraisals, the following points are relevant in answering this question:

(1) In general, it would appear that the weakest link--or the major problem--in carrying out an appraisal of a watershed project relates to the identification and quantification of the *physical* input-output relationships and the costs and benefits involved. Once costs and benefits have been appropriately *identified* and *quantified* in physical terms, there do not appear to be any *special* problems involved in *valuing* them and comparing them in terms of the measures of project worth commonly used. With regard to this point, it would appear that there are a lot more data available on input-output relationships than is generally thought and used in projects. The problem is that very little has been done to bring this information together in a *practical* form that can be used by the general project planner. Thus *there is a need to spend a lot more time and effort in developing comparative studies and translating highly technical information into practical guidelines that can be used by project planners.*

We fully recognize that the technical specialist and researcher may argue that each case is a different one and that it is impossible to transfer the experience from one situation to another situation. While we agree that there is seldom a situation where experience from one project fits perfectly the conditions for another project, we also suggest that most analysts are dealing with averages and orders of magnitude in their attempts to analyze new projects, particularly in developing countries. They have no choice.

(2) *Economists and the other technical specialists have to interact at all stages in the project planning process,* for the economist cannot carry out an economic analysis unless he has the basic physical input-output information on which to base his analysis. *The economist has to make known at an early stage his information needs.* If he does not, then he can rightly be criticized. However, the primary responsibility for generating the needed information lies squarely on the shoulders of the hydrologist and other technical specialists. This is not within the economist's area of competence. His main responsibility starts when the *appropriate* information has been generated. We stress the word "appropriate" since in a number of cases it has been observed that a great deal of information has been accumulated for a project, but it is not the *right* information for the purposes of quantifying and valuing costs and benefits. Thus, for example, it is not enough to have information on average per hectare soil losses under various conditions. The agronomist and soil experts must make a specific link between soil loss and crop loss, for benefits in this case have to be specified in terms of *consumption* losses avoided. We do not "consume" soil, we consume the products grown on it. In order to value such product losses *avoided* through implementation of a watershed project, we will need to link soil loss to crop production changes. The same argument holds for other types of relationships.

With the above in mind, *we strongly recommend that if an economic analysis is to be carried out for a watershed project, then the economist should be included in the planning process at an early stage so he can make his information needs known.* It may well be that the information he needs cannot readily be generated with available time and funds. In such cases, it will not be possible to carry out an economic analysis that considers both costs and benefits. Rather, the economist will have to stock to a cost-effectiveness analysis or some other types of partial analysis. Or, at the extreme, he will have to state that an economic analysis is not possible, given the present state of knowledge and data availability. However, at this point we should stress again that, in many cases, more information is available than is generally thought and used. It would be well worthwhile to spend some time and effort on bringing together such information in a form that is readily understood by general project planners and decision makers.

CHAPTER XII

INSTITUTIONAL CONSIDERATIONS

INTRODUCTION

In essence, two sets of limitations dictate the degree of success in watershed resources management. First, there are natural limits involving biological, physical and hydrological relatioships, which determine the responses of watershed resources to a given management practice. (To a large extent, the materials presented in this syllabus are directed toward considerations of these natural limits.) Second, institutional limits to watershed resources management, which include legal, social and economic concerns, are every bit as important as natural limits in the development of an effective management strategy. Institutional limits, unlike natural limits, are established by man to meet specific conditions and, therefore, can be modified by man in response to changes in legal, socioeconomic and political situations.

LEGAL CONSIDERATIONS

Perhaps the most important of the institutional limits to watershed resources management involves legal considerations, or limits sanctioned by law. In specific, two primary areas of law must be regarded in the development of watershed resources management strategies: laws which address the ownership and use of water, and laws which regulate the use of land.

Laws of Water Ownership and Use

Individual countries have formulated legal frameworks in which laws of water ownership and use can be made. In general, these legal frameworks have evolved in accordance with the development and subsequent utilization of the water resources in a country. While it is not possible to generalize laws which treat the ownership and use of water, brief mention of the two types of water law applicable to the United States may be of interest.

In the eastern part of the United States, the doctrine of riparian rights, based upon common law, prevails. Under riparian law, all of the owners of land touching the lake or stream course of natural water have the right to use the water. It is important to note that with this right, the use of water by an owner cannot harm the equal right of any other riparian owner; thus, upstream owners must insure that downstream users receive water that is unchanged in quantity, quality and regimen. With the exception of withdrawal for domestic use, any use which reduces the right of other riparian owners is prohibited or requires compensation.

In the arid regions of the western United States, the doctrine of prior appropriation has been developed to regulate water use. This doctrine of water use is different than riparian rights, in that it was developed to guarantee water supplies where land and natural resources are essentially worthless without water. Under prior appropriation, the first to claim a limited water supply had the first right to its use. However, the claimant was restricted to the amount of water he could use beneficially. Any other person was entitled to claim water in excess of a first claimant's use. Claims could be made for successive units of unclaimed water until the supply was exhausted. In times of short water supply, the first claimant had priority to use the limited supply, the second had the next priority, and so on, until the supply was fully appropriated.

A combination of riparian law and prior appropriation is used in some states. Even in some states with the same basic type of water law, details of application and interpretation often vary.

Laws Regulating Land Use

Laws regulating the use of land are also varied, with individual countries formulating those laws appropriate to their needs. Many of these laws are regulatory in nature; others have been designed to establish public policy to insure adequate consideration of natural resource values on watersheds. Again, a brief discussion of some of the more important laws that regulate the use of land in the United States may illustrate the purposes of such laws.

The Forest Preserve Law of New York State is an example of a regulatory law that considers the importance of maintaining water yields from upland areas for use by man. By this law, the Adirondack Park was established in 1892, with the provision that the state-owned lands within the Park be preserved, maintained and cared for as land open (for the health and pleasure of all people) and as forest lands (necessary to the preservation of the important rivers in New York). An amendment in 1894 provided that these state-owned lands should be protected from sale and that the timber on these lands should not be sold, removed or destroyed. Unfortunately, the restrictive nature of this law has prevented subsequent applications of water yield improvement practices involving timber harvesting, a means of land management designed to relieve water

shortages. Therefore, a well-intentioned law has somewhat prevented attainment of the objective for which it was established.

As mentioned above, not all of the laws regulating the use of land are restrictive. Some of these laws have been formulated to set public policy with respect to recognition of natural resource values on watersheds. Two of the most important of these are the "multiple use laws" that set policy for the management of public lands in the United States under the jurisdiction of the Forest Service and the Bureau of Land Management. Though separate laws exist for each agency, these laws establish policy for the management of public lands so that all of the various natural resources involved (water, timber, forage, wildlife, recreation, *etc.*) be considered in the planning effort. However, these laws do not prescribe the means to meet planning goals; these decisions are left to the respective management agencies.

It should be clear that a watershed resources manager must be aware of all laws, both regulatory and permissive, applicable to his particular situation to do a proper job.

SOCIAL CONSIDERATIONS

In essence, legal considerations are "formalized rules" that guide the conduct of watershed resources managers. Less explicit, but equally important, guidelines derived from other cultural features (tradition, religion, folklore, *etc.*) also dictate the activities permitted by, or demanded of, these managers. As with laws, these other social considerations must be reflected in the decision making processes. Failure to do so may lead to adverse reactions that can severely restrict operational freedom.

It is beyond the purpose of this syllabus to describe in depth examples where social considerations determine the options available to watershed resources managers. However, from the flood plains of the Mekong River Basin in Southeast Asia to the fragile desert environments of Northern Africa, situations can be found in which social patterns restrict the implementation of particular management practices. What is important to remember is that to answer questions such as whether or not an erosion abatement practice should be initiated, whether or not a flood control reservoir should be constructed, *etc.*, the cultural features that characterize a society must be considered.

In essence, it becomes the responsibility of a watershed resources manager to function within existing social limitations or, if possible, determine how these limitations can be modified to achieve a desired end. As social constraints are often difficult to assess precisely and because they are not usually susceptible to easy solutions, inclusion of these concerns in a management strategy can easily be ignored; however, to do so would be folly. If sound watershed resources management is not achieved, it may likely be the result of a lack of human understanding rather than a lack of technological ability.

ECONOMIC CONSIDERATIONS

Quite often, watershed resources managers must select the best course of action in implementing a management practice, given a set of alternative plans. The decision of which alternative to select and implement often requires economic considerations. Although a part of the institutional framework, economics involve certain patterns of rational analysis, the techniques of which are well-established in many situations.

No attempt will be made here to provide a review of economic theory and practice. Furthermore, structures in which economic analyses are made are often unique in a given country. Generalizations are difficult. Many of the more general aspects of economic considerations in watershed resources management have been presented elsewhere in this syllabus.

To make an economic assessment of alternative courses of action, three general criteria are usually analyzed to form a basis of choice. These criteria are:

(1) to maximize benefits;

(2) to maximize the returns on an investment; and

(3) to achieve a specified "production goal" at least cost.

It is conceivable that no single course of action will satisfy all criteria at the same time. However, analyses of these criteria should give the decision maker a better understanding of the economic implications of selecting a particular course of action.

To analyze the first two criteria, maximizing the benefits and the returns of an investment, estimates of physical responses to alternative management actions and associated costs of implementation must be known. This information can be obtained from previous experience or, if the course of action is newly prescribed, through simulation techniques. In either case, the source data must be objective and representative of the situation being studied.

To satisfy the third criterion, achieving a specified "production goal" at least cost, goals must be established for various levels of production. These goals are often set through value judgements made by watershed resources managers, coupled with long-range goals derived through the political process.

CHAPTER XIII

MODELING AND SIMULATION TECHNIQUES

INTRODUCTION

Models, regardless of their purpose, are simply representations of how some part of the real-world operates. Models are often essential for the solution of complex problems, but models do not have to be complex to be useful. In fact, models can vary in structure from simple, logical statements, to network diagrams or to sets of detailed mathematical equations. With the advent of present-day electronic computer systems, the development and subsequent application of models has progressed quite rapidly.

In general, models may be *deterministic* or *statistical*. A deterministic model shows a relationship between variables without any random elements: a statistical model presents relationships between variables in terms of probability distributions. Both types of models are useful in watershed resources management.

Simulation techniques are used to reproduce the behavior of a system in the form of a model that closely represents real life. Through simulation, appropriate models are operated to obtain alternative solutions to management problems. Simulation techniques do not necessarily generate optimal solutions, rather they show alternative results that allow an investigator to make a decision on the levels of inputs that are best for a given purpose. Simulation exercises are normally carried out on digital computers, since these exercises usually require much calculation. However, the concept of simulation is not dependent on electronic computers; simpler exercises can be executed without them.

It is not the purpose of this syllabus to introduce the details of modeling and simulation techniques. Rather it is hoped that the reader will gain a general understanding of how these methodologies can be applied to evaluate the potential impacts of alternative watershed resources management.

DEVELOPMENT OF MODELS

Models can be developed from source data in a number of ways. One common approach is through linear regression analysis. With this approach, the *best straight line* through a scatter diagram of source data is calculated, with the independent variable regressed against the dependent variable. The best line will facilitate prediction of the dependent variable from knowledge of the independent variable. Statistically, the line is positioned such that the deviations of actual dependent values at observed independent value points from those predicted by the linear regression equation (when squared and summed) are minimal.

Often, when source data are plotted in a scatter diagram, a straight line is not the appropriate regression model to use. In these instances, curvilinear (nonlinear) functions should be selected to represent the data. Again, regression constants are calculated to minimize the sum of squares of the deviations of observed and predicted dependent values.

In a curve fitting process, it is quite useful to use a regression model that expresses some natural relation between the variables. Sometimes, knowledge of the behavior of the variables used in a relationship allows one to select one regression model over another.

From the multitude of regression models from which to choose, selection of the one to represent a given data set is somewhat of an art. The person making the choice should be aware of the statistical characteristics of various regression models, as this may reduce time and costs required to arrive at an appropriate fit of the data. Knowledge of the following regression models will often suffice for many data sets encountered in watershed resources management: linear, polynomial, logarithmic, semilogarithmic, and periodic. One, or some combination, of these forms will usually fit the source data. However, other regression models may be more appropriate in a specific case.

The assemblage of one or more appropriate *predictive functions*, such as those defined by regression analysis, may allow [illegible] simulation of a given system. Simulation of a system may be used to achieve the following: examination of the response of a system to different inputs and levels of inputs; determination of parameter sensitivity; optimization of system design; observation of the effects of system modification; evaluation of overall performance and suitability; and assessments of subsequent development in a system and collection of any required support data.

With the advent of computer equipment has come the synthesis of computer simulation techniques. Mathematical models that were previously interpreted manually can now be analyzed on a computer, allowing the models to be operated rapidly. Consequently, models can now be increased in complexity and sophistication. This increased speed of

computation facilitates the use of modeling techniques seldom used before due to their excessive time requirements.

In computer simulation modeling, mathematical models of a system are constructed. These models are then translated into a set of instructions in a higher order computer language, such as FORTRAN (FORmula TRANslation). Models expressed in a computer language are entered into a computer and the appropriate descriptive or input data are introduced. Then, through "solutions" of the models, output that predicts system response is obtained.

For ease of operation, many models require input data introduced to them through answers to questions posed to the user by the program. These are termed *interactive models*, in contrast to numbers on cards or assemblages of data records which are input to *batch* or *noninteractive* models.

Computer simulation modeling is widely used in many fields of science, largely due to the savings of time and cost associated with it, and the flexibility it exhibits as an analytic tool.

WATERSHED RESOURCES SIMULATION MODELS

A group of interactive computer simulation models has been developed to aid natural resource managers estimate the impacts of land management practices on ecosystems. The group includes three general modules: WATER for assessing streamflow yield, sedimentation and chemical quality; FLORA for estimating responses of vegetation (*e.g.*, forest overstory, herbaceous understory, *etc.*); and FAUNA for evaluating wildlife habitats, carrying capacities (wild and domestic), and population dynamics (Figure 1). A command system enables users to operate all modules through a common language written in straightforward user terminology. This design provides flexibility in representing management activities by operating selected modules interactively.

The computer simulation models have been designed to be used by resource management professionals at remote locations to obtain reliable predictions using readily available data and modest computer equipment. To date, models have been developed to evaluate the effects of silvicultural practices on forest ecosystems. The methodology is readily adaptable to the severe problems of shifting agriculture, fuelwood harvesting, and forest grazing practices which prevail on the upland watersheds in most of the developing nations. This project will modify and adapt the procedure to these problems.

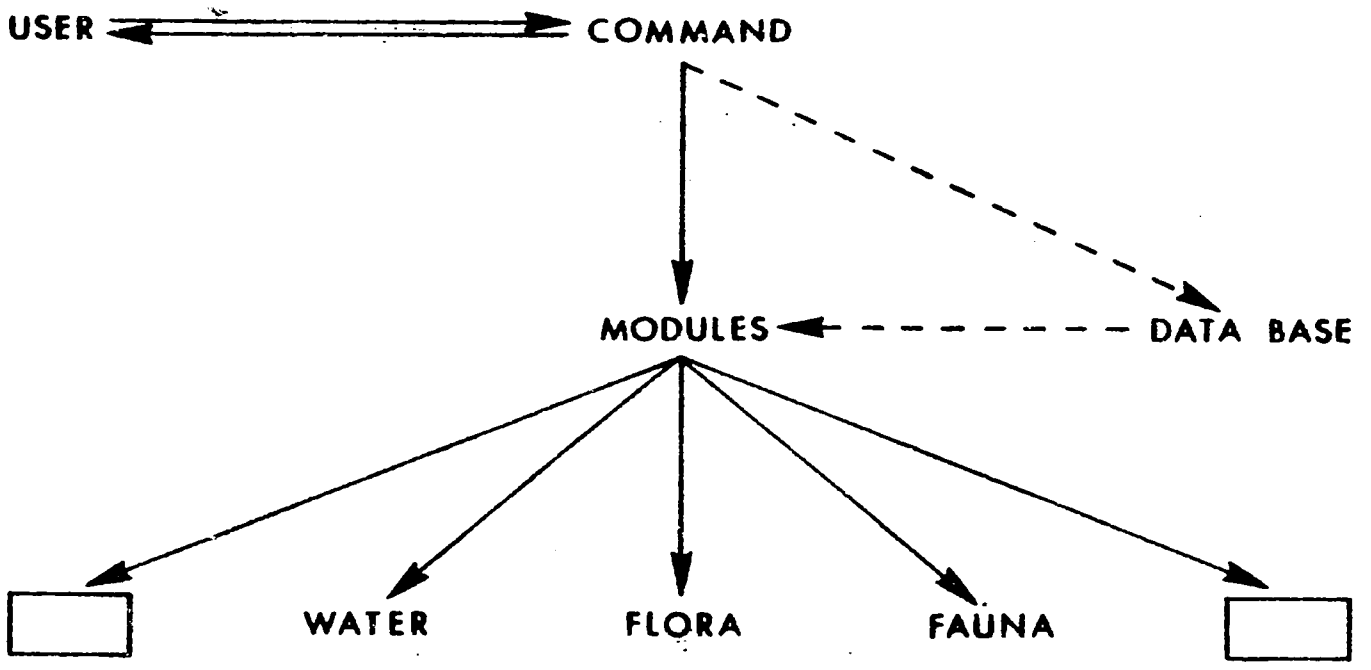


Figure 1. Components of watershed resources simulation models.

WATER MODULE

The WATER module is comprised of generalized components to predict streamflow yield, as well as suspended sediment and chemical quality of streamflow.

Streamflow Yield

The requirement for a small model with simple data needs to represent streamflow yield has led to the development of a model called YIELD (Figure 2). Within YIELD are several water yield prediction components which may be included in other simulation models to predict water yield.

One modular component simulates a water balance on a daily basis Data inputs that are required from the user are few and commonly available. Another component is a water balance model developed to handle various depths and textures of soil, and either coniferous or deciduous forests.

Coupled with these water yield components may be other models, such as those which predict the accumulation and melt of snow. There are currently two models in YIELD which may be utilized to predict water yield from snow. One is a model based on degree day concept of snowmelt. Another is a routine which models intermittent snowpacks and is dependent on four daily input variables: maximum and minimum temperatures, precipitation and shortwave radiation. A general model, which predicts water yield from an area for all times of the year, includes models for both snow and nonsnow conditions. Initializing requires only limited knowledge of watershed and snowpack parameters.

The primary "driving variable" within YIELD is daily precipitation. The primary initialization variable is a measure of forest density conditions, expressed here in terms of basal area. Outputs from the model are values representing daily runoff, change in soil moisture, evapotranspiration, melt and deep seepage. Linkages to other components in the group are used to obtain basal area, while the outputs of daily runoff are, in turn, inputs to the components used to predict sediment and chemical quality.

Sedimentation

Another modular component in WATER, called SED, predicts the amount of suspended sediment in streamflow (Figure 3). This model is structured to offer a choice between two alternative sets of input data requirements. Depending upon the data which are available, the user will select one set to be used. Input data, which either represent forest density conditions or spatial distributions of organic materials

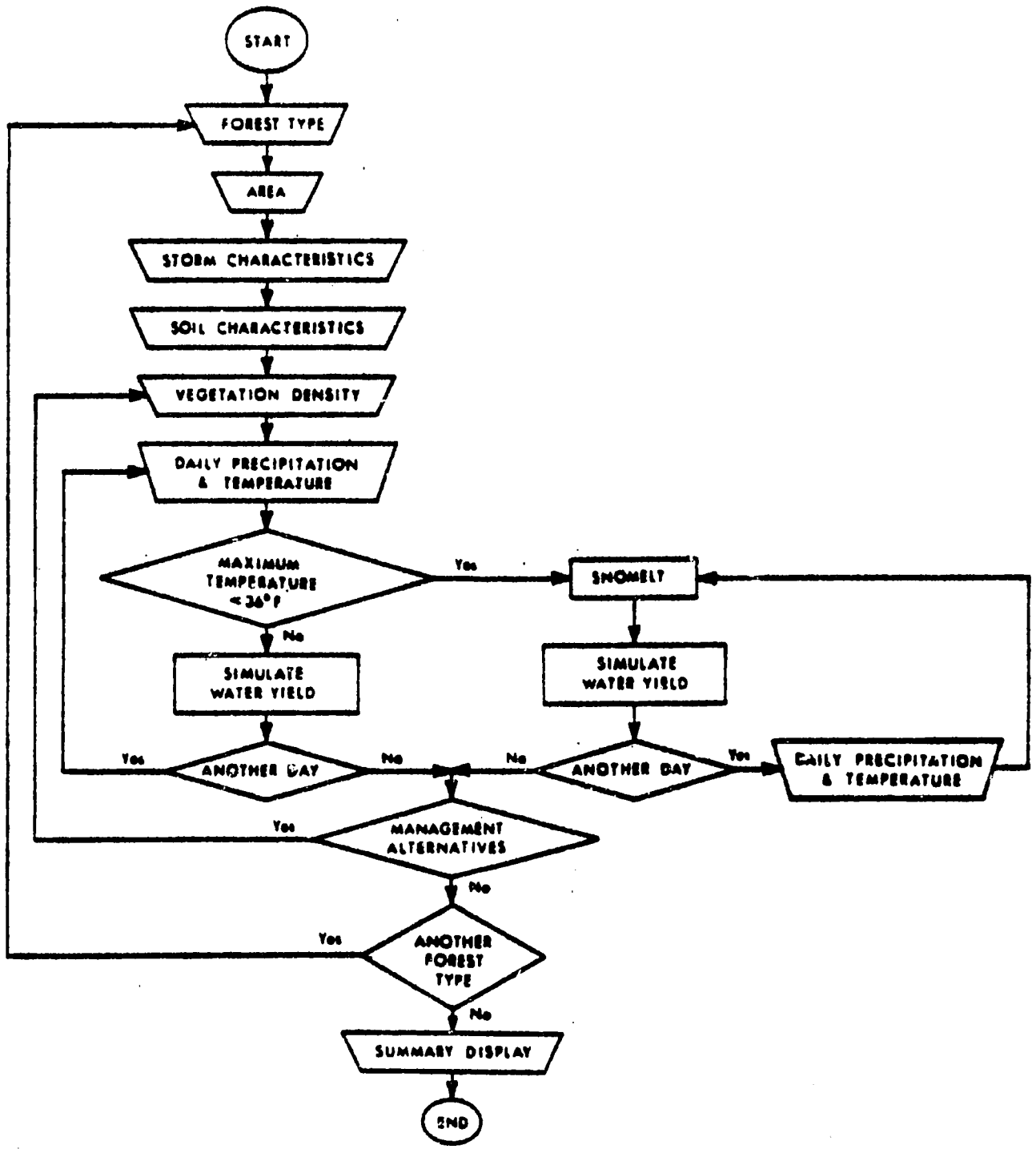


Figure 2. Flowchart of YIELD.

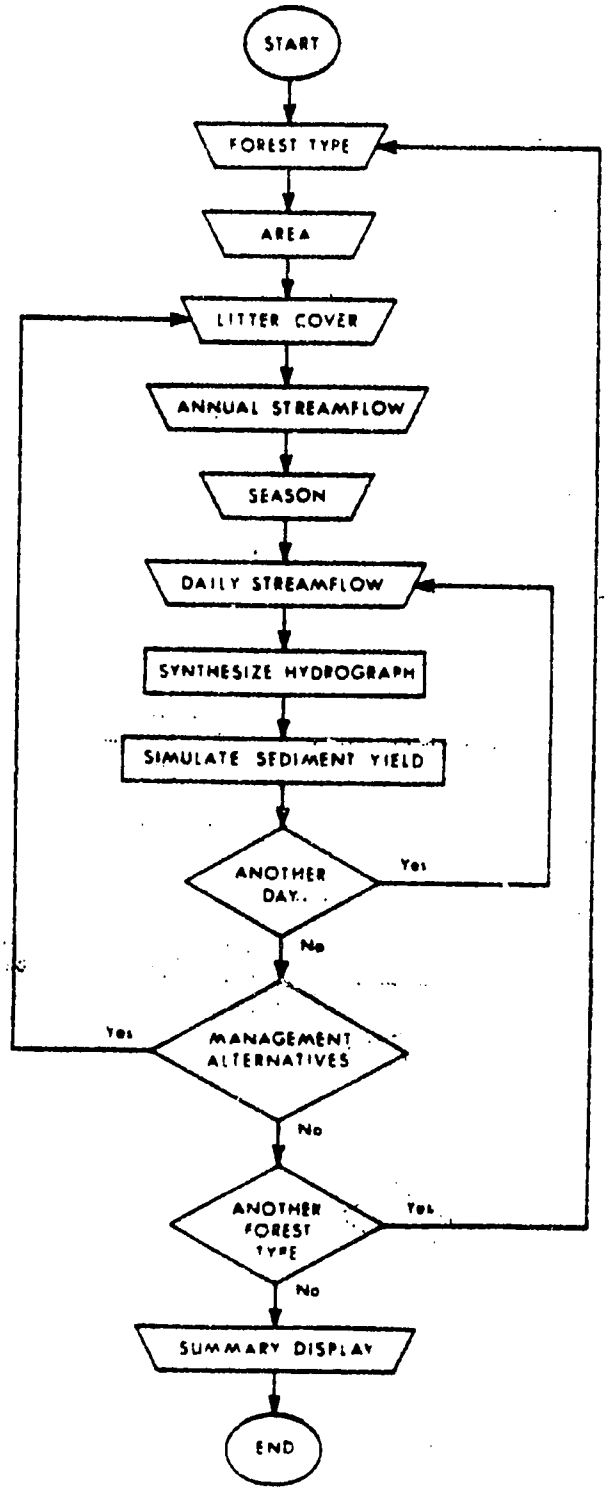


Figure 3. Flowchart of SED.

on a forest floor, are entered directly by the user or generated by other models. The other data input needed, streamflow yield, may be obtained from YIELD. The program outputs the maximum concentration of suspended sediment each day, the maximum streamflow discharge, and the total weight of suspended sediment produced under alternative silvicultural management practices simulated.

Chemical Quality

As an initial attempt at developing a modular component to predict the chemical quality of streamflow, a simulator has been devised to estimate maximum concentrations and daily volumes of selected dissolved chemical constituents. This component of WATER, called CHEM, is specifically aimed at describing the chemical quality of discharges from watersheds in forest ecosystems (Figure 4). The primary "driving variable" is streamflow quantity, the magnitude of which will often vary with alternative silvicultural management practices. This input variable can be entered directly by the user or obtained from outputs from YIELD.

Presently, thirteen constituents are estimated with the CHEM framework: calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), chloride (Cl^{-}), sulfate (SO_4), carbonate (CO_3), bicarbonate (HCO_3), fluoride (F^{-}), nitrate (NO_3^{-}), phosphate (PO_4), total soluble salts, hydrogen ion (*pH*), and conductivity. Efforts are underway to include other water quality parameters, such as heavy metals (Zn, Fe, Cu, Pd, Cd, *etc.*) and dissolved oxygen.

FLORA MODULE

The FLORA module consists of computer simulators that predict the growth, yield, and diversity of forest overstories; the production and (to some extent) composition of herbaceous understories, and the development and accumulation of organic material on the forest floor.

Forest Overstories

The component simulators designed to estimate the growth and yield of forest overstories generally fall into two categories: first, models that are broadly structured to represent a wide variety of tree species (or tree species groups); and second, models that are specifically structured to represent a particular tree species (or tree species group).

Within the first category, three simulators have been developed, or are presently under development. These simulators, called TREE, STAND and FOREST will estimate the growth and yield of an individual

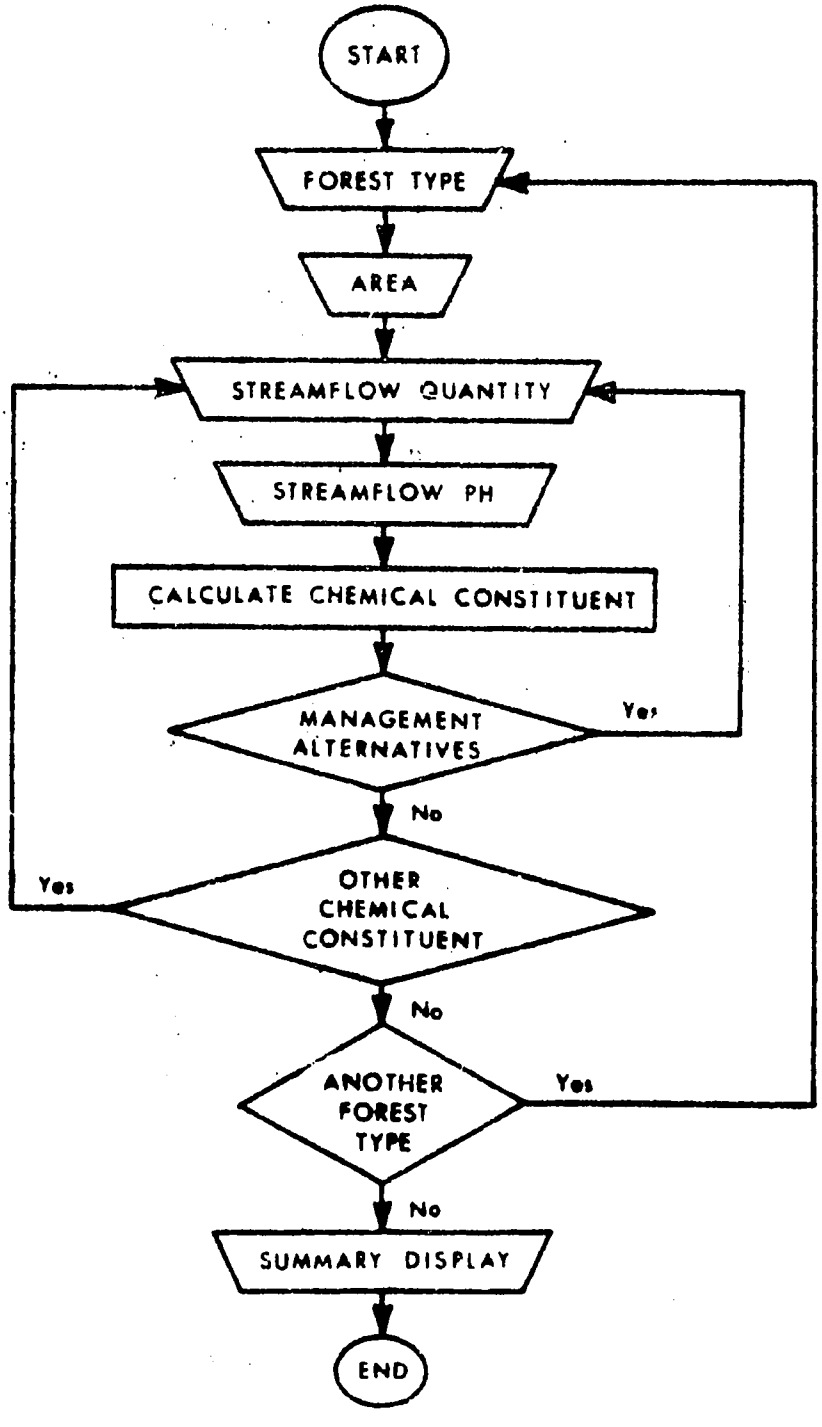


Figure 4. Flowchart of CHEM.

tree, a forest stand (by definition, a community of trees possessing sufficient uniformity in composition, age, spatial arrangement, or condition to be distinguishable from adjacent communities), and an entire forest property, respectively.

TREE is an interactive modification of a computer model that simulates the growth of an individual tree from knowledge of diameter, height and volume. In addition, one can easily see how individual tree growth is influenced by tree size and age. While this is not a new concept in forestry, the approach exemplified by TREE differs from that of others who have employed mathematical formulas to simulate tree growth phenomena.

The primary reason for including TREE in the group of models is to analyze changes in tree growth influenced by alternative silvicultural management practices. Such assessments furnish direct insight to the understanding of the dynamics of even-aged and uneven-aged forest stand developments.

STAND, is structured to estimate the growth and yield of forest stands comprised of single tree species or a mixture of tree species (Figure 5). In essence, the mensurational input to STAND involves the simplification of stand projection methods applicable to uneven-aged forest stands.

The simulation objective of STAND is to predict the growth (both gross and net) and yield of forest stands prior to and, if appropriate, following the implementation of various silvicultural management practices. Inputs to this modular component include a listing of trees per hectare by size class, and associated diameter growth rates and volume expressions. As management is prescribed to change these inputs, posttreatment growth and yield are interactively generated. Silvicultural management practices that can be simulated within STAND represent an array of viable options for the different forest stand compositions being considered.

Outputs derived from STAND, including summaries of basal area levels through time prior to and following a management redirection, are readily used by other modular components in FLORA and others. As the manipulation of forest overstories is a primary management activity affecting many aspects of an ecosystem, such interfaces among modular components are critical to realistic simulation of an ecosystem's overall behavior.

FOREST is being assembled as an interactive version of other general computer models that have been structured to simulate the growth and yield of single or mixed tree species, and even-aged or uneven-aged forest properties. This modular component addresses topics of forest growth and yield such as seed production, dispersal and germination, as well as competition, mortality and stocking manipulation by man.

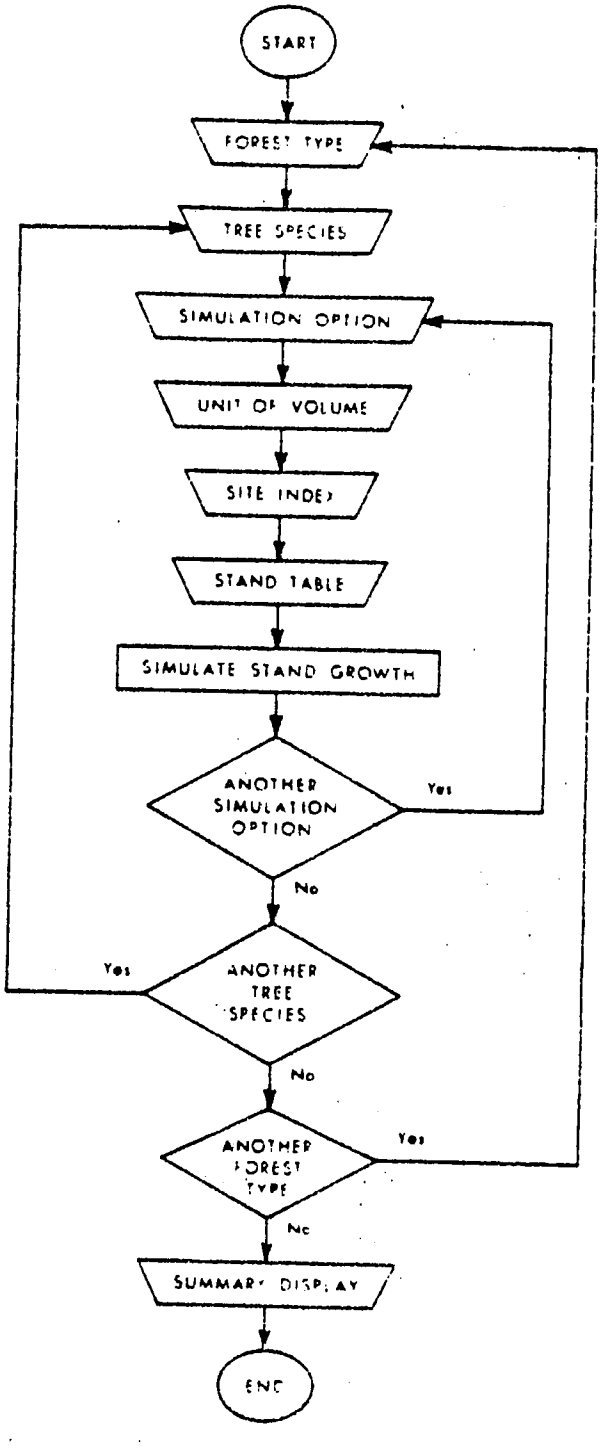


Figure 5. Flowchart of STAND.

In concept, inputs to FOREST include a set of real or generated tree locations and associated tree characteristics. Each tree is then grown for a specified number of projection periods, based on potential growth functions modified by competition measures synthesized from relative tree size, crowding and shade tolerance. Mortality is generated conjecturally and depends, in part, upon the competitive status of the individual trees. Reproduction is represented by simulating seed production and germination and, if appropriate, sprout production from the forest overstory. Numerous site alterations and harvesting options can be specified as the forest develops over time. Outputs from FOREST will be in the form of periodic tables displaying data on stocking, mortality and yield for an array of primary wood products and total biomass.

There are many examples of simulators designed to estimate the growth and yield of a particular tree species (or tree species group). In using these models, users generally initialize the model by selecting prestored stand tables, by entering tallies from point sample inventories, or by entering the number of trees per hectare by size class. Then, harvests can be specified at intervals through a sequence of questions and answers to meet a particular management objective.

In addition to computer simulators that predict growth and yield, a modular component is under development in FLORA to estimate the diversity of (and within) forest overstories. This component, called DIVER, has two primary options with respect to manipulations of forest overstories: clearing and thinning. The clearing option derives a diversity index that represents the edge irregularity of a clearing (or other type of forest opening). The thinning option calculates a diversity index that represents the proportion of an area that is stocked to different forest density levels.

The diversity index derived by the clearing option is based on a previously reported analytical model that quantifies wildlife habitat. The geometric shape with the greatest area and the least perimeter or edge is a circle. If the ratio of circumference to area of a circle is arbitrarily given in index of 1, a formula can be used to compute an index for comparison of any area with a circle. The higher the index value is above 1, the greater the irregularity, and, by definition within DIVER, the greater the diversity.

In the thinning option, the calculated diversity index is obtained through solutions of forest stocking equations that are developed for the particular forest type and size class distribution being evaluated. Stocking equations define curves which describe the proportion of a forest area (the dependent variable, expressed in percent) that is stocked to minimum basal area levels (the independent variable). Values that represent minimum basal area levels for alternative silvicultural management practices are the required inputs to the simulator.

Herbaceous Understories

A computer simulator has been structured within the FLORA module to estimate herbage (all understory species) production from knowledge of forest overstory parameters, precipitation amount, and if appropriate, time since the implementation of a silvicultural management practice. Depending upon the particular simulation objective, a user may operate this component, called UNDER, individually or as part of another model (Figure 6). In the latter instance, outputs from other modular components in FLORA and other modules in the group are utilized as inputs. An interactive language is used in either case.

Many of the previous attempts at developing computer simulation techniques to estimate herbage production have been dependent, primarily, on input variables depicting forest density conditions. While this approach remains viable and has been utilized in several UNDER subroutines, the herbage production simulator will eventually also utilize knowledge of forest overstory growth. Estimates of herbage production that are based on knowledge of this variable appear consistently of higher precision than those based on knowledge of forest density alone.

Subsequent additions to UNDER will facilitate partitioning of simulated herbage production into (at least) three categories: grasses and grasslike plants, forbs and half-shrubs, and shrubs.

Organic Material

Two modular components describe the development, accumulation and distribution of organic material on a forest floor. One component, referred to as FLOOR, estimates the accumulation of tree leaves and needles (by layer of decomposition) on a forest floor at a point-in-time, the rate of accumulation with respect to time, and the spatial distribution in space. Other components called CROWN and BOLE predict the magnitude of tree crown and branchwood accumulation, respectively, associated with alternative silvicultural management practices being simulated. These models may be executed individually or as part of other models.

FLOOR is an interactive component which outputs parameters that describe the development, accumulation and distribution of tree needles and leaves as a function of forest density levels (usually expressed as basal area) for different management practices (Figure 7). In terms of accumulation at a point-in-time, the following individual layers are considered: litter, fermentation, humus and total. To date, the rate of litter accumulation is the only FLOOR simulation output that provides a time dimension. Regarding spatial distribution, only the total forest floor (all layers) is represented.

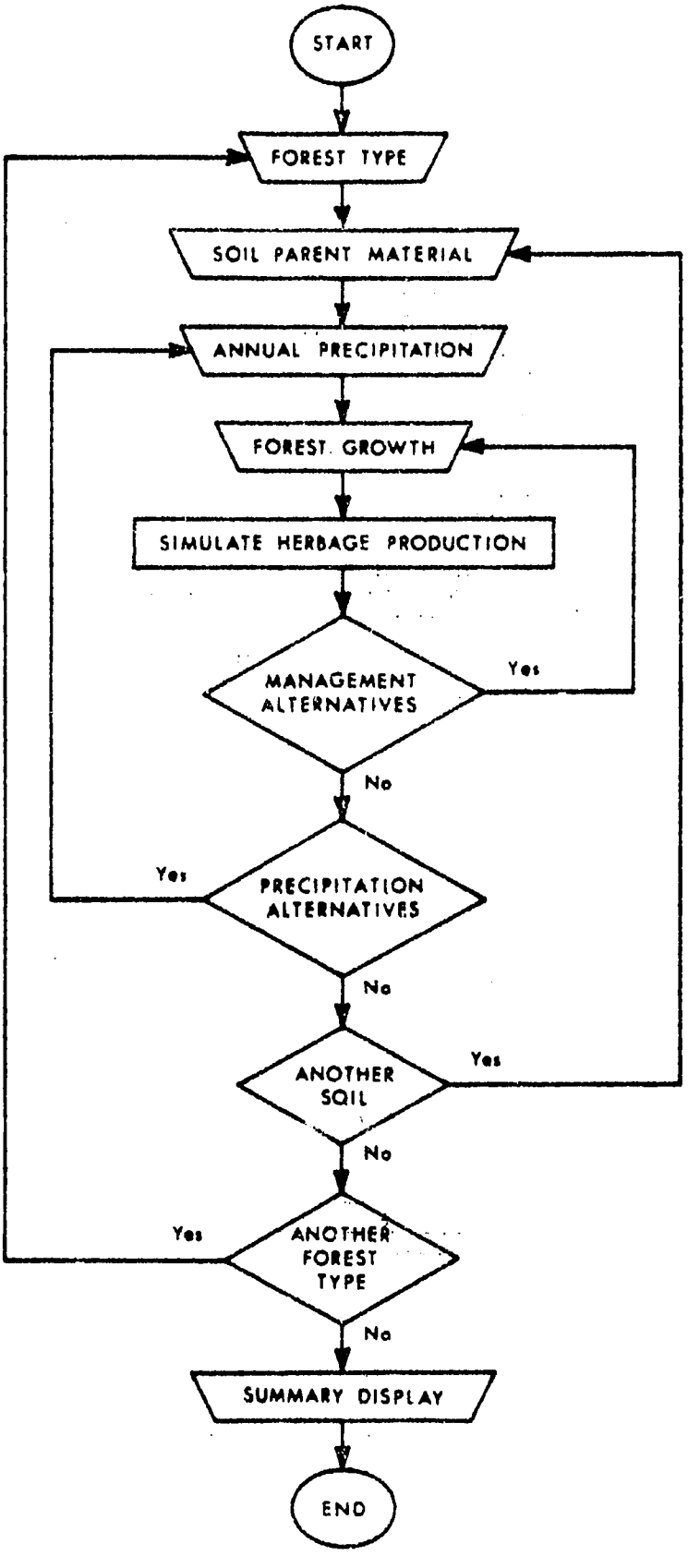


Figure 6. Flowchart of UNDER.

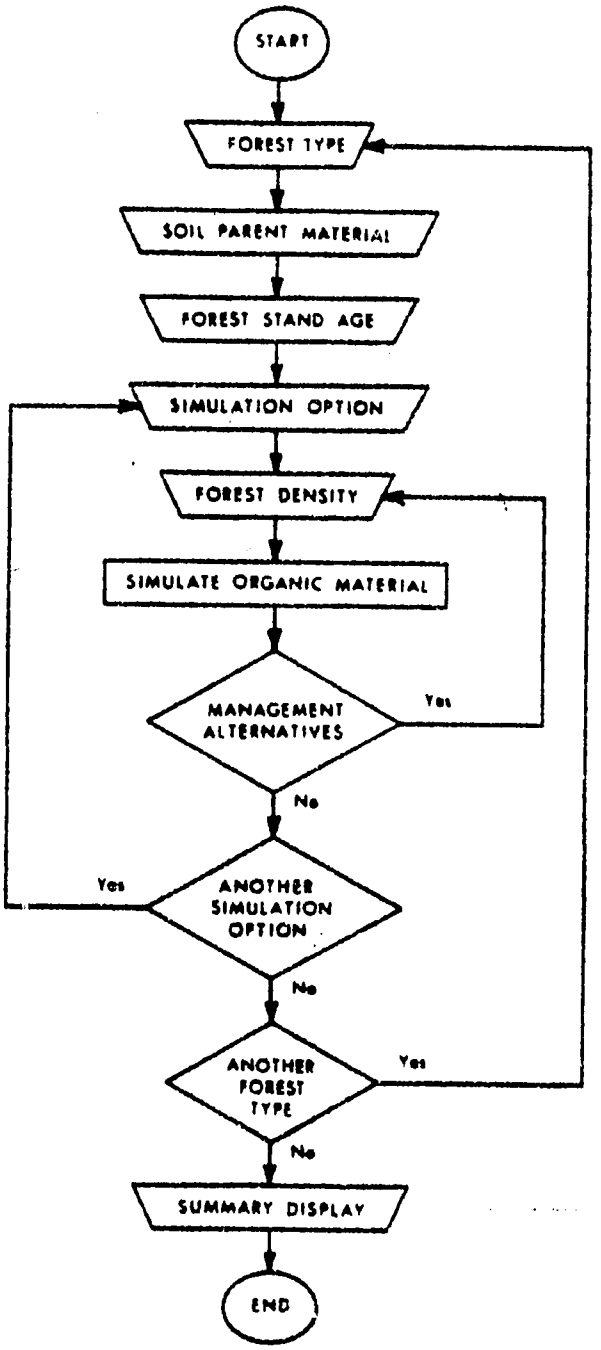


Figure 7. Flowchart of FLOOR.

CROWN and BOLE are intended to present knowledge of tree crown and branchwood volumes by area for a given forest stand prior to the implementation of a silvicultural management practice. These volumes provide a reference point to assess the quantity of tree crowns and branchwood that will occur as logging residues on the forest floor after a management treatment.

FAUNA MODULE

The FAUNA module includes interactive computer simulators that describe the habitat quality for a variety of animal species, the potential animal carrying capacity of an area, and the dynamics of selected animal populations within specific ecosystem situations.

Habitat Assessment

Simulators that assess habitat quality fall into two categories: models broadly structured to represent a variety of animal species (including game, nongame and domestic) and models specifically structured to represent a particular animal species.

An example of a modular component in the first category is HABRAN (HABitat RANking) (Figure 8). In essence, this component synthesizes ranked response predictions which, in turn, can be summarized and arrayed as pattern recognition models. Within HABRAN, animal habitats are assigned numerical values ranging from 0 to 10, with habitat quality in an ecosystem increasing with numerical value. The specific assignment of these values is achieved through analyses of functions that relate habitat preference to readily available inventory-prediction parameters, the magnitude of which are altered by alternative silvicultural management practices. By comparing numerical habitat quality values for existing conditions with those predicted for habitats modified by management redirection, either an increase (+), a decrease (-), or no change (0) is determined. Then, a matrix of pluses, minuses and zeros arrayed for all animal habitats and management alternatives of interest (by definition, a pattern recognition model) can be displayed to provide insight into comparative management impacts.

The HABRAN component of the FAUNA module is, in a sense, a first-level-of-interest assessment of the impacts of alternative silvicultural management practices. In many instances, this sort of analysis may be all that is required. However, if estimates of carrying capacities and animal distributions are needed, other modular components may be called into play.

Many simulators exist to represent habitat quality of a particular animal species. In most instances, changes in food, cover, and diversity resulting from the implementation of a silvicultural management practice are used to simulate changes in the rating of habitat quality.

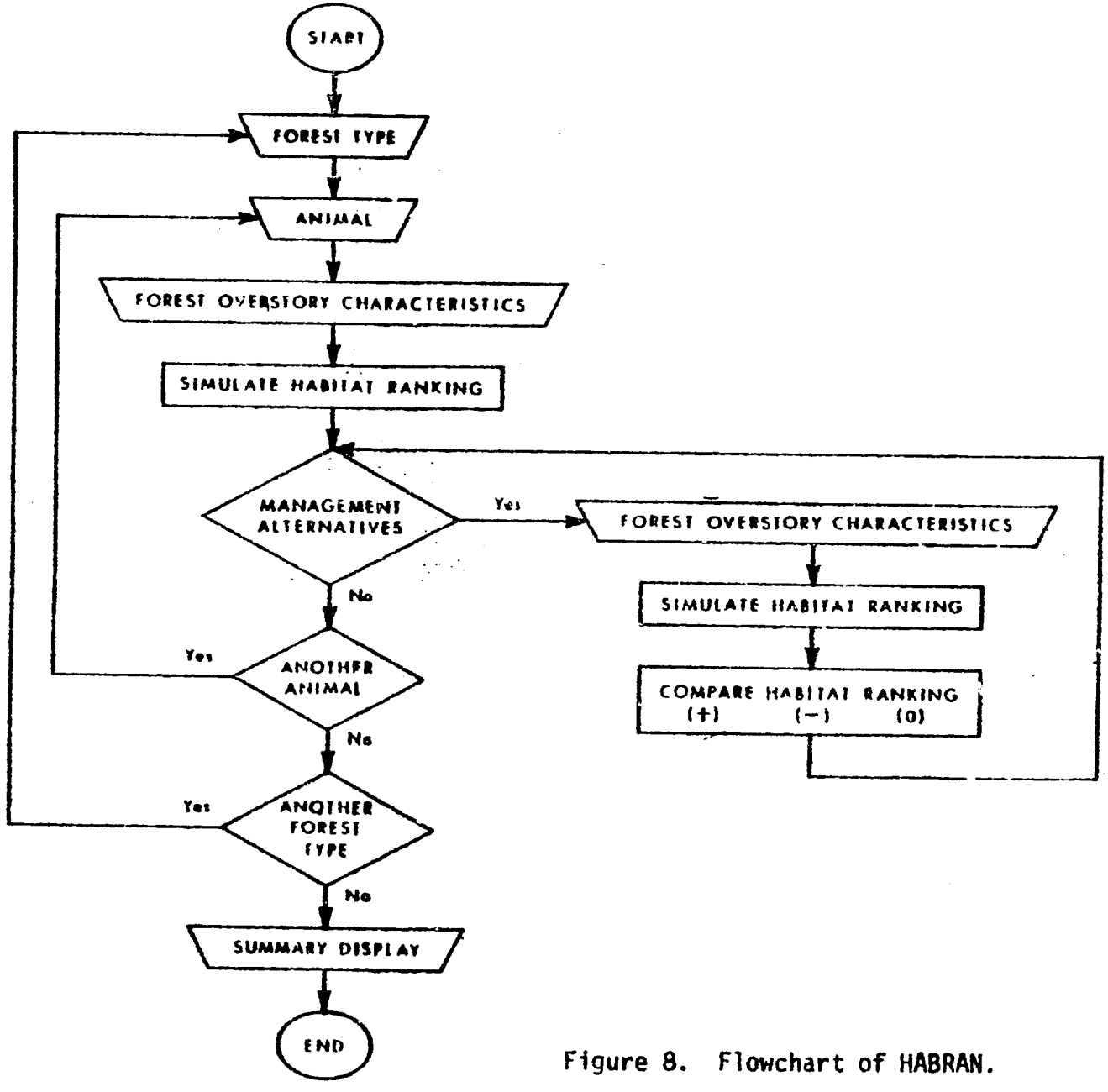


Figure 8. Flowchart of HABRAN.

Animal Carrying Capacity

In the modular component that has been structured to predict animal carrying capacity, referred to as CARRY, herbage production (entered as a direct input by the user or obtained from the herbage production simulator) is partitioned into usable forage for domestic livestock and wildlife species (Figure 9). Appropriate plant species to include in each forage component were ascertained from existing literature relevant to the preferred foods for these animals, along with information about appropriate or proper utilization percentages.

It has been assumed that the proper use factors to be applied in CARRY will be introduced by the user in an attempt to meet specific management objectives. It may be necessary, for example, to reduce a proper use factor on a particular range that has been subjected to prolonged overgrazing pressures. As baseline information relating to proper use factors increases, the ability to predict carrying capacities will improve accordingly.

The amount of usable forage required per animal unit month (AUM) for the animal species being considered is input directly by the user.

With respect to the number of months that domestic livestock and wildlife species will actually be consuming forage on any tract of rangeland, this value is quite variable depending, in part, upon weather factors that characterize the particular ecosystem and year of simulation (time of snowfall in the autumn, time of snowpack disappearance in the spring, *etc.*). At best, only estimates based on local knowledge of average situations in the long run can be made. However, to provide a point-of-departure in utilizing CARRY, specific forage consumption time durations have been selected. It should be emphasized that the user can readily override these default duration values to more accurately reflect local conditions if better information is available.

At this time, relatively little can be said about possible constraints that may affect the distribution of animals that are considered by CARRY. While it is known that various factors may restrict (or at least modify) animal movement, explicit identification and subsequent quantification are currently difficult. Conceivably, portions of a tract may be eliminated from use because of movement constraints (physiography, fences, *etc.*), which may necessitate appropriate reductions in animal stocking rates.

The effects of alternative silvicultural mangement practices on animal carrying capacities of a given area are primarily evaluated through predictions of changes in the level of herbage production. As forest overstories are reduced in density, a corresponding increase in herbage production commonly occurs. The increased production of herbage is then partitioned into forage which, in turn, is converted into AUM values that are distributed over the range.

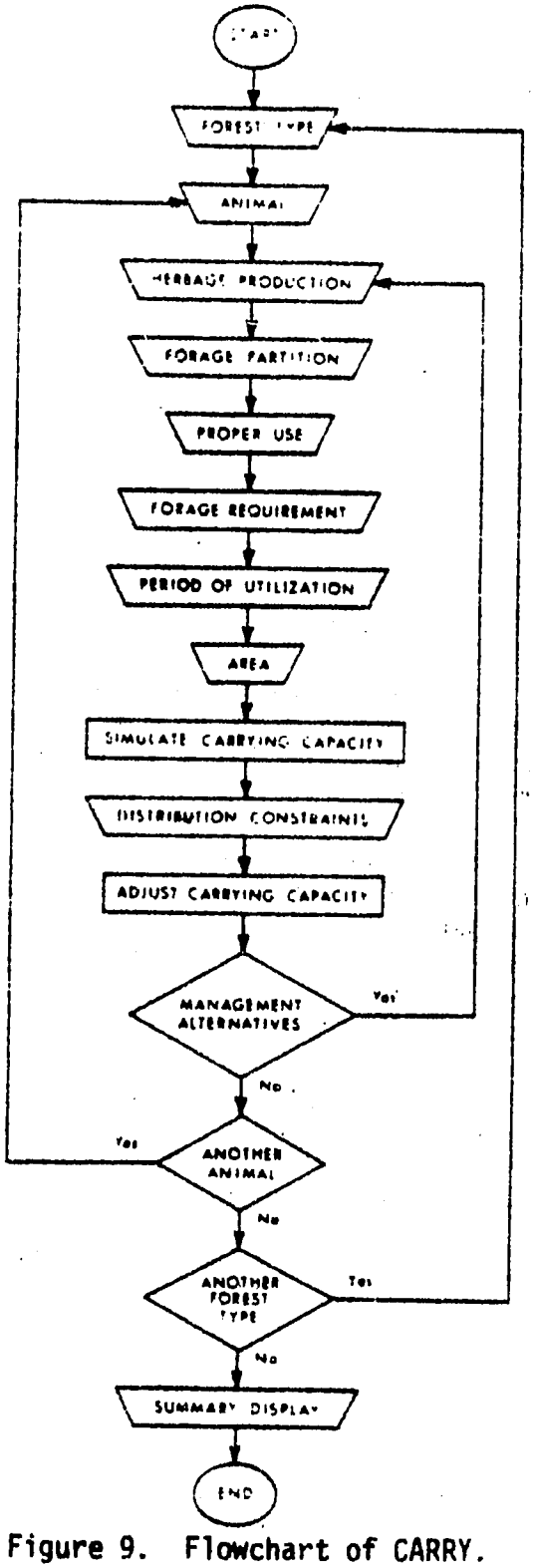


Figure 9. Flowchart of CARRY.

Population Dynamics

Although still in the formulative stage, an interactive population dynamics model, called DYNAM, is intended to predict the impacts of silvicultural management practices on the reproduction, growth, mortality, and structure of selected animal populations. More specifically, this modular component is to predict the manner by which a given population, specified by the user as reflecting existing conditions within an ecosystem, will respond to changes in food, cover and diversity that are attributed to management redirection.

THE COMMAND SYSTEM

The command system of the group of watershed resources simulators is largely dispersed into the respective modules. In fact, there is little evidence of a main command system in the overall operation of the group of models. Initial selection of the modules and components to be used and subsequent assignment of default values needed in the operation are handled by the command system. Also, timing and sequencing of operation of individual modular components are carried out by the system. Additionally, summary displays (tables, graphs, maps, *etc.*) of the simulation results are achieved through the command system.

All of the modules in the group have been structured to have three modes of operation: initialization, cycling in time and summarization. In the initialization mode, all needed data are either introduced directly by the user or entered from stored files. The second mode of operation is a cycling in time of the processes being simulated (daily streamflow, yearly forest growth, *etc.*). Finally, the third mode of operation is summary and, if appropriate, other activities at the end of a simulation problem.

When a user informs the command system which modular components are to be operated, he also states when they are to be used in the simulation problem. For example, the component CHEM may be required to operate only in the fifth year of simulation, while all other components may be operated every year. The command system stores this directive and acts accordingly.

The entire system is designed to operate with minimal input data. Default values are offered with nearly all of the interactive questions posed so that, whether or not the user has the required data or reason for overriding the default values, simulation can still proceed. Similarly, if a module or component is not directly included in a simulation problem, default values are loaded into the system to provide estimates of needed parameters normally obtained as output from the unused modular components.

After the system cycles through the specified number of simulation years, individual models are entered into the summary mode of operation. Any needed computations to allow display summaries of the operation to be output are done at this point. Output summaries may be obtained either on a local computer terminal or at a central computer location. These summaries may be brief or detailed, depending upon the user's need. In general, the parameters shown are representative of the various modules and components used in the problem. If a component is not used and default data are utilized, the parameters for the unused component will not alter the display.

FUTURE DIRECTIONS

Future work in the development of computer simulation models designed to assess the inputs of land management practices will follow two directions: synthesis of other modules and components, and extrapolation of the interactive system into other forest and range ecosystems.

While in various stages of development, several other modules and components are recognized as part of the group of computer models. For example, to facilitate overall planning with respect to a particular simulation problem, a module called PLAN is being structured to generate a PERT network of activities necessary to reach an objective. Another module, referred to as AREA, calculates the adjusted surface area of management units within an ecosystem, correcting for sloping or broken terrain. As knowledge of site quality is required as input to some modular components in the group, a module called SITE is under development to generate site quality directly (through estimation of site indices) or indirectly (through analyses of plant indicators, physiography, soil surveys, *etc.*). Outputs from this module will describe productivity potentials for both forest overstories and herbaceous understories.

To evaluate depth and quality of view within an ecosystem in terms of current and, if appropriate, anticipated conditions, a module named SEEN is being evaluated as part of the group. Another module, called FIRE, predicts the probability occurrence of wildfires of given intensities from knowledge of fuel properties and sequencing of meteorological events; this module also estimates the impacts of fire on an ecosystem. SNOW is a module that interactively simulates the dynamics of snow pack accumulation and melt within forests comprised of trees in varying spatial arrangements. ROAD allows for predictions of sediment loads resulting from the construction of roads with alternative design criteria.

To further aid managers and planners in analyzing land use alternatives, a module that facilitates the development and subsequent display of basic production economics models (production functions, product-product relationships, *etc.*) has been synthesized. This module, referred to as ECON, also includes components that represent various LP and Goal programming techniques. Other modules and components will be considered

within the group to more completely provide socio-economic simulation capabilities.

The primary emphasis in the initial developmental work on the group of models has been placed on simulation within forest ecosystems in the United States. Current plans are to extend this work into other forests and, as the need arises, into range and arid ecosystems.

Many of the modular components in the group that have been synthesized only require "localization" of coefficients for use in other ecosystems. Other models, particularly those structured to represent an explicit plant or animal species, are only appropriate for use in simulating those ecosystems in which they occur and must be replaced by other species-specific models that characterize other ecosystems under consideration. However, even here, replacement is relatively easy within the overall structure of the command system.

CHAPTER XIV

ENVIRONMENTAL MONITORING

INTRODUCTION

Understanding the impacts of watershed resources management policies and providing significant input in formulating more effective watershed resources policies requires long-term environmental monitoring. A program of long-term environmental monitoring must address basic scientific questions and ecosystem functions as well as policy, human health, and safety issues. For the purposes of this syllabus, reference to environmental monitoring shall mean the process by which selected environmental variables are systematically observed, measured, and interpreted for defined purposes. Such purposes will be directed toward describing the state of an environment and identifying trends.

NEED FOR LONG-TERM MONITORING

In 1971, the Scientific Committee on Protection of the Environment (SCOPE) reported that the imperfectly understood cause and effect relations and environmental budgets of many substances had given rise to important questions relating to the complex interactions between man and his bio-environment. Furthermore, it was recommended that a program be initiated to obtain a picture of how all of these processes occur, the rates at which they take place, the timing and nature of equilibrium situations, and their effects on man and the life-support systems of air, water, soils, climate, and biota. Also, a need to develop mathematical simulation models of environmental interactions that can predict the results expected from varying types and degrees of remedial actions was recognized. The capability of advance-warning before an adverse situation becomes irreversible is absolutely essential.

The United Nations Environment Program (UNEP) stated in 1977 that an ecosystem is best considered as a total concept with the natural resources its components. Soils, air, water, animals, plants, and other genetic resources combine to form ecosystems in which the fate of individual resources is bound with that of others and of the ecosystem as a whole. Problems in an ecosystem can be examined within the context of the ecosystem

itself or by considering natural resources occurring widely in different ecosystems. At the same time, the intricacies of ecosystem functions demand a specific and quantitative approach to the solution of problems brought about by imbalances in the systems.

In general, timely and accurate data from long-term monitoring projects are invaluable to agencies managing their lands within certain guidelines. Yet, seldom is there sufficient knowledge about an ecosystem to totally assess the impacts that a given land management practice may exert. For example, fire was long considered contrary to the concept of conserving an ecosystem. However, after long years of scientific study, it is now understood that fire can play a critical role in ecological succession and, in some cases, should be allowed to run its natural course.

There is an increasing need to know the effects that actions such as timber harvesting, livestock grazing, or controlled burning will have on future uses of land. Long-term environmental monitoring clearly provides one solution to better land management and is in the interest of any country's future.

Recently, a framework for international long-term environmental monitoring programs was identified by UNESCO's Man and Biosphere (MAB) Program. Under the monitoring framework established by MAB, countries are able to emphasize nationally important subject areas and implement monitoring programs at a level necessary for sound decision making.

In Scandinavia, scientists have long monitored atmospheric deposition in their countries to determine the effects of decreasing *p*H levels and to better understand long-range atmospheric transport. The World Meteorological Organization (WMO) has a global network of weather stations that monitor atmospheric conditions, including *p*H levels. Recently, the United States has begun to monitor atmospheric depositions due to a concern over the apparent trend toward a lower *p*H in northeastern and northcentral regions of the country. Within the framework of the MAB environmental monitoring program, a "chemical" monitoring effort has been initiated to provide data on which to base air pollution control laws and to better understand the issues of atmospheric transport.

Recognition is made of the fact that some countries may have minimal interest in atmospheric deposition, while being quite concerned about other facets of their environment. Under such conditions, individual countries may choose to emphasize subject areas that help them better understand and quantify the interactions between man and his environment.

DATA MANAGEMENT

Information and data exchange are obvious requirements if the results of an environmental monitoring program are to have wide benefit. Numerous information and data exchange systems exist. For example, UNESCO uses a computer-based system to provide continuously updated information relating to MAB studies in many countries. UNEP uses national

focal points in its International Referral System (IRS) to link the source of information with requests from throughout the world.

Before a long-term environmental monitoring program is begun, basic questions regarding data management must be resolved. Determination of user groups, hierarchical options, analytical methods, bibliographic files, *etc.* must be addressed. Proper management of large masses of source data in itself can contribute to scientific advances, as happened in several instances with the International Biological Program (IBP). There is a rapidly growing trend in the scientific community toward reanalyzing data using newer concepts. Therefore, the availability of monitoring data, both historical and current, plays a critical role in filling important data gaps and allows other scientists to broaden their monitoring efforts.

Information and data exchange systems have reached a point such that they can be designed 80 to 100 percent complete in terms of storage, access, quality control, analytical capabilities, and editing prior to entry of the first data item. With proper design, data coming from 100 monitoring stations to a central facility with terminals or mini-computers at the monitoring site would require no more personnel at the facility than that coming from 10 stations.

IMPLEMENTING A LONG-TERM ENVIRONMENTAL MONITORING PROGRAM

Using the long-term environmental monitoring framework established by MAP as a guideline, a philosophy upon which a monitoring program should be developed consists of three fundamental precepts. First, land managers and policy makers would be in an improved decision making position if better basic information were available to them on a timely basis. Second, a great deal stands to be accomplished through increased cooperation between the many organizations which conduct ecological monitoring and research activities. Finally, there are processes occurring in the natural environment which can only be understood through an examination of long-term data sets.

The underlying theme behind development of a long-term monitoring program is to determine a process which provides increasingly sophisticated amounts of information relating to the interaction and sensitivity of an ecosystem. Therefore, a "state-of-knowledge" is necessary to acquire gross levels of data on features such as surface water, topographic maps, land use maps, soil and geologic conditions, *etc.* With the establishment of a "state-of-knowledge," various parameters may be identified as significant to the ecology or to the human management of an area. In some cases, the parameters may be specific to the area or the surrounding area (such as a declining species) while they are of global significance in other areas (such as the CO_2 cycle).

Recognizing the importance of environmental monitoring and using the MAB framework as the basis, four broad subject areas relevant to a long-term monitoring program can be identified: biological, geophysical, chemical, and anthropological.

Among the biological topics to be considered in an environmental monitoring program are flora and fauna species checklists, descriptions of biotic populations and communities, and quantifications of ecosystem processes and dynamics (Table 1). Geophysical topics include measurements of precipitation, air temperature, and streamflows; descriptions of soil types and associated physical and chemical properties; and estimates of areas or volumes of landslides, intensity and extent of windstorms, *etc.* (Table 2). Chemical monitoring topics involve the detection of pollutants and measurements of natural substances through the examination of critical components in the atmosphere, precipitation, streamflow, soil and litter, and vegetation (Tables 3). Anthropological monitoring includes the assessment of demographic characteristics of an area, land ownership patterns, legal and institutional structures, *etc.* (Table 4).

GUIDELINES AND STANDARDS IN ENVIRONMENTAL MONITORING

As may be expected, long-term environmental monitoring programs can assume different levels of sophistication. Depending upon the specific objectives in a country, guidelines and standards to monitor an ecosystem should provide a flexible progression from a minimum level of monitoring effort to an extensive and intensive monitoring program. Monitoring of a particular area should be trailored to meet the specific needs of the area.

To provide a basis for the design of a long-term environmental monitoring program, the framework established by MAB can be considered as broad guidelines and standards. Here, three levels of monitoring have been specified, ranging from the least sophisticated and technologically intensive (level one) to the most sophisticated and technologically intensive (level three).

While level three is the most sophisticated and technologically intensive, it does not necessarily represent the "best" approach to a particular monitoring effort. If adequate and reliable source data can be obtained by simpler monitoring techniques, they whould be used. Indeed, it should be noted that many of the elements at level three may be projects of limited duration, possibly repeated at intervals as long as five years apart.

Table 1. Biological topics in an environmental monitoring program.

Types of Data	Level One	Level Two	Level Three
Species	List of vascular plants & vertebrate animals Significant species (rare, endangered, extinct, economic, exotics)	Habitat preference Geographic distribution Residence status (migratory, permanent, ephemeral) Reference collection Trophic level-major species	Inventory endemic plants and animal species Identify & monitor indicator species for pollutants, growth rates, habitat requirements Archive select plant & animal tissues
Populations/ communities	Relative abundance (rare, common, abundant) of major vertebrate and vascular plant species Major communities Low level aerial photos ERTS imagery	Annual census major species 1-3 permanent plots Low level aerial photos (100m) (5 yr cycle) on seasonal basis Estimate net productivity (major producers) Composition (major vegetative communities)	Population dynamics major vertebrate species Quantify distribution and abundance major plants and animals Describe ecosystems within Reserve Monitor for changes in composition, trophic organization, and diversity Permanent plot system Groundtruthing
Ecosystem processes			Successional patterns Energy flows Nutrient and System respiration Nutrient retension
Ecosystem dynamics			System shifts Gene pool diversity Genetic drift

Table 2. Geophysical topics in an enviornmental monitoring program.

Types of Data	Level One	Level Two	Level Three
Event/occurrence	Recording and where possible, quantifying unusual geological, geophysical or meteorological events, such as mass wasting, earthquake, windthrow, *etc.*		
Meteorology			
precipitation	Monthly storage	Daily or weekly storage	Recording gages along precip. gradient:
air temperature	Daily max/min	Standard weather station to include shortwave solar, & recording hygrothermograph	Recording weather station compatible with WMO network
Geology/Geomorphology	Geological map - - - - - - - - - - Morphology - - - - - - - - - - -		Geological map at 1:24,000 Minerology of parent materials
coastal			
permafrost			Channel characteristics
Hydrology			
streams	Inventory perennial & intermittent streams	Stage height at rated cross section	Automatic gaging
lakes/streams	Perennial or intermittent ice free dates	Stage height, inlet/outlet discharge	Automatic gaging
wetlands			Automatic gaging
groundwater		Seasonal depth measurement	Map groundwater resources
Soils	Soil type map Rooting depth	Organic content Mechanical analysis Physical analysis Infiltration rate -	Water holding characteristics Soil/water erodibility indices Soil productivity (composite index)
Geochemistry			
precipitation	pH		
soils	pH	Cation exchange capacity	
water	pH		
surface		NO_3, N, PO_4, P	
ground			
physical water quality	Temperature	Turbidity, color	Total dissolved solids, suspended and bedload

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Table 3. Chemical topics in an environmental monitoring program.

Level Two								
Level One								
			Atmospheric deposition				Atmospheric	
Measurement	Rainfall	Surface waters	Wet (rain)	Dry (dust)	Surface waters	Accumulation-animals, soil, litter, vegetation	Gasses	Particulates
pH	X	X	X	X	X			
Cond.	X	X	X		X			
$SO_4^=$			X	X	X			
PO_4			X	X	X			
Cl^-			X	X	X			
NO_3^-			X	X	X			
NH_4^+			X	X	X			
K^+			X	X	X			
Na^+			X	X	X			
Ca^{++}			X	X	X			
Mg^{++}			X	X	X			
Hg				X	X	X	X	X
Pb				X	X	X		X
Cd				X	X	X		X
As				X	X	X		X
SO_2							X	
O_3							X	
Level Three								
Trace metals			X	X	X	X		X
TSP								X
Benzopyrene			X	X				
Cl hydrocarbons			X			X	X	

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Table 4. Anthropological topics in an environmental monitoring program.

Types of Data	Level One	Level Two	Level Three
Map	Land use map (every 5 years)		
Activities	Human activities (farming, trapping, hunting, mining, recreation, forestry, industry, etc.)	Quantify (yield/acre, visits, economic species yield, board feet, tons, miles, etc.)	Inputs (fertilizer, pesticide) Outputs (yield/area)
Ownership	Land ownership public (area) private (area)	Public-area by agency Private-area by size class, # of owners	Private names of owners by area
Demography	Human population (#) residents neighbors visitors	Age/sex distribution Diet Educational levels Health (incidence of disease) Housing (type, location)	Per capita income Physiological parameters Origin of visitors (nationality, #)
Animals	Livestock Pets Other domestic } by species	Quantify (#)	
Legal	Acts Regulations Policies } as affecting reserve	Management plan Management activities (type, extent, frequency)	
Education	Research & training activities by type	Quantify Support (facilities, budget, staff)	
Development	Public facilities, infrastructure, services (sewer, water, electricity, roads, hospitals, campgrounds	Quantify Locate on map(s)	
Benefits	Benefits derived by man	Quantify	

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CHAPTER XV

WATERSHED RESOURCES MANAGEMENT IN THE MULTIPLE USE CONCEPT

INTRODUCTION

Watershed management is simply a component of the overall management plan and system to the wildland administrator actively pursuing a multiple use land management. Similarly, timber management, range management, and wildlife management are components of the management scheme. In many instances and situations, one or two of the wildland resource products may prevail due to local demands. However, even when one tree or a stand of timber is cut for sawtimber to attempt to increase water production, herbage production and aesthetic and recreational values will almost certainly be affected. Therefore, to effectively and efficiently practice one component of multiple use management, such as watershed management, the wildland administrator must be aware of the associated wildland resource management implications.

THE MULTIPLE USE CONCEPT

In almost any discussion of wildland management problems, multiple use management is cited as a guiding principle. At times, one gets the impression that multiple use is a cure-all for all the problems of wildland administration. However, while there has been little difficulty in gaining general acceptance of the multiple use concept, it has had far less success as a working tool of management. Most people concede that timber or water production is not necessarily the sole production function of wildlands, and that forage, wildlife and recreation should be considered in management decisions. But how much managerial effort should be allocated to each potential land use is a problem that wildland administrators have not always been able to resolve. Reconciliation of conflicting interests continues to be an important responsibility of wildland management agencies.

MEANING AND OBJECTIVE OF MULTIPLE USE

The term *multiple use* may be applied either to areas of land or to particular wildland resource products. When applied to land areas, multiple use refers to the production and management of various resource products or resource product combinations on a particular land management unit. The relation of several resource products on a management unit to one another may be competitive, complementary, or supplementary. A *competitive relation* exists between resource products when one must be sacrificed to gain more of another, as may occur between timber and water or between timber and forage. In *complementary relations*, both resource products increase together, as may occur between forage and water once the timber has been removed. A *supplementary relation* is one such that changes in one resource product have no influence on another, as may take place with livestock and wildlife within limited ranges or changes in forage production.

Conceivably, the relation of several resource products to one another on a particular land management unit may be competitive, complementary *and* supplementary, depending on the area of management concern. In this situation, it is important for the wildland administrator to know what area of management concern confronts him. For example, if working with a supplementary relationship between timber and water, the administrator may not be able to influence water production by altering timber production (Figure 1).

When applied to a particular wildland resource, multiple use refers to the utilization of the resource products for various purposes. Water may be utilized for irrigation, industry or recreation. Timber may be used for lumber, pulpwood, or Christmas trees. Forage may have value as feed for livestock and wildlife, or for watershed stabilization. Here again, the utilization of resource products may be competitive, complementary or supplementary.

In practice, multiple use management involves both the multiple use of land areas and of particular wildland resource products. Demands on particular resource products (water) for specific uses (irrigation), in turn, place demands on the land where the resources are produced (watersheds).

The basic objective of multiple use management is *to manage the wildland resource product complex for the most beneficial combination of present and future uses*. The idea of maximizing the benefits from a given resource product base is not new, but it has become more important as competition for limited and interrelated resource products increases.

The multiple use concept as described by law does not necessarily demand that every land unit in question should be utilized for all possible uses and resource products simultaneously. Instead, most public wildlands are utilized, to varying degrees, for a wide array of uses, as dictated by productivity and demand.

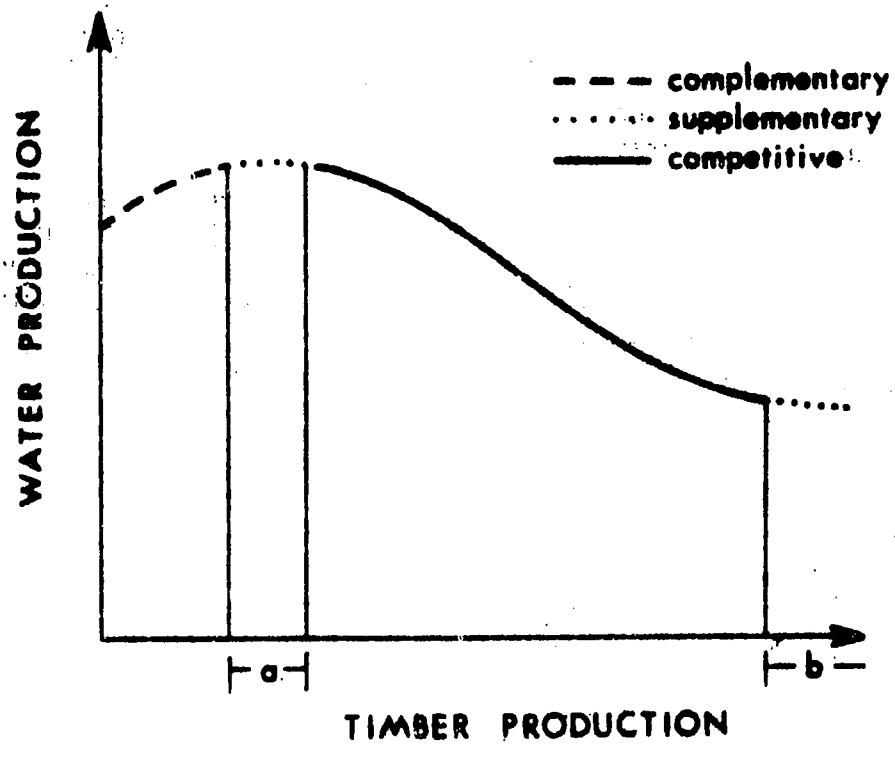

Figure 1. A hypothetical relationship between water and timber production on a land management unit, illustrating competitive, complementary, and supplementary relations. It is imperative that the wildland administrator ascertain which relation confronts him before implementing a land management redirection. Here, for example, the administrator will not be able to influence water production by altering timber production if operating in area "a" or "b."

Multiple use land management of wildlands may be accomplished by any one of the following options, or by combinations of the three:

(1) Concurrent and continuous use of the several wildland resource products obtainable on a particular land management unit, requiring the production of several goods and services from the same area.

(2) Alternating or rotating the uses of the various resource products or resource product combinations on a unit.

(3) Geographical separation of uses or use combinations so that multiple use is accomplished across a mosaic of units, any specific unit area being put to the single use to which it is most suited.

All of these options are legitimate multiple use management practices and should be applied in the most suitable combinations.

From society's point of view, regardless of the land management unit in question, multiple use involves a broader set of parameters that concern the private investor. Generally, society is more interested in preserving wildland benefits for future generations, requiring investments beyond the dictates of limited business economics. On the other hand, the private investor makes decisions based upon relatively short-term profit motives commonly related to limited resource product uses. Effective multiple use management should accommodate the full spectrum of today's needs and provide for tomorrow's requirements.

TYPES OF MULTIPLE USE MANAGEMENT

There are two fundamental types of multiple use land management, that which is resource-oriented and that which is area-oriented. *Resource-oriented* multiple use management is dependent upon knowledge of interrelationships describing how the management of one resource affects the production of others, or how one use of a particular resource affects other uses of the same resource. Essentially, substitutions between resource products or resource uses, and the associated benefit-cost comparisons of alternative production combinations are taken into account. Resource-oriented management may deal with a single resource product with alternate uses, or with two or more resource products with alternate uses for each.

Resource-oriented multiple use management requires the understanding of wildland resource production capacities. However, to accomplish effective and efficient multiple use management, resources must not only be related to each other but also to the needs and wants of people. *Area-oriented* multiple use management meets this general objective through consideration of the physical, biological, economic and social factors relating to wildland resource product

development in a particular place. This type of management provides a framework in which information concerning the administration of land management units can be arranged, analyzed and evaluated for the purpose of making sound management decisions. Area-oriented management draws that information needed to describe wildland resource product potentials from resource-oriented management and then relates this to the dynamics of local and regional demands. Area-oriented management is not necessarily intended to replace other forms of management, but rather to complement it. Hopefully, this will help to close the gap between resource management and problems on the ground.

INTEGRATING WATERSHED MANAGEMENT WITH MULTIPLE USE

The problems of integrating watershed management within the multiple use concept, a necessity in effective and efficient wildland management, are not always fully realized by the wildland administrators. While these problems may often be structured in resource-oriented management objectives during the initial phases of management implementation, wildland administrators must continually be aware of area-oriented management implications, especially when management plans and systems are developed for application over large land areas. Numerous land management considerations, policy formulations and institutional conflicts confront the wildland administrator attempting to integrate the component parts of multiple use land management. Although many of these issues are common to all components, several problems unique to watershed management implementation must be considered.

Land Management Considerations

Often, watershed management involves the development, evaluation, and application of land management systems designed to alter water production. The impact of management systems on a river basin may extend beyond simple attempts to alter the flow of water into downstream reservoirs. Many wildland resource products in addition to water are in demand from upstream lands, and these resource products must be allocated to maximize total benefits to society.

Land management systems designed to alter water production are commonly recommended by various interests groups. These systems often require sweeping modifications of vegetation on lands where the potential to alter water production is the highest. Some of these systems could jeopardize other land values; and some are irrevocable, at least in the short run, in that they can easily be made but cannot be undone if they turn out to be mistakes. Furthermore, technological and economic guidelines have not been sufficiently developed to carry out the implementation of the system effectively and efficiently, in many cases.

The implications of land management systems designed to alter water production are of particular interest to upstream land management

agencies since these agencies are charged with administering a large portion of the potentially better water yielding areas. But, because these management agencies are committed to the concept of multiple use management, the implications of these land management systems extend beyond considerations of water production alone.

The problem is to determine advantages and disadvantages of land management systems designed to alter water production before the systems become operational.

Estimates of Wildland Resource Products

Measurements of the yields of all wildland resource products are necessary to determine their responses to land management systems. These products include water, timber, range for livestock and wildlife, and recreation. Consequently, estimates of water yield and quality before and after a management system has been imposed are desirable. Timber growth and quality measurements should also be obtained on a before and after basis. Likewise, records of forage production and utilization can subsequently be translated into beef gains and wildlife habitat potential. Records of game and hunter use can be used to assess recreational values.

The measurements of wildland resource products on a management unit can be summarized in tabular form as a *product mix*. This table describes multiple use by quantitatively presenting all resource products derived from a particular area or class of land. Product mixes developed before a land management system is implemented will form a reference for comparison with product mixes developed after implementation. These comparisons will show what is gained and sacrificed in multiple use terms, assuming that a resource product response to a system can be determined with before and after measurements. Such comparisons form a basis for deciding among land management systems in terms of an appraisal of the advantages and disadvantages in resource product responses (Table 1).

On one hectare, if things remain as they are, T_0, the annual output will be 4.2 cubic meters of timber growth, enough forage for 0.068 kilograms of livestock gain, 0.021 deer, and 15 centimeters of water. No timber will be cut.

With conversion of moist sites to grass, T_1, the annual output will be 2.5 cubic meters of timber growth, enough forage for 0.48 kilograms of livestock gain, 0.034 deer, and 22 centimeters of water. Approximately 9.0 cubic meters of timber will be cut on each hectare.

Columns T_2 and T_3 contain the elements of uneven-aged and even-aged forest management systems, respectively.

Table 1. Product Mix Vectors for Southwestern Ponderosa Pine Forests 1/

Item	T_0 As is	T_1 Convert	T_2 Uneven-aged	T_3 Even-aged
Timber cut (cubic meters)	0.0	9.0	4.9	3.8
Timber growth (cubic meters)	4.2	2.5	5.5	5.2
Livestock (kilograms gain)	0.068	0.48	0.0045	0.27
Wildlife (number of deer)	0.021	0.034	0.032	0.033
Water (centimeters)	15.0	22.0	16.0	18.0

1/ Adapted from efficient development and use of forest lands: An outline of a prototype computer-oriented system for operational planning by R.J. McConnon, 1965.

It is important to note that, if T_0 is the best as judged by an assessment of the advantages and disadvantages in natural resource product and use response, the existing management system should be continued.

Direct Costs and Benefits

Determining the costs of implementing and maintaining a land management system, as well as the direct returns associated with the management system, is prerequisite to efficient multiple use land management.

A large body of information on costs is available in the literature. Unfortunately, these data normally reflect a particular economic situation and time, and cannot easily be adjusted to local conditions. Consequently, gross job time costs data in terms of physical input-output variables characterizing the management system and land area may be required. Inputs collected include labor time, equipment time, direct supervision time, and materials. Outputs specify total production as units thinned, cleared, *etc.* Costs are then determined by multiplying inputs by current wage rates, machine rates, and material costs. The sum of costs divided by the number of production units accomplished gives an estimate of the average unit costs for a management system.

Direct returns to the land management unit may largely be dependent on the sale of timber removed in the initial establishment of the management system. Remember, calculations based on a "saw-timber-only"

market, as currently exists within many market areas, could become obsolete if a pulpwood or veneer mill is installed. The presence of these additional outlets could alter the expected dollar returns by making previously unmerchantable material saleable. Therefore, since market conditions can change quickly, and since they affect returns so significantly, the timber resource should be described in terms of multi-product potentials, providing timber quality and yield information for management and utilization decisions on a continuing basis.

Direct returns derived from other resource products, *i.e.*, forage for livestock and wildlife, recreation, *etc.*, could conceivably be determined by comparable objective analyses, although these markets may be more poorly defined than timber.

The flexibility derived from the collection of objective cost-benefit data will allow land management systems to be reevaluated as economic conditions change through time. Consequently, a system initially considered economically impractical could become operational with a change in wage or machine rates, or with increased market outlets.

Economic Evaluations

To make an economic evaluation of a recommended land management system designed to alter water production, the following criteria could be selected to form a basis of choice:

(1) Maximize benefits.

(2) Maximize the returns on an investment.

(3) Achieve a specified production goal at least cost.

Data required to satisfy the first two criteria include estimates of resource product values and physical responses resulting from land management redirection, and costs of implementing the management system. To satisfy the third criterion, goals often derived through the political process must be established for various levels of production.

Economic evaluations essentially consist of an array of pertinent economic analyses designed to help wildland administrators make a better decision. Individiaul analysis may yield a one-answer solution to the problem of selecting a land management system that maximizes the returns to the land. A group of such analyses, based on different criteria, will result in an array of items for decision makers. Such an array may include:

(1) Estimates of multiple use production associated with different land management systems.

(2) Estimates of costs of management alternatives.

(3) Least cost solutions for different goals of multiple use production.

(4) Gross and net benefits associated with a range of management alternatives.

(5) Investment returns and cost-benefit ratios associated with different management systems.

Policy Formulations and Institutional Conflicts

Given the above array of economic relationships, the watershed manager (acting as a wildland administrator) should be able to choose the best course of action in terms of implementing a land management system. However, it is anticipated that there may be policy issues and institutional conflicts that must be resolved before a land management system becomes operational within the multiple use concept.

The question of who will pay for the establishment of a new land management system *specifically* designed to alter water production must be answered. The group of people that executes the system may not derive direct benefits from all of the multiple uses affected. For instance, it is questionable whether the U.S. Forest Service, who will carry out many of the operational programs necessary to implement a management system, will receive benefits commensurate with their costs. The role of downstream groups benefiting from increased water production from upstream lands will have to be established regarding costs.

The costs and benefits of a land management system designed to alter water production to society's needs must be ascertained. Various viewpoints will need to be adopted so people can determine how a management system is going to affect them individually and collectively.

Local groups on or near the land area directly affected by a land management system will want to know how a program may affect them personally. Their viewpoint can be developed by the valuation of raw multiple use products onsite or by the value added through manufacturing stages in the economic stream from resource to consumer within the local area. A single economic solution may not be suitable, but analyses reflecting the various viewpoints may yield the required answer.

Regional interests will probably bear a large portion of the investment in a land management system. A determination of the effects of a management system on a state's economy seems appropriate to this viewpoint. Finally, the national viewpoint must be the basis for some evolution, primarily because most of the land that may be subjected to a management system will be federally managed and the federal government will make at least a portion of the investment.

Perhaps the greatest problem facing the watershed manager pursuing multiple use land management is that of developing an efficient institutional framework through which land areas subjected to the multiple use

concept can be managed. A realistic multiple use management plan (such as that outlining a land management system designed to alter water production) must either work within the existing institutional structure, or modify it in order to be effective. An evaluation of the political and social organizations through which wildland resources are currently administered may suggest a necessity for institutional reform.

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Section V

REGIONAL LECTURES

V-1 INTRODUCTION TO WATERSHED RESOURCES MANAGEMENT IN HUMID

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Presented in Regional Training Course on Watershed Resources Management and Environmental Monitoring in Humid and Tropical Ecosystems. Northern Region Agricultural Development Center, Chiangmai, Thailand,
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INTRODUCTION

Today, world population has been increased rapidly in every country. Basic needs for human lives have been followed inevitably time to time. Evidently, lands over the world were invaded for human activities use, especially for food production as well as for human settlement, industrial factories, and urbanization. In fact, these lands long time ago used to be the forested areas, when the people needs the land, they get rid of the forest trees by clear cutting. Those clear lands, then after, were turned to be agriculture, resettlement, urban, and industrialization. Unfortunately, the people who occupied the land don't know how to keep it productive forever, only utilizing day-by-day without taking any good care.

It must be emphasized that land troubles as mentioned above found very basic problems in tropical areas which are allocated in Africa, South and Central America, South-East Asia, and Australia. These areas seemed to supply more population while the comparison were taken with the other parts of the world. Also, the people were indicated as the most poorest in the world as much lacking of education and nealthy.

A serious limitation is that population exposure and land occupancy the basic needs, the natural conditions of the land are also constraint to put the development project in terms of depletion of forest area. In other word, the soil property is usually erosive and producing more sediment yields when there is no completely any plant cover. After clear lands were abandoned very short period, soil fertility showed less productivity. In addition, some hazardous events are often seen in following continued reaction such as floods, drought, social deterioration, economic ruins, and political conflicts. In contrary, there is less problem in the world of developed countries such as United Stated, United Kingdom, Belgium, etc. Main reason would be the non-tropical condition as well as less population and good management planning in natural resources of those countries.

Good management plan for resources utilization is the main principle how to keep the land and some environments in sustainable yields for human needs forever. This principle may be called as environmental conservation management. Also, some conservation groups used to call this principle as the "Watershed Management" in the past even in the present time. However, there main concept is very much similar as the basic principle how to manage the natural resources under the rational use aspect that to serve human needs.

According to the differences of natural resources component between tropical and non-tropical ecosystems, some difficulty might come up to establish the management plan. Because of the instability of tropical ecosystems, the principles of watershed resources management must be collectively differed from the temperate and cold regions as well as developed countries in all parts of the world. Summarily speaking, this paper will

be presented principal concept in watershed resources management by emphasizing on the humid tropical zones. But some principles and methodologies may be included in the details of presentation. Directedly, in part of an Introduction to Watershed Resources Management would be the basic knowledge of someone who are participating the works of watershed management and environmental management one way or another. Also, it is hopeful that the people who are concerned with humid tropical natural resources management would be applied in useful way and to set aside good management plan for their own countries in the future.

THE WATERSHED AND NATURAL ENVIRONMENT SYSTEMS

Term watershed is understood among many people as some area on high elevation which could produce large amount of water to lowland area, mostly covering by the natural forest. To some, watershed means a small area inside the river basin, usually located on hilly or rugged terrain up to the mountains, mainly production would be water flow and some non-timber products. To very few number of people, watershed is an area containing some environments inside its boundary. In addition, the conservationists understand the word watershed as an area for rational use and management of natural resources. To avoid the confusion of these various understandings, USDA (1957) introduced the meaning of watershed as "the total area above a given point on a stream the

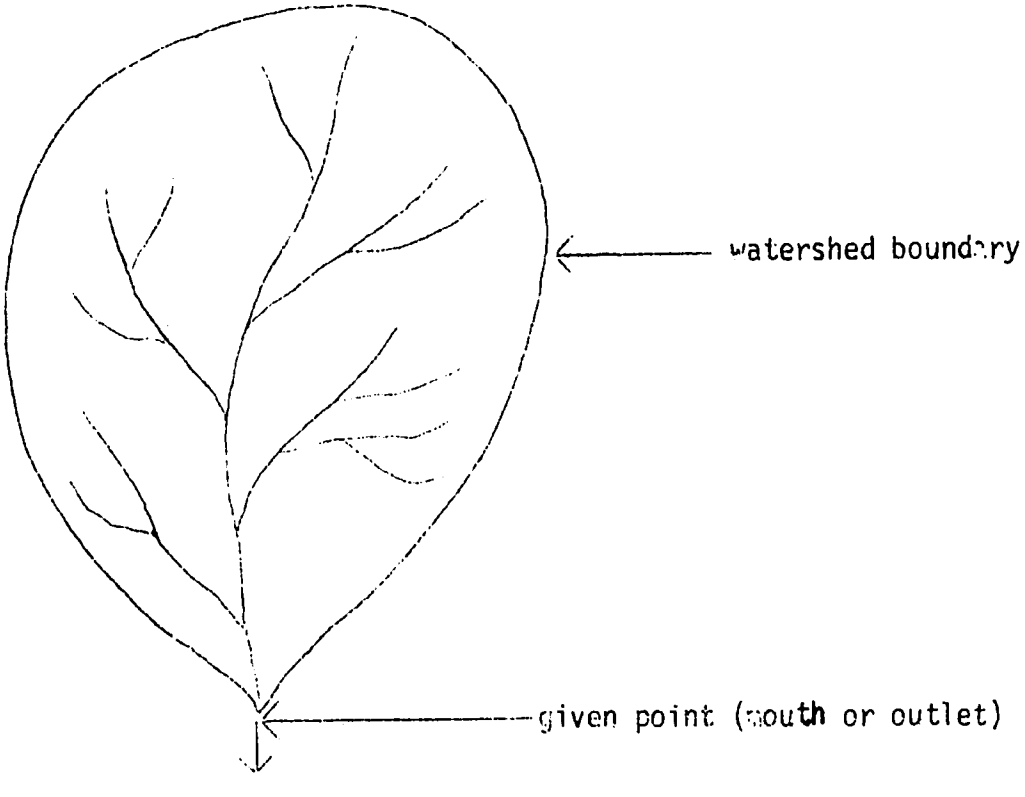

Figure 1. Watershed area which includes boundary and a given point to mark as mouth or outlet of stream.

contributes water to the flow at that point" An illustrated of this definition has been showed Figure 1. Which indicates the topographic boundary (watershed boundary) and a given point as an outlet of stream. In the same meaning, Webster's New World Dictionary of the American Language (1957) explained the terminology of watershed as "the drained by a river system." The difinition did not indicate the size and boundary, it mentioned on any area having the river for drainage out of water. Bullard (1971) proposed the watershed as the obvious unit of land management for protecting the water resources and improving its distribution in both time and space, it may be small basin of a few hectares feeding an intermittent stream, or it may comprise the 10 million hectare basin of the Chao Phya river. To be able to clarify, Prof. R.E. Dils* gave the definition in the lecture class of Principles of Watershed Management in the winter quator of 1963-1964 that "watershed is a basin unit we deal with the water management, it has no size, it is put up by the individual, the type of study." This definition has been used by his students around the world such as Taiwan, New Zealand, Thailand, Gana, Turkey and United States. In this context, Chunkao (1972) has modified Prof. R.E. Dils' definition which will be applied the meaning in all parts of this report and defined that watershed is a unit area which related particularity to water management, no size limitation but depending on individual objective and scope of work. In addition, USAID/UNESCO-MAB described the watershed in two implications such as (1) the term watershed implies a domain or system within boundaries. The boundaries may be physical ones, such as watershed divides, or they may be defined the processes such as runoff and (2) the watershed domain may be further divided into subcomponents of smaller watersheds or into subprocesses such as overland flow; watersheds may be controlled with physical structure such as the series of dams operated by the Tennessee Valley Authority in the United States or uncontrolled as area most watersheds in developing countries.

Conclusion of previous concept, the term watershed could be taken to state a new definition that watershed is the land area dealing with water resources management, and rational use natural resources. Its boundary would be encompassed by the individual objectives as well as physical topography of mountain ridge which are controlled by the processes of runoff, sediment transport and the right of occupancy by laws. This definition implied that watershed would be forest, agricultural area, wetland, highland, lowland, waterbody, city, rural area, mountains, even the ocean, but they must be proposed and limited, by the individual objective. In so far, there are a lot of environmental resources components inside a mentioned watershed which would be biotic, abiotic, physical and man-made elements joining together as the system (Figure 2). They, undoubtedly, form the structure and function under the principle of ecology, i.e., including producers, consumers, decomposers, and nutrient pool (supporters) in relation to species diversity, quantity, and proportion as seen in Figure 3.

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As ordinarily used by the watershed scientists, "watershed" is synonymous with the terms "catchment" or "drainage basin" or "river basin" and/or "drainage area."

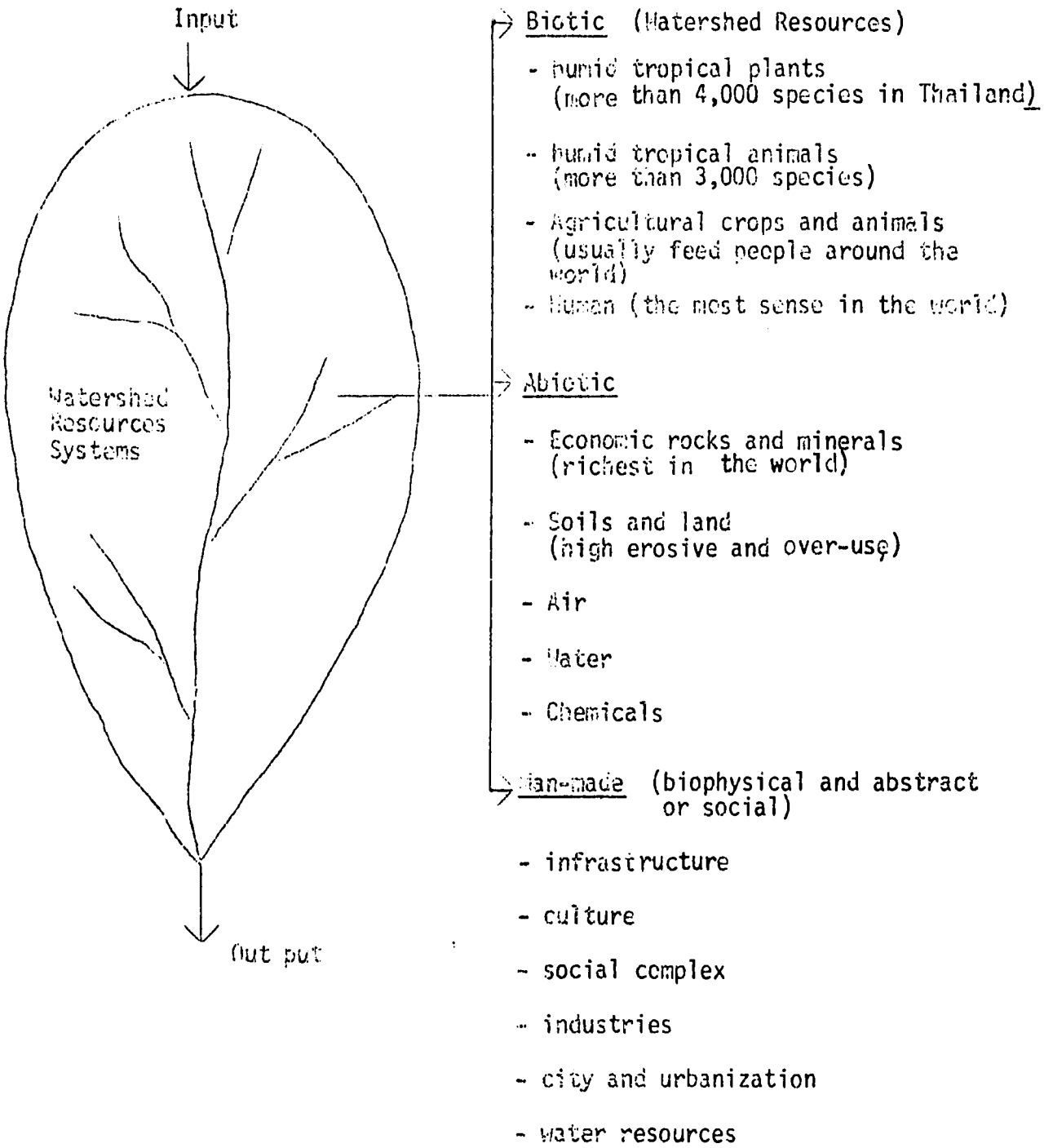
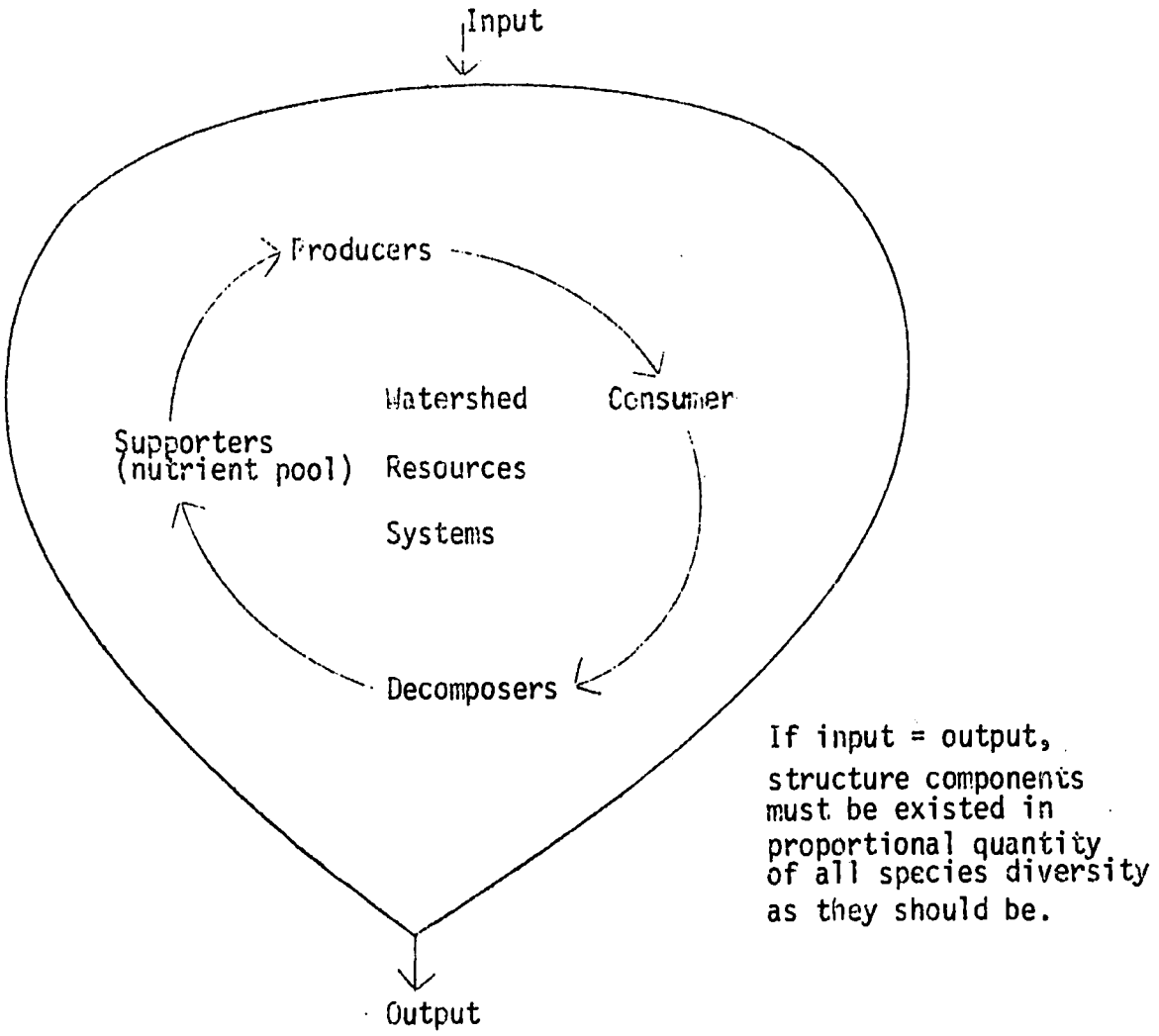


Figure 2. Environmental components inside the watershed resources systems of humid tropical zone.



Consideration : 1. species diversity
2. quantitization of each species
3. proportional quantity
4. functioning the processes

Figure 3. Components, functioning processes and status stage of watershed resources system.

Last decade, the period was called the decade of environmental sensitiveness. These were many activities concerning with environmental issues, especially toxic contamination, population growth, depletion of natural resources, energy crisis, economic and social deterioration and lack of human basic needs. The context has paved way for environmental scientists to take serious study in environmental issues. They modified exactly the same principles used in watershed management but they called a new term as environmental science. To some of them, they stated clearly and figuratively that watershed seems very similar to environmental systems, it regulates the relation between input and output of that systems. In this case water flow and some other natural resources inside the watershed ecosystems as well as taking the interaction among them. However, the structure of watershed ecosystems would be composed of various elements which are functioning by their roles for regulating the systems (Figure 2 and 3).

Watershed scientist usually classifies the watershed area at the hydrological unit which provides the ecological interaction to regulate the water flow i.e., control optimum flow which may be defined the watershed as systems to regulate the relation between input and output to reach the equilibrium stage. When the rainfall is supposed to be input to the watershed systems, if the regulators inside the systems stabilized, the output such as water flow would be good quality and normal flowing likewise the natural conditions. If the regulators are not in good conditions, water flow would not indicate good quality and normal flow. Therefore, the watershed at the present time should be defined as the environmental systems which included many subsystems and regulators as well as environmental resources such as plants, soils, man, and other. To some people, this system may be called as watershed ecosystems which is composed of many components inside this systems (Figure 2). Each subsystem plays important role to regulate quantity, desirable quality, and flow characteristics in interrelation with their functioning processes (Figure 3)

Natural resources and environments are disagreed in definition among the conservationists, to some implies that they are alike, but to many they are mostly alike but having some differences in meanings, To pinpoint this controversy, Irland (1974) considered natural resources as natural environments which are valuable to fulfill human needs. While, O'Riordan (1971) stated that natural resources as attributes of the environment which according to the evaluation by the human population are valuable or needed within a period of time, as influenced by social, political and institutional conditions. Soerianegara (1978) proposed the definition of natural resources as the elements of natural environments, physical as well as biological, which are needed by man to satisfy his needs and increase this well-being. By these presentation of some conservationists, it could define a working definition of natural resources as environments which are used by man to fulfill the needs. With regard to the controversy, all kinds of natural resources must be attributes of environments but, all environments are not necessary to be natural resources, depending time is needed by man and also the importance to be the basic

human needs to provide their life.

To clarify the previous presentation, natural resources and environments are formed together collectively and interrelatively to grouping area surrounding by the boundary line which is called as ecosystems or environmental systems, for watershed scientists, they called this unit area as watershed area or watershed ecosystems. In so far, watershed ecosystems may be synonymous with the terms "environmental systems" or "watershed area" which is composed of elements of natural resources or environments inside this unit boundary, also natural resources inside the watershed defined as watershed resources. Naturally, the environmental structure may be contained both the natural environments and man-made environments as well as biophysical and abstract (social) environments (Figures 2, 3 and 4) to which they are functioned by their own behavior and appropriate conditions. By this concept, each watershed ecosystems or environmental systems may be performed in different statuses, to some implies very strong to be stabilized, and to many it is easily changed. It also depends upon the components of species diversity, quantity, and proportion which are collectively composed inside that unit area. This conceptual idea has been brought the limitation of resources utilization as expressed in Figure 5.

WHAT IS WATERSHED RESOURCES MANAGEMENT

In nature, water is meaningful literally and figuratively everyone's activities. When the population growth with an increases and new demand for water, they pay more and more attention to the water resources and its management. As a consequence, Professor Dr. R.E. Dils described on the lecture class of Principles of Watershed Management in 1963-1964 that the term watershed management has meanings to many people. To some watershed management implies the management or manipulation of the water on the land; to many it refers to management of all resources of a watershed, including the forest, range, wildlifes, fish and resources (Figures 1, 2 and 3); to others it means the distribution or allocation of water resources, that is, it involves the administration of water rights; and to still others it is synonymous with managing water in channels, reservoirs, or canals. The same context, Hewlett and Nutter (1969) stated thay watershed management has been defined as the management of the natural resources of a drainage basin primarily for the production and protection of water supplies and water-based resources, including the control of erosion and floods, and the protection of aesthetic values associated with water. Also, Hughes (1969) defined the watershed management as the management of land for optimum production of high quality water, for the regulation of water yield and for maximum soil stability, along with other products and uses of the land.

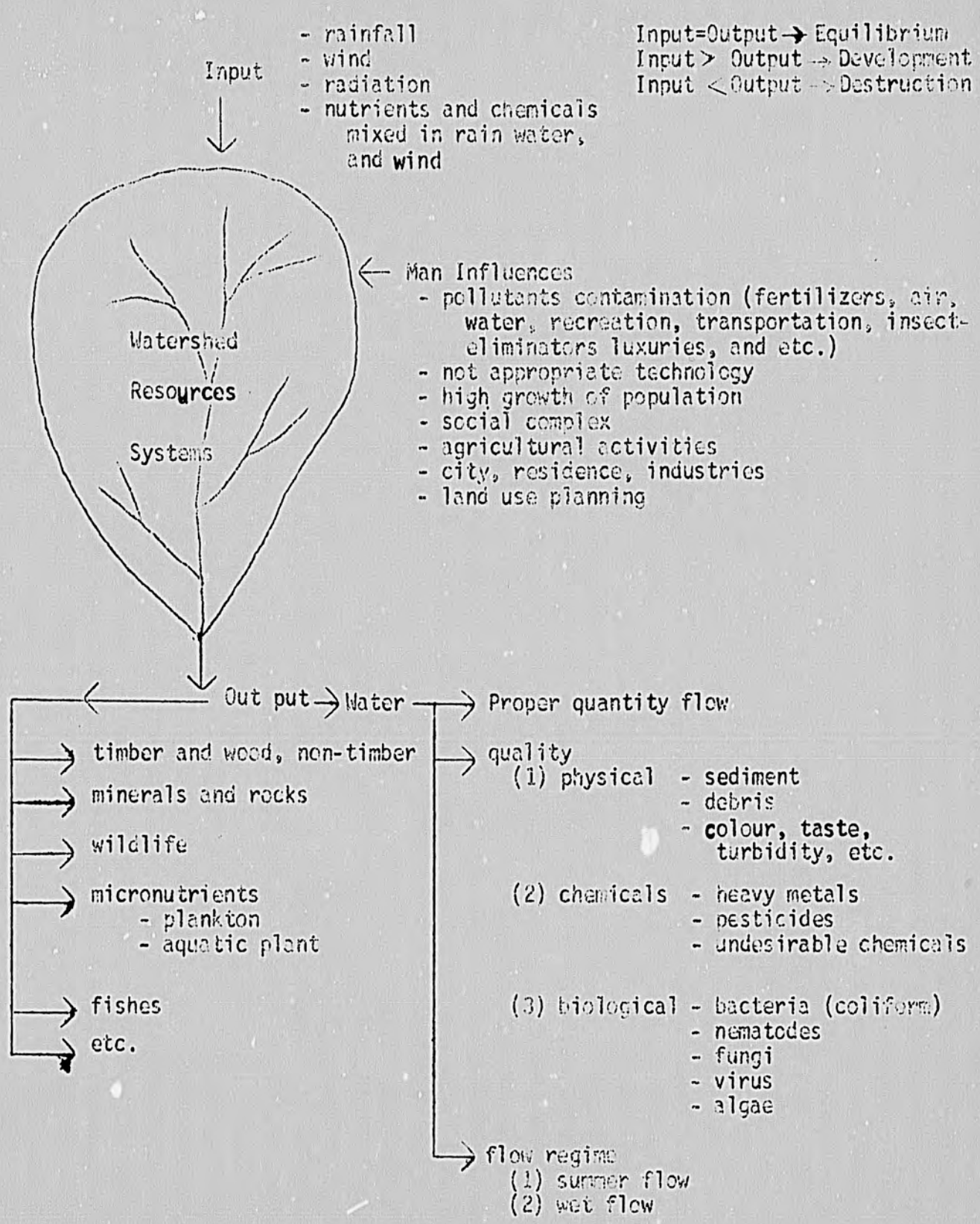


Figure 4. Environmental elements and its pathway from input through output of watershed resources systems.

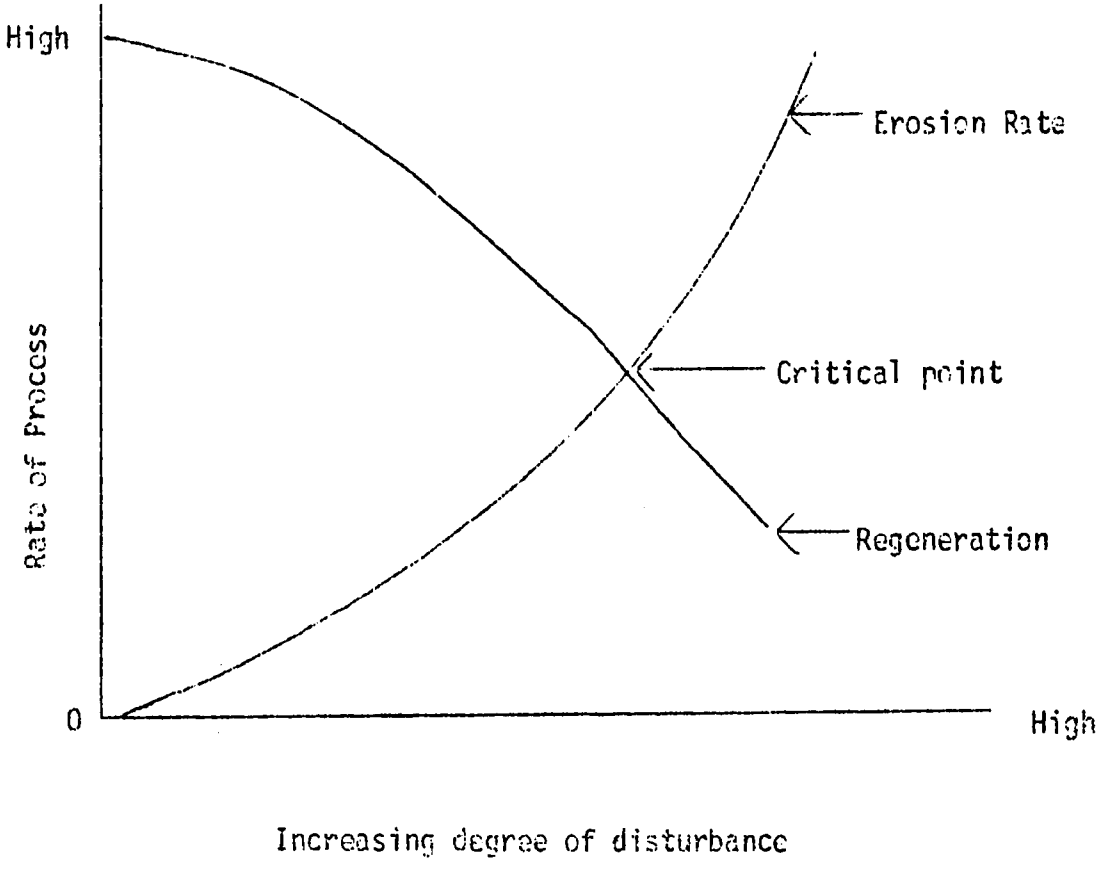


Figure 5. Relation between regeneration and erosion rate as obtained by increasing degree of disturbance (resources utilization) and rate of process which would provide the optimum point (critical point) for conservation practices.

Burton (1969) added that watershed management is clearly an integral part of water resources development; in particular it seeks, by manipulation of land use factors, to modify the streamflow characteristics of the river basins, small and large, which are the basis of all water resources development systems. In other word, watershed management is alike as natural resources management under the principles of conservation, meaning that watershed resources can be utilized with care for serving the human needs and to be sustained yield basis in the future. Soerianegara (1978) stated that there is no differences between natural resources management and environmental management, if the object of the natural resources management is the natural resources ecosystem, then the environmental management is already included. In follows, watershed resources management would be allowed to apply the same principles as natural resources management (to emphasize on particular unit boundary) and environmental management.

Jolly (1978) proposed that environmental management is, in essence, the process of allocating natural and man-made resources so as to make optimum use of the environment is satisfying basic human needs at the minimum and more, if possible, for an indefinite future. Dasmann (1976) has emphasized environmental conservation likewise the term environmental management which is defined as "the rational use of the environment to provide the highest sustainable quality of living for humanity". In the same statement, environmental management or watershed resources management is man's endeavor in the utilization and the manipulation of the natural resources ecosystems so as to obtain the maximal benefits by maintaining their sustained production and service (modified the statement of Soerianegara,1978).

To maintain the stabilization of watershed resources, Dasmann (1980) introduced the word "ecodevelopment" to be applied for environmental resources utilization. He emphasized that rational use of natural resources in the environmental systems would be appropriate principle to keep the watershed ecosystem producing the sustainable yields for human in the future. Also, principles of ecology must be considered as important approach to change as well as to regulate the use natural resources (Watt, 1969 a.). To obtain a clearer idea, the concept ecodevelopment has been focused on the influences of man who can utilize the natural resources and environments but not beyond the carrying capacity and its recovering for life quality in that watershed resources ecosystems.

In this report, the watershed resources management would be defined as conservation practices to obtain the maximum benefits utilizing, maintaining and regulating the sustained production and services of evironmental resources in the environmental unit without any damages of quantity, desirable quality, and flow regime.

GENERAL CHARACTERISTICS OF WATERSHED RESOURCES SYSTEMS IN HUMID TROPIC

Ecological basis, watershed resources systems has their own characteristics, structure, and function. But they often perform their general characteristics in follows ;-

1. In theoretical aspect, the environments, which are synonymous with watershed resources in this report, may be differentiated in the main forms of biophysical environment of land, water, air, plants, animals, human beings, and infrastructure (Figure 4) the other group would be abstract (social) environments of culture, religion, and tradition. Roughly fifty per cent of the forest land of the world is tropical forest as shown in Table 1. (UNESCO, 1978), interpretation of this information would be indicated that natural environment in the tropical watershed mostly containing with the green plant and the others would be less coverage.

2. All environments in the watershed systems found interaction and interchange among themselves. Naturally, the watershed resources are surely characterized in grouping by topography, geology, soils, and land capability vegetation, animals, and population density (Table 1). Also, they are functioning in term of processes such as interception, streamflow erosion, infiltration, percolation, evaporation, and transpiration.

3. Everything inside the watershed resources systems is related to everything else (Figures 2, 3 and 4). This is the reason why the watershed has been called as regulator to control the relation between input and output. If the regulator works well smooth, there is more or less difference between input and output, for example, when the forest trees were clearly cut out then after the soil and water translocated out from the humid tropical watershed systems (Table 2) that would cause the depletion of soil fertility as well as the confrontation of drought in dry period (Dasmann 1976, Chunkao and Makarabhirom, 1979, and UNESCO 1978).

4. Formulation of each watershed system has their own characteristics, some watershed may be too strong to be changed from one form to another, but some are easily breakable. Because, the structural environments inside the watershed systems are usually differentiated among diversity, quantity, and proportion. These are a lot of information that reported the humid tropical watershed as not stabilization likewise the temperate watershed, even they have more species diversity, because of less soil stability, high rainfall, non-educated-dense population (Table 3).

5. In the humid tropic, the watershed resources found out abundances in species diversity, quantity, and its proportion when it compares with cold and temperate zone. Green plants are mainly environmental components in the systems which play important role as producers for human and animals consumers (Table 3). Many plant ecologists have found that there are a lot of nutrients containing in part of the plant tissue. If the plants were move out from the area, nutritions would deplete directly and indirectly from the watershed systems (Dasmann, 1976).

Table 1. Total area, forest area and human pupulation in the continents containing tropical forest (UNESCO, 1978)

No.	Region	Land Area x1,000 km^2	Forest				Population	
			Total		Closed		x 10^6	%
			x1000km^2	%	x1000km^2	%		
1	Tropical Africa	22150	7,340	38	2,100	29	267	26
2	South and Central America	14890	9,210	45	5900	72	218	20
3	South-East Asia and Australia	9050	3,600	19	3,000	33	584	55
	Total	46,090	19,150	100	11000	-	1,069	100

Table 2. Sediment yields of different countries (After United Nations, 1953)

No.	Country	Sediment (mm)	Remarks
1	Burma	0.55	
2	India	1.01	
3	China	1.75	
4	Mekong	0.44	
5	Indonesia	1.90	
6	Thailand	0.08	Lang Suan River Chumpern, Southern Thailand (1980 data)
7	U.S.A	0.49	

Table 3. (cont.)

No.	Items	Characteristics		References
		natural condition	disturbed	
5	Human Resources			
	1. population	very high	very high	Burbridge (1978)
	2. density	very high	very high	Soerianegara (1978)
	3. education and health	poor	poor	Dasmann (1980)
	4. perception	poor	poor	Chunkao (1979)
				Watt (1969 b.)
6	Ecosystem Stability			
	1. resources components	good proportion species diversity	heavy decrease	Jolly (1978) Dasmann (1980)
	2. change	little change	drastic change	Watt (1969 a.)
	3. biotic potential	excellent	low	Brown (1963)

Table 3. General characteristics of watershed resources systems in the humid tropical areas described in nature and in case of disturbances as modified from various references

No.	Items	Characteristics		References
		natural condition	disturbed	
1	Plants			
	1. species diversity	plenty	rapidly decrease	Spurr (1969)
	2. quantity	plenty	less but some increase	O'Riordan (1971)
				Dasmann (1976)
	3. proportion (age, sex, size, species, and products)	excellent	more variation	Ireland (1974)
2	Animals			
	1. species diversity	plenty	rapidly decrease	Spurr (1969)
	2. quantity	plenty	less but some increase	Dasmann (1976)
				UNESCO (1978)
	3. proportion (age, sex, size, species, and products)	excellent	more variation	
3	Soils and Land			
	1. agricultural potential	high	rapidly decrease	Chunkao et al. (1978)
	2. stability	good	low	UNESCO (1978)
	3. sediment loss	less	very high	United Nations (1953)
	4. water regulator	excellent	worse	Hewlett and Nutter (1969)
				Hibbert (1965)
4	Water Supply			
	1. quantity as related to rainfall	high (30-50%)	a little change	Chunkao and Makarabhirom (1979)
	2. quality	usable	usually pollutants contamination	Chunkao et al. (1978)
				UNESCO (1978)
	3. flow regime			Anderson et al. (1976)
	1) summer flow	high	very low	Lassen et al. (1952)
	2) wet flow	low	very high	Burton (1969)

6. High-rainfall characteristics of humid tropic may be the main factor to introduce soil and water losses from a high degree of agricultural activities of hunger population on the denuded areas, especially on rugged terrain and mountainous lands that characterized soils mostly more erosive (Table 3). This would be supported by research works and found high soil losses in the humid tropical areas as reported by United Nations (1953), UNESCO (1978), Chunkao (1979) and Nakano (1978) also Table 3.

7. Water yield refers to the long term volume of runoff, frequently expressed as annual yield. Forest cover plays very important role to this water yield, especially it regulates water flows in quantity, quality, and regime (Satterlund 1972 and Lassen et al. 1982). Hibbert (1965) reviewed thirty-nine predominantly North American forest treatment studies and concluded that reduction of forest cover increases water yield, and establishment of forest cover on sparsely vegetated land decreases water yield (Table 3.) In contrast to Hibbert (1965)'s conclusion, several Soviet authors have reported increases in water yield with increases in forest cover. Although these conflicting generalizations can be adequately reconciled when individual studies are considered in the context of their geographic setting and precipitation form, they serve to illustrate the limitations of applying generalizations to a particular catchment. Unfortunately, a majority of water yield studies have been carried out very few in the humid tropic as reported by UNESCO (1978). However, the humid tropical area produces water flow from the watershed areas greater amount, approximately 60 percent of rainfall in hill-evergreen forest in Thailand (Chunkao and Nakarabhirom, 1979), than temperate and cold areas (Chunkao 1979), USAID/UNESCO-MAB 1979, UNESCO 1978, and Molchanov 1960). Forest also influences to water quality control in the role of flow regulation as gradually contributes the clean water into stream as well as controlling the biophysical pollutants and toxic substances not pouring to the stream. There are a lot of reports concerning with positive influences of forest on water quality control such as Anderson et al. (1976). UNESCO (1978), Burton (1969), Satterlund (1972) and Nikolaenko (1970).

8. Land inside humid tropic have been utilized to serve the basic needs of dense population. This would be the cause why the forest areas are rapidly destroying day-by-day. The situation has been spreaded out all parts of lowlands and also on the mountains for setting the human settlement, agriculture, industries, villages, and urbans as reported by Kunstadter and Chapman (1970) UNESCO (1978), Dasmann (1976) and Dasmann (1976) and Dasmann (1968). In order to set aside sustainable utilization of land, wise management planning of land use must be considered as vital importance to watershed resources conservation measure (Kunstadter and Chapman 1970, and Brown, 1968).

9. When the watershed ecosystem is taken an account of regulator (Figures 2 and 3) this means that any environmental resources existing in this system would play vital role to regulate the relation between input and output. If the output is greater than input, watershed resources systems will be classified as the system at the stage of destruction. In opposite way, when the output is less than input, the

system will be on the stage of development. Finally, the equilibrium usually exists at the stage of output equivalent to input (Figure 4). In reality, it is difficult to achieve the equilibrium stage in any system, understanding stage of watershed resources ecosystems or environmental systems that would provide baseline information how to establish the watershed resources management plan for sustainable utilization of watershed ecosystems to reach the equilibrium stage with no harm done to human life, animals, and plant species, even its ecosystems.

Due to information above, good management plan would be preferred to operate watershed resources in the humid tropic. Not only explosive population need natural resources to serve their life, but also general characteristics of its systems found easily changeable from one form to another.

CONCEPTS OF WATERSHED RESOURCES MANAGEMENT IN HUMID TROPIC

The vital concepts of watershed resources management in humid tropic will be focused on the maximum benefits utilizing, maintaining, and regulating all environmental resources to obtain sustained production and services for human life without any damages of desirable quality water and its flow regime. Under this statement, some concepts will be discussed details in the follows :-

1. Resources Utilization and Conservation

Natural and environmental resources must be well planned to utilize under the conservation principles, which were concentrated to specify the rational use and get rid of waste, to repair and rehabilitate deteriorated things, and reserve rare and endanger resources for long term utilization. In other word; natural resources and environments must be rationally utilized to serve real needs of human, also utilize it without having waste output. Any resources were destroyed at the stage of inactive utilization, they should be repaired and rehabilitated when they are in good condition then after they should be employed to serve human needs. Furthermore, if any things were identified as rare and endanger types, they must be reserved with good care.

In humid tropic, there are plenty of both biological and physical environments (resources), but community prefers to full scheme management and technical know-how to utilize for human needs. Mismanagement would introduce more serious troubles than the temperate and cold region (UNESCO 1978, Satterlund 1972, and Nakano 1978). Therefore, any natural resources which must be taken in out, or other actions from the watershed systems should consider the decreases of that resources as well as pollutant contanimation, as seen the description in Talbe 4.

2. Land Use Watershed Resources Management

The role of the watershed resources manager is first and foremost that of a conservationist working toward and maintaining an ecological

balance (Watt, 1969 b.). Land planning seems to be the vital work to keep this ecological balance for the watershed resources systems in the humid tropic. Resources utilization and some activities must be considered carefully to keep the watershed ecosystems under the equilibrium stage by controlling species diversity, quantity, and proportion of environmental resources.

At any given time and for any given level of technology, land in the humid tropic will be used for the purpose which produces the highest net returns in term of local money and community satisfaction. Watt (1969 b.) explained the importance of land use interrelated and partialized to watershed management, in consequence, water yield which produced by this system. Many research papers reported land use change from humid tropical forest to be cultivated land, industry, human settlement, and recreational areas that caused low quality of water such as high amount of soil losses, less summer flow and high wet flow, high amount of chemicals and coliform bacteria in stream water, as found by Watt (1969 b.), UNESCO (1978), Satterlund (1972), Hughes (1969), Anderson et al. (1976), Hibbert (1965), United Nations (1953), Burton (1969) and Chunkao (1972). They concluded the same trend that watershed land resources must be taken in first priority to plan for rational utilization, to avoid the disturbance of ecological balance which may provide water flow and some other resources. It would be remembered that watershed resources systems in the humid tropic is quite so different from the other parts of the world, if anything changes the serious problems usually occur, as seen in Figure 5.

3. Multiple Use Watershed Management

The land in a catchment is mostly classified by its principal use. It may be primarily industrial or commercial land, residential land, arable farmland, grazing, forest or barren land. Of course although it may be best suited to one of these uses, such as grazing, it might instead be given sonar other species use, such recreation, or commercial forest land for water supply protection, all those statement, Hughes (1969) called as multiple use. He pointed out that a true multiple-use system aims to perpetuate the maximum safe production of all the naturally-renewed resources of a watershed-be they water, timber, forage for grazing animals, or herbaceous crop. Also, less substantial products such as the aesthetic pleasures of scenery and public recreation, have their own value.

To modified the concept, watershed resources management is needed the basic guideline to utilize environmental resources inside the systems in direct and indirect benefits to serve human activities. Sometimes, land resources may use for city resident but it could be provided for recreation and some other purposes. In the tropic, people have learned how to utilize the watershed resources under multiple use long ago. They utilize all resources for food, medical care, cloths, and housing as well as recreation damage protection, and others. This would be proposed the conceptual idea that watershed resources in the humid tropic must be well planned to utilize and people (Figure 5 and Table 4).

Table 4. Proposed measures for planning of watershed resources management in the humid tropical areas for control the equilibrium stage of the system

Case	Resources Utilization option	Measures Application		Resources Patterns	
		renewable resources	non-renewable resources	renewable	non-renewable
1	Taking out from the systems	taking only increment to provide sustainable yield	Appropriate technology (1) more effective instrument (2) less pollutants outflow to system	Timber, non-timber, agriculture, grasses, animals, water	rocks, minerals, soils water, medicals, chemicals, cultural issues, air
2	Taking in the system	controlling explosive population well-planned	Appropriate technology	exotic plants and animals, human, medical cares	commodities fertilizers, pesticides, equipments, minerals, petroleums, natural gas, culture, social complex
3	Utilizing inside the systems (not taking in and out from the system)	utilizing only increment for basic needs, well-planned	Appropriate technology	plants, animals, water	minerals rocks, air,
4	Influences from other surrounding system	keeping conservation practices effectively in utilizing the resources	Appropriate technology	Try to keep the systems	try to keep the system in equilibrium

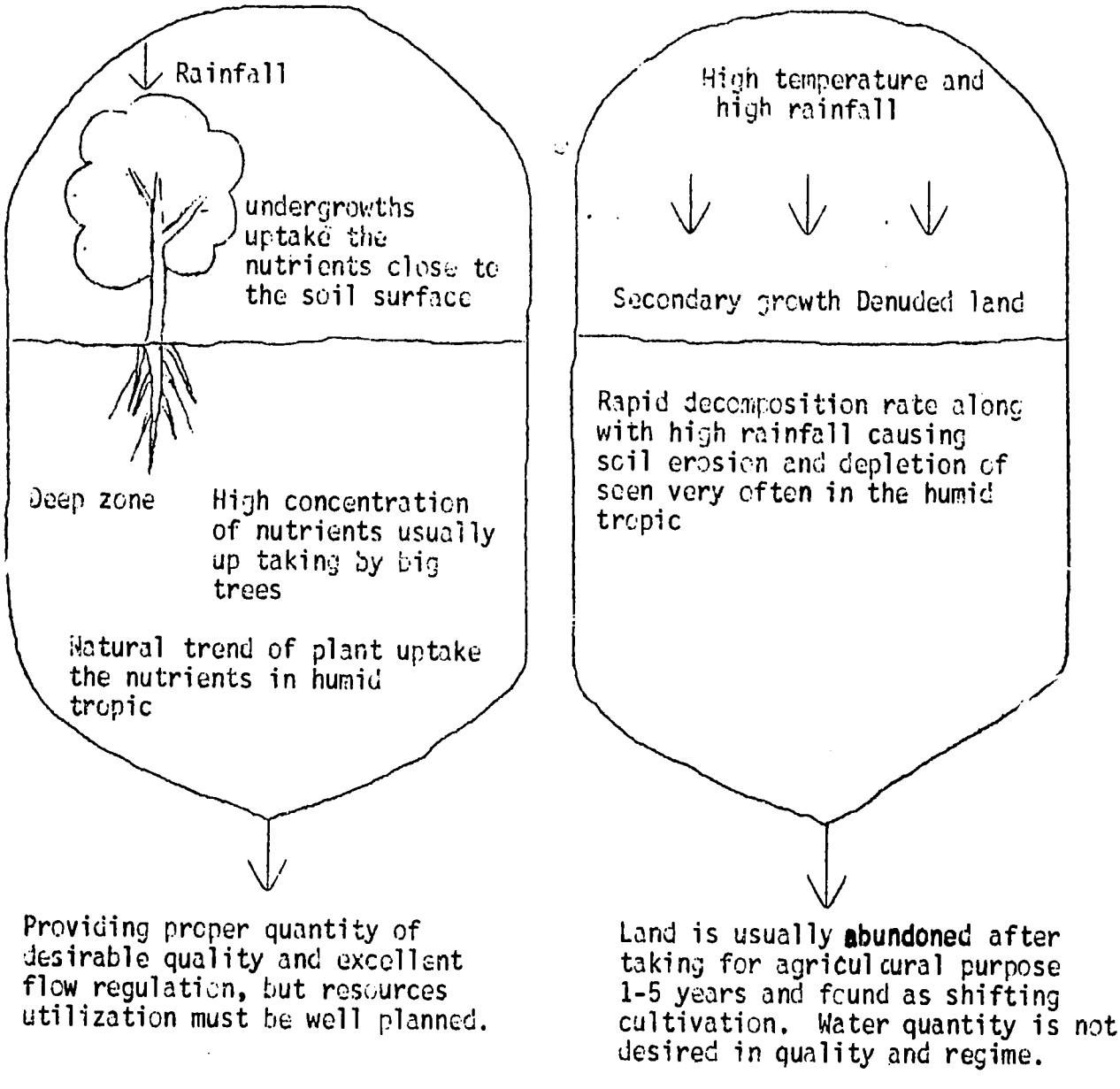


Figure 6. Schematic illustration the natural phenomenon and conditions after natural land changed to agriculturize for human purposes in the humid tropic watershed resources systems (modified from Spurr (1969), Dasmann (1976), UNESCO (1978) and Chunkao et al. (1976).

4. Water Resources Development

Satterlund (1972) stated that water resources management includes all the myriad of activities undertaken to obtain, distribute, use, regulate, treat, and dispose of water. Watershed management is clearly an integral part of water resources development; in particular it seeks, by manipulation of land use factors, to modify the streamflow characteristics of the river basins, small and large, which are the basis of all water resources development systems (Burton, 1969). In humid tropic as applied the basis concept likewise some other countries, watershed management is concerned with mostly how to manage the land for allocation and sustained utilization without disturbance of ecological balance (Figures 2, 3, 4, 5 and 6) including how to produce water in terms of quantity, quality, and timing together with all natural resources utilization under the conservation principles. In the program of water resources development, therefore, would undoubtedly be included the principal works of watershed resources management one way to another, but more precaution for setting a plan would be taken in serious consideration as described in Table 4.

5. Environmental Management and Conservation

In the beginning of this paper has been mentioned the similarity of both words the environmental management and environmental conservation. Also, they are closely related to the word of watershed management, and in turn to the field of natural resources conservation. In other word, all resources in the ecosystems can be used for serving the human basic needs and provided sustainable yields for long term condition. Pollution and lack of resources use must be taken an account as vital issue in the management planning in the humid tropic (Figure 6 and Table 4). However, the watershed resources management is considered the water yield basis, especially quantity, quality, and flow regime of water in the stream, while the baseline concept of environmental management and conservation takes pollution, population growth, energy crisis, and natural resources availability as the indication of environmental issue (Table 2 and 4). According to high amount of population in the humid tropic, development and resources utilization are evitable to confront. Concept of ecodevelopment as introduced by Dasmann (1980) should be applied to propaganda among the people in this region. Development for economy, industry, agriculture, human settlement and some other infrastructure may be conducted but they must be under the principles of ecology. By this statement, watershed resources systems is finally reached equilibrium stage and it could provide sustainable products to human life.

In conclusion, watershed resources management should be applied the systems approach for management plan. Any watershed resources in the will utilize, principles of conservation and ecology must be taken seriously into consideration. Be aware that humid tropical watershed resources systems identified as easily to be breakable, utilization of all resources should avoid the pollutants contamination, energy crisis, lack of resources for human life, high growth of population, and deterioration of social community. Sustainable production is always needed for human life as described the details in Tables 3 and 4, and Figure 6.

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V-2 Watershed Management Strategies in Humid Tropical Ecosystems

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1. Introduction

Watershed management strategies in any area depend largely on historical background, cultural and socio-economic components of that particular region or location. Even in the same country which comprises different social components, different cultural practices, different topography and environment, the planning for watershed management strategies also varies in the method of solving the problems. Base on the topic given "Watershed Management Strategies in Humid Tropical Ecosystem", this is too broad. If it is agreeable, it would be appropriated to narrow it down to Watershed Management Strategies in Thailand. Yet, due to different parts and locations of the country, the strategies being applied are varied and adjusted to suit the locality.

The approach in the planning of watershed management strategies whether it is for single purpose or multiple purpose, the state of ecosystem, has to be taken into account. Each watershed possesses its own characteristic and its own ecosystem, basically, "everything is related to everything else". The principle components of a watershed ecosystem are Man, Land, Aquatic biota, Terrestrial biota, Air (atmosphere), Water and Solar energy. Natural linkage of energy transfer in an ecosystem can greatly be changed by such environment alteration during the course of development, for example forest clearing by man for crop cultivation would result in poor water quality, excessive run - off, erosion during wet season and rapid evaporation would result in dry season. In Thailand, human element (Hominisphere) is the main agent that courses a great change in the ecosystem of a watershed.

For understanding, the following diagram will show relationships among a watershed and its ecosystem.

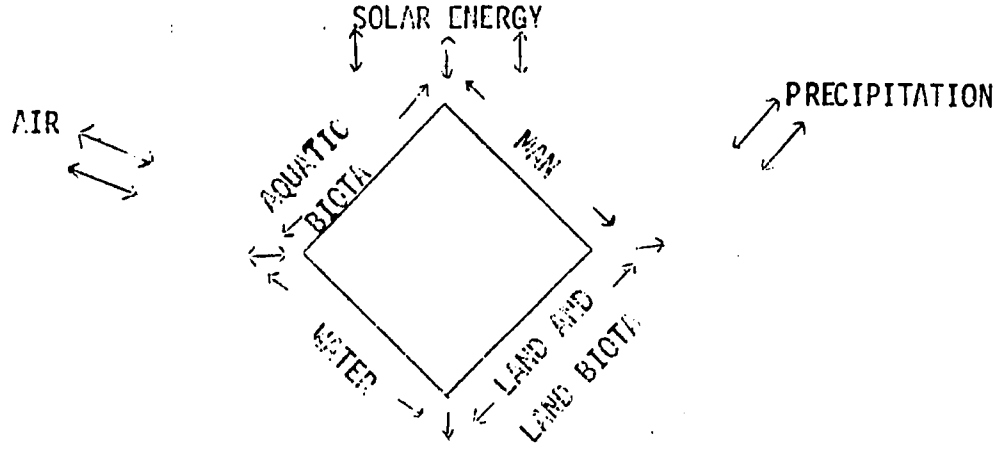

Diagram - 1 showing relationships among watershed and it's ecosystem.

By and large, in most of developing nations the imbalance of nature, especially watershed degradation, often caused by people because of ignorance and economic backwardness including their outmoded culture and social systems.

These bring about :

- Cultivation on the land which is not suitable for agriculture and without adequate soil and water conservation practices.

- The practices of shifting cultivation and encroachment of forest area which in turn resulting in drastic soil erosion and run off.

- Degradation of forest which is the result of setting fire to the forest on purpose or negligence such as hunting, honey collection, bamboo shoot collection and etc.

- Huge amount of siltation in river bed or reservoir due to careless engineering work such as road construction or other public works. An engineer can construct a very good road from engineering view point but not a good conservationist. Improper agricultural techniques also contribute to considerable amount of sediment.

- Flood, drought and pollution. Flood often occurs during rainy season due to watershed degradation. This is because forest vegetation which acts as natural barrier as rain interception and flood detention become deteriorated. In connection with degraded watershed, drought will follow during dry season.

Pollution could result from many human activities within a watershed such as improper use of insecticide and fungicide, disposition of waste material from industrial plant, domestic waste and sewage disposal and etc.

2. General situation

Thailand is an agricultural country with the local area about 519,953 km.^{2}. 80% of the population live on farms. Rice is the main product and also main export of the nation. Next to rice are maize, munghean, cassava, sugar canes, sorghum and others. The following figures indicate that agricultural product export is about 2/3 the total export.

Table - 1 : Agricultural products export

Year	Total value of Agricultural, Forestry and Fishery exports Unit : million baht.	Total domestic exports.	Percentage
1974	36,846.1	49,164.4	74.94
1975	34,107.6	47,504.5	71.80

Year	Total value of Agricultural, Forestry and Fishery exports Unit : million baht	Total domestic exports	Percentage
1976	46,505.7	60,188.6	77.27
1977	50,793.1	70,397.5	72.15
1978	53,353.7	81,251.8	65.66

Source : Agricultural Statistics of Thailand crop year 1978/79.

Needless to say that water is an important factor for agriculture especially during dry period. If water is available in dry season, second crop or third crop could be produced from the same agricultural land. That means intensive land use could be practiced, agricultural production would increase in the same unit area. Eventhough this practice may involve the use of fertilizer, certified seed and modern technique, it is worthwhile. situation now is that the people attempt to incease their productivity through the expansion of their agricultural area. This is the problem of forest destruction. In the north, the villagers are trying to move upland and highland, on the other hand the Hill Thais (Maeo, Lahu, Lisu, and others approximately 500,000 peoples) living on highland tend to move down because they have destroyed forest for shifting cultivation. In the northeast, the east and the south, shifting cultivation,forest destruction, encroachment of forest land and illegal cutting are also prevalent. This pressure on land requirement may arise from the increase of population. Aside from that water need for every day use also increases. The following table shows population growth from 1963 to 1978 and water consumption.

Table - 2 Population growth and Water Consumption

Year	Population (1,000)	Water Consumption (1,000 m^3)
1963	29,500	11,400
1964	30,080	12,032
1965	31,030	12,412
1966	32,000	12,800
1967	33,000	13,200
1968	34,040	13,616
1969	35,110	14,044
1970	36,370	14,548
1971	37,490	14,996

Year	Population (1,000)	Water Consumption (1,000 m^3)
1972	38,590	15,436
1973	39,690	15,876
1974	40,780	16,312
1975	41,870	16,748
1976	42,960	17,184
1977	44,273	17,709.2
1978	45,222	18,088.8

Source : National **Statistics** Office

Naturally, the population increases the need for agricutural area is in great demand, the rate of forest destruction varies directly with number of population. The following table shows the rate of forest depletion.

Table - 3 Forest destruction (1961 - 1973)

Region	Total Area km^2	Forest area km^2		Forest Depletion km^2	Percent of depleting
		Aerial photo 1961	Land Sat. 1973		
North	171,775	116,275	95,842	20,433	2.2
East	36,394	21,163	15,036	6,127	2.3
North-east	174,407	70,904	47,466	23,438	3.2
Central	67,189	35,660	23,970	11,690	3.8
South	70,188	29,626	18,435	11,191	3.8
Total	519,953	273,629	200,749	72,880	3.2

Source : Royal Forest Dept.

Twelve - year period the forest was destroyed averaging 6,073.33 km^2/year. Eventhough the government put all effort to stop it but it was in in vain. Five years later (1973 - 1977) there had been another forest resource survey. The results were as the followings.

Table - 4 Forest destruction (1973 - 1977)

Region	Total Area km^2	Forest area from Land sat. km^2		Forest Depletion km^2
		1973	1977	
North	171,775	95,842	68,588	27,254
East	36,394	15,036	6,524	8,514
Northeast	174,407	47,460	27,519	19,947
Central	67,189	23,970	12,398	11,572
South	70,188	18,435	16,756	1,679
Total	519,953	200,749	131,785	68,964

Source : Royal Forest Dept.

From the above two tables one can visualize a big different of forest destruction between 1961 - 1973, and 1973 - 1977. The twelve - year period rate of destruction is less than that of the five - year period. This means the agricultural area has increased as the population increased but the productivity was not satisfactory as comparing to other countries such as Korea, Japan, China.

The following figures show average productivity of rice in Thailand as compare to selected countries.

Country	Yield / rai (kg)
Korea Rep.	1,048
Thailand	309
Burma	323
Fed. Malasia	404
China	565
Japan	1,000
Iran	574
Indonesia	467

Source : Office of Agricultural Economics, Ministry of Agriculture and Cooperatives

As a result of wide range of forest destruction, Thailand is now facing with three serious problems.

- Flood
- Erosion
- Drought

Flood brings about a great damage to agricultural area, public and private properties including lives of people. The government spent a lot of money to repair roads, public buildings, aside from that medical treatment and all kind of aid must be given to those who suffer from flood. Erosion from highland and upland increase the sediment in stream bed and river bed, finally in the reservoirs. The following table shows sediment in selected rivers in the north.

Table - 5 Sedimentation of selected rivers in the north

Year	Mae Nam Ping at Chomtong Chiang Mai Ton/year	Mae Nam Yom at Srichatchanalai Sukothai Ton/year	Mae Nam Chao Phya at Nakornswan Ton/year
1960	540,181	-	21,427,160
1961	770,231	-	62,806,752
1962	590,958	-	35,543,688
1963	625,785	-	24,004,500
1964	627,294	876,358	33,907,872
1965	455,605	1,074,664	8,188,746
1966	458,111	840,566	21,455,944
1967	686,519	1,440,508	14,183,622
1968	268,712	317,281	5,568,548
1969	586,577	618,281	17,879,640
1970	1,133,726	4,774,171	57,630,920
1971	1,175,981	3,048,550	19,583,604
1972	427,426	735,782	3,095,777
1973	1,653,919	7,619,692	7,391,632
1974	679,527	2,479,793	6,255,967
1975	1,399,667	4,039,736	20,491,291
1976	479,834	1,565,528	12,151,666
1977	630,008	1,302,337	5,730,844
1978	862,332	2,900,885	-
Average	739,389.11	2,241,609.67	30,961.125.16

Source : Royal Irrigation Department.

In the northeastern region and eastern region, the destruction of forest areas are also great. Thus, the following table shows sediment in some selected rivers.

Table - 6 Sedimentation of selected rivers in the east and northeast

Year	Lam Dom Yai Ubol Ton/year	Lam Chi Chaiyaphum Ton/year	Klong Pra Satung Prachinburi Ton/year	Klong Pra Plong Prachinburi Ton/year
1963	-	23,172	-	-
1964	-	285,414	-	-
1965	-	58,669	-	-
1966	308,372	129,098	-	-
1967	145,469	-	44,815	37,470
1968	165,555	38,474	26,532	21,882
1969	148,120	306,838	64,869	40,505
1970	141,792	91,370	47,382	30,758
1971	182,881	83,615	95,668	36,768
1972	555,881	49,621	42,489	32,286
1973	43,348	40,500	76,251	39,808
1974	111,965	47,327	107,586	32,562
1975	195,605	136,581	80,516	28,927
1976	181,181	199,334	79,770	41,227
1977	139,661	96,872	49,371	12,518
1978	280,445	437,845	89,403	38,816
1979	-	-	10,261	-
Average	207,713.46	135,115.33	63,224.08	32,793.92

Source : Royal Irrigation Department.

After studying problems in waterhsed area over the country, a decision can be made that a system which is suitable at the present is the Integrated Watershed Management.

The system is to develop both natural resources and community simultaneously according to individual watershed. By and large the structure of the activity will be as follows : -

Diagram - 2 Showing Watershed Management Strategies

Watershed Management Strategies

Watershed Analysis

Natural Resources Development	Socio-Economic Development
- Land classification - Rehabilitation of demaged area - Management of existing forest fire protection - Agro-forestry - Extension and public relation etc.	- Resettlement - Road access - Agriculture, Horticulture - Irrigation - Education - Hygiene - Marketing - Other welfare activities etc.

3. Steps of work

Watershed Analysis of a watershed must be done prior to any activity. Every detail should be recorded both natural resources and human elements. Land classification is then conducted to avoid conflict between forest land and agricultural land uses. Each watershed possesses its own characteristic, in general, the land has been classified according to steepness or slope. The following restrictions are set as guideline for practice.

Class	% Slope	Description for uses
I	$<$ 12	agricultural land, no need for soil and water conservation practice.
II	12 - 35	agricultural land, but soil and water conservation practice is needed ; range land.
III	35 - 50	agricultural land with soil and water conservation practice ; range land and fruit trees.
IV	50 - 85	Fruit trees/woodlots and watershed area.
V	$>$ 85	Watershed area.

The above land classification can not be applied to northeastern region due to the fact that this region is a great plateau and rolling area. Special measure will be applied according to circumstance. Protection function of forest, utilization of wood and other forest produce must be taken into account.

3.1 Resettlement

Resettlement of the villagers living in watershed area is a policy adopted. This resettlement is sometime called "forest village" or in case of hilltribes or hill Thais it is called "Hill Thai village". The idea is to group those villagers scattering in watershed area together in form of village, so that it is easy to manage for example housing project, agricultural area, medical care, irrigation system etc. A number of watershed rehabilitation units both in upland and highland are following this policy. New houses, schools, medical care, road access, agricultural land, range land, reservoir, fish pond, woodlot and other welfares have been set up. Mini-hydroelectric power plants are put up (10-50 kw) for light and small industry such as canning of vegetables, furniture plant, oil seed extraction equipment and others.

It is a privilege to think that man stays permanently in one place if he has a job as forest worker or he stays in good house and works in the land set aside for agriculture or in form of agroforestry. There is a school for his children; there is medical care for him and his family. Road access is available for communication and transportation of agricultural products. Again, he may sell his crops individually or in form of co-operatives in order to maintain fair price. Other welfare activities are provided including new technologies for agriculture. The old cultivated land is reforested. The combination of forestry programme and community development so far work out smoothly. This strategy should be supported and extended through out the country.

3.2 Implementation

During the course of the development there should be no delay or stop working. Budget is usually the main problem that changes the course to a negative condition. The villagers will have no confidence in government official. Once they are convinced, work has to be done right away. Extension officer should be chosen carefully because working with villagers in a remote area, one has to be active, well trained, patient, devoted and creative minded. The result of any experiment to be introduced to the villagers must be rechecked and followed up.

3.3 Assessment of the work

Assessment has to be done after a period of time say one year, two years or five years in order to findout whether the work has been proceeded as planned. There are things that need to be changed as time passes. Especially social changes, the requirement for community tends to be changed. Revision of watershed activity may have to be conducted after an assessment.

4. Conclusion

The strategy in planning for a watershed management is to manage both natural resources and human elements. These two must be developed simultaneously to suit the need of the locality, for example, water quality, water quantity, flood retention, erosion control, drought control, stream flow etc. The measure for solving problems does not need to follow the structure of activity and step of work given herein. It depends on technical-know-how to deal with the problem and the ability of the management.

The management must follow and attend to the problem closely. Should anything goes wrong, it should be corrected immediately.

V-3 THE LEGAL ASPECTS

ONEB REGIONAL WATERSHED MANAGEMENT TRAINING COURSE

Chiang Mai, Thailand

May, 1981

by

Judha Krishnamra 1/

and

M.L. Prachaksilp Tongyai 2/

1. Introdution

Honoured Collegues, Welcomed Guests, Ladies and Gentlemen ;

It is with a mixture of excitement and boredom that brings us together today, basically because Watershed Management is a topic which is easy to talk about, but much more difficult to actually carry out in an ecologically acceptable manner which will reflect upon our technological intelligence, political acumen, business morals, social consciousness, environmental awareness, financial wisdom, and, most important of all, our practical and pragmatic attitudes and activities in Watershed Management which displays and continues to affirm our covenant with the spiritual side of our earth bound existance.

Please pause a moment to reflect upon the deep meanings behind the religious philosophies and teaching which appears within the religion which you profess to hold covenant with.

We cannot deny that all religions would like all of us to actualy live in a dynamic, humble, harmonious, and commensal manner where the aggressive survival instincts of mankind is transformed into a productive creativeness which harmonizes with the natural resources and environments contributing to the physical, psychological and spiritual well-being of man and his environment.

1/ Mr. Judha Krishnamra, Land Development Specialist, Project Manager, Thai-Australia and World Bank Land Development Project , Land Development Department, Bangken, Bangkok 9 ,Thailand.

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What watershed management deals with, therefore, must take into account these non-physical and non-material aspects which developing countries like Thailand often reluctant to incorporate into development planning and activities for expediency purposes or because of the emphasis upon over simplified Benefits/Costs ratios which economists and financing institutions consider to be conventionally adequate.

However, like many other developing countries, Thailand faces two closely related problems : over-population or over-rapid population growth and under-development or unsystematic and counter-productive development. While these problems are being tackled by the Government and a few private institutions, much of their efforts and programmes are unrelated and uncoordinated and the results, in conventional Benefits/Costs and Socio-logical terms, have been failures and negatives. There are even instances where activities of one sector are counter-productive to another sector within the same plan.

Collective experiences from various sources and our own indicates that failures of development efforts have their basic weaknesses rooted in the type of understanding or concepts one has of the term "Development".

We need to understand that "development" means that there is a disturbance of the socio-economic patterns and of the lives of people, as well as, communities, and as such, should be introduced gently....on a small scale...and strive to create trust, credibility, and tangible benefits to individuals and communities.

If the initial step is accepted, it will generate momentum for the introduction of bigger changes...at a faster pace and with greater cooperation.

In the past, these initial changes have often been far too big, too incomprehensible, far too expensive for people and sometimes lacked credibility....or did not have sufficient guarantee of benefit.

"Development" programmes or projects are more likely to succeed if opportunities and resources reach individuals and communities and when community personnel actively participate in the implementation of activities in their own communities on a community self-help basis.

Regional, National and smaller scales of development programmes will always have to deal with two basic resources...land and water... with the most critical being the combination of the two within sloped areas which we technically call "watershed" areas.

We have now reached a basic understanding of the complexities and subtleties of the concepts confronting watershed management decision makers, planners, designer, users and, most challengingly , the full-time managers of macro and micro watershed programmes.

Instinctively, we should now escape from this watershed management course before we are dragged into the depths which are associated with full-time responsibilities in management. However, we cannot escape realities and responsibilities, thus, we should deem it a high honour

that we are being prepared for such an essential and critical foundation construction task...the foundation for our national social and economic security which will emanate from our ability to manage the utilization of our land and water resources, of all watershed areas, in a manner which maximizes and sustains the benefits of our individual, muu-Ban, tambon, amphur, changwat, national and regional level development programmes.

2. Frustrations and Obstacles

Although we may become well prepared technically and otherwise there will be frustrations and obstacles arising from conflicting concepts, disciplines and policies or policy interpretations. These frustrations and obstacles are relevant and non-conducive to the objectives of watershed development.

3. Watershed Development Objects

What are we seeking through the wise and comprehensive management of watershed development ?

Ideally, the objectives of watershed development are to provide the fullest protection, development, and management of the land and water resources to maximize the net economic return, consistent with objectives and values that cannot be measured in economic terms either by the community or by the nation.

Included in the specific measure to attain these objectives are land stabilization, soil improvement, irrigation and drainage, flood prevention, development of municipal and industrial water supplies, pollution abatement, and the enhancement of fish and wildlife and recreational opportunities.

The objectives of the watershed programmes for Thailand and other nations, therefore are to obtain the development and improved management of the land and water resources in small watersheds through project-type undertakings, planned and carried out jointly by Tambon, Amphur, Changwat and Central Councils and Agencies...which combines the full understanding and support of a large majority of the public and private land owners and operators within a watershed area.

Such joint planning and joint operations must be organized and carried through all projects related to watersheds. Basically, because watershed protection and management is not a new concept...it clearly defines the relationship of forest cover to streamflow and the interrelationship between the use of land in the watershed and the run-off and streamflow.

Such relationships are apparent to hydrologists and engineers, where mathematical and engineering models and designs for control are available while the farmers do not have such theoretical and high engineering knowledge, they are also well aware of the effects of water run-offs on their land and crops.

Thus, nothing very effective can be done about it without the organized joint efforts of the majority of landowners and other interests in the watershed community. Nothing can be very effective in obliviating frustrations and obstacles if the basic structures for effective and constructive development of watersheds are not created.

4. The Rationale

If Thailand and her sister nations look ahead to the year 2000 A.D.it is not difficult to visualize a population size approximately double that of what we have at present. This would mean that all the basic requirements for human existance would have to be doubled in order to cope with the demand.

Viewed from a salesman's position, this means a better marketing opportunity. Viewed from an industrialist's position, it becomes one of the ability to manipulate raw materials and production overheads in a manner which keeps the per unit of product's real cost, as low as possible, in order to allow for marketing and distribution costs to be absorbed and end up with a retail price which is acceptable to consumers and competitive to other alternatives.

Viewed from a consumer's position, this means that there will be greater competition for the same absolute amount of resources... especially when that resource is land and potable water.

Thus, the manager of a family, community, or nation is confronted with the need to employ defensible and realistic policies. The manager must always keep in mind that efforts towards watershed resource development projects to the exclusion or neglect of resources conservation programmes aimed at maintaining and protecting the productivity of resources already developed could not be a realistic and defensible policy.

Therefore, the activities related to resources development projects which is integrated with resources conservation programs constitutes comprehensive management of resources management...specifically and most critically...the management of watershed development.

It should be remembered that our management efforts are future oriented...that is, the effects or results will be felt in the future. This means that we shall attempt to input as much science and technology into the improved use and development of land and water resources.

However, we must not forget that the amount of land brought into cultivation through improved irrigation and drainage is likely to be more than offest by the amount of farmland taken up by urban, industrial, recreational and other non-agricultural uses.

With such an outlook, resource conservation and resource development must be given first priority. Productive land will become more and more important...not less important...in our total economy. Those who would advise neglect of the conservation of productive soils because they rest their hope upon technological advancement in machinery, fertilizers, or biological improvements...would be gambling with their nation's security.

Thailand's experiences in the river basin portion of watershed management planning has already clearly demonstrated its greatest usefulness only as a general guide for future development. There is no "comprehensive" river basin plan which can serve as a blueprint for all water and land resources development.

There are many reasons for not attempting a "comprehensive" blueprint development plan for a river basin, but ONE PRINCIPAL reason is the TIME LAG between-overall planning and the actual installation of all the features.

No group of planners can foresee the technical ,social, and other changes which will be present over a period of five decades or more--the period over which installation must extend.

However, the population size and other changes which occurs over a period of time and the competition for the use of water and land makes it an economic and political factor...and often a limiting factor to economic development...especially where public opinion is not allowed to be utilized as an effective coordinating Force and an important factor in planning and managing watersheds and river basins.

As in the case of Thailand there are many legally established COMMITTEES assigned the tasks dealing with the allocation and distribution of land and water resources... and these COMMITTEES become keenly aware of how critical these problems can become when there is a drought,flood or pollution condition.

A part of the responsibility for finding solutions for meeting expanding needs rests on the Central Government, because the problems have become larger than the individual community, and may involve many communities or many provinces...however, communities must continue to participate actively.

The inter-relationships of watershed or river basin developments, therefore, must be resolved in a climate of extreme competition for the use of land and water. Watershed planning and management throughout Thailand cannot escape this environment of competition, because socio-economic development activities will bring about competition.

However, competition can become a constructive influence and force if managed wisely. The basic conceptual need here would be for a watershed programme which would assist in closing the gap between the work of individual land owners and operators, on the one hand, and of the Central Government public works on our major rivers on the other.

A Community Watershed Protection Program might be an appropriate movement for bridging the gap between the management of water where it falls...that is, on the farm, orchard, forest or ranch...and the control of water in the major rivers.

Such a movement would aim at conserving and improving our land and water resources in accordance with a technically and economically sound plan, subscribed to and believed in by most of the affected people.

A plan which relates work on one farm to that on the next, with a recognition of the needs not only of the farmers, but also, of all members of the community...including the urban people the industries downstream and the recreationists.

The term " COMMUNITY WATERSHED " seems to be appropriate since it indicates a community of interest. If there is not a community of interest between most segments of society, within a watershed, there is little likelihood that a successful conservation and development job can be done.

The watershed community is not necessarily coincident with any other type of social community. It may embrace several urban communities and several rural communities or it may straddle communities which are centered on divides between watersheds.

At the same instant, the watershed community must originate and have its growth in an understanding of land and water development problems, especially the latter...water. It must be based on sound and often prolonged informational efforts. In many parts of Thailand this will create a strictly new type of community and bring about new social and political alliances.

However, it should already be apparent that the Community Watershed is the natural planning unit through which the gap between the older land and water resource programs can be filled.

Community Watersheds, we believe, are the KEY to total river basin development. Since a river basin is too large a unit for really effective coordination of the agricultural and industrial interests in each tributary watershed, the practical approach to complete river basin development is to start with the planning and treatment of its individual watersheds.

Community Watersheds will be multiple-purpose in nature. It will apply the required soil conservation measures and form conservation plans on the farms of the watershed, as well as, minimum requirements for conservation practices on the forest lands and range lands, either public or private.

Community Watersheds will assist in flood prevention or the reduction of damages from flood and sediment in the flood plain. The reduction of flood damages will not be confined to agricultural values alone, the protection of urban values is equally eligible.

Another principal purpose of the the Community Watershed Programme is the development of benefits from agricultural water management. This involves improvements which serve two or more farms, including drainage, irrigation, and measures to provide a more uniform supply and distribution of water.

Works of improvement for municipal or industrial water supply, for recreation, power generation, pollution abatement by streamflow

regulation, and saltwater intrusion control...all...may be included in the Community Watershed Work Plans, provided they are integral parts of the plans for the protection and improvement of the entire watershed.

5. The Basic Management Needs

5.1 Need for Education and Understanding

No single factor can be more important than a broad base of understanding among all elements of the Community before a watershed improvement project is undertaken. In fact, until there is such a widespread understanding, there can be no community of interest and, hence, no true Community Watershed Project.

Agreement on objectives and understanding of potentialities cannot be confined to farmers and ranchers, alone, or to business interests, or to sportsmen's interests, or to any other group. They must be mutually understood and agreed upon by all of these components of the community.

5.2 Need for Sound Technical Planning

There is a need to provide sound and adequate technical help to local organizations in developing a plan for their Community Watershed Improvement.

5.3 Need for Tangible and Widespread Benefits

The basic concept of a Community Watershed Project is the protection, improvement and management of ALL of the land and water resources of that area.

No project can be successful if it is motivated by the desire for carrying out a single-purpose objective to the exclusion of other watershed needs.

Moreover, the benefits must be real and tangible and in excess of what it will cost to achieve them. Often the cost of achieving certain objectives that are sound in principle may so far exceed the tangible benefits that can be realized that the time, effort, and money required might better be expended elsewhere.

5.4 Need of Adequate Legal Authority for Local Organizations

Local units of government to carry out the will of the majority of the local people to accomplish local objectives. Such as, law enforcement, fire protection, and all of the elements of community life which are of primary concern to the community are needed...and have been the form of ancient Thai government during and prior to the Sukhothai and Ayudhaya Periods of History.

Similarly, with Watershed Protection Projects..if the tasks are too big for the single individual to do, and too limited in scope to be a Central Government public works project, then, there must be

a mechanism whereby local organizations can be empowered with the authority and responsibility needed to achieve their objectives.

Many local units of government have certain authorities to achieve certain of the objectives of a complete watershed improvement program. But experience, to date, has shown the desirability in most situations of having special-purpose legal districts through which local people can exercise, by majority vote, such legal powers as are customarily exercised by local units of government...including the condemnation of land, the raising of tax revenues, the issuance of bonds, the operation and maintenance and, if necessary, the policing of improvements.

While these needs can sometimes be adequately met by a combination of existing authorities of several kinds of units of government, it should be pointed out and seen that there is great wisdom in providing, through NEW LEGISLATION, a basis for the creation of Watershed Improvement Districts or similar forms of local special-purpose districts to carry out the over-all objectives of watershed improvement work.

5.5 Need for Improved Changwat Legislation

A read need exists in the continuing need for improved Changwat legislation to enable Tambon and Amphur level local organizations to carry out their watershed improvement objectives...as in many other spheres of Thailand's national economy...for the Changwat to better equip themselves to carry their share of the responsibility, both administratively and financially, rather than leaving this task solely to the agencies of the Central Government.

Changwats, particularly,need to improve their water rights legislation, their administration of state conservation agencies, and to provide greater financial support to local organizations in planning and carrying out watershed improvements.

5.6 Need for a National Inventory of Land and Water Resource Development

There is a continuing need for developing the framework of total national needs, within which individual watershed improvement undertakings can be accomplished.

6. The Present Legal Aspects

Watersheds and the land and water resources of river basins of Thailand are administered through many separate pieces of legislation which have appeared during the course of national evolution. The more important legislations includes the following :

1. The Forest Reserve Act. B.E.2507 (A.D.1964) is the result of amendments made to the original Forest Protection and Reservation Acts of B.E. 2481 (A.D.1938); B.E.2496 (A.D. 1953) and B.E.2497 (A.D.1954).
2. The Forest Act, B.E.2518 (A.D.1975) is the fifth amendment of the original Act which was first enacted in B.E.2484 (A.D.1941)
3. The Wildlife Preservation and Protection Act, B.E.2503 (A.D.1960)

4. The Land Code, B.E.2497 (A.D.1954)

5. The Minerals Act, B.E.2522 (A.D.1979) is the result of amendments to the Minerals Act, B.E.2510 (A.D. 1967) and B.E.2516 (A.D.1973)

6. The Enhancement and Conservation of National Environmental Quality Act, B.E. 2518 (A.D.1975)

7. The Agricultural Land Reform Act, B.E.2518 (A.D.1975)

8. The Agricultural Land Consolidation Act, B.E.2517 (A.D.1974)

9. The Act Controlling the Hire of Paddy Land, B.E.2517 (A.D 1974)

These main Acts and Codes have to be systematically analysed in order to understand the Legal Aspects which confronts the Management and Managers of Thai Watersheds and River Basins.

7. The Key Legal Officials of the Acts and Codes

7.1 The Forestry Reserve Act

This Act has determined two types of Law Enforcement Officers:

1. A Committee, consisting of a representative of the Royal Forest Department, Department of Provincial Administration Department of Lands and two other persons appointed by the Minister of Agriculture and Cooperatives.

   The Committee has powers and functions which includes controlling competent officials; investigating and considering complaints of any person who claims the right or benefits in the reserved forest , but is not empowered to arrest or suppress offenders in any respect.

2. Competent Officials, are appointed by the Minister of Agriculture and Cooperatives, as follows:

   the Director-General of the Royal Forest Department,
   the Deputy Director-General of the Royal Forest Department,
   the Expert of the Forest Products of the Royal Forest Department.
   the Provincial Governors,
   the District Officers and the Deputy District Officers attached to the Sub-Districts, and
   the various officials of the Royal Forest Department.

7.2 The Forest Act

In this Act the Law Enforcement Officials are the Competent Officials appointed by the Minister of Agriculture and Cooperatives, they are, in fact the same Competent Officials as that appointed under the Forestry Reserve Act...with the inclusion of Forest Police.

The Forest Police are attached to the Police Department at the Headquarters level (Central Investigation Bureau) and have powers under the Criminal Procedure Code and the Territorial powers of the Forest Act and related laws...and they are under the Command of the Director-General of the Royal Forest Department.

7.3 The Wildlife Preservation and Protection Act

Under this Act, there are two specifications of the Competent Officials who take care of and protect wildlife :

1. The Committee, called "the Committee for the Wildlife Preservation and Protection", consists of :

   1.1 A Permanent Committee or the Ex-Officio Committee, namely:
   the Under-Secretary of the Ministry of Agriculture and Cooperatives,
   the Director-General of the Royal Forest Department,
   the Director-General of the Local Administration Department, and
   the Director-General of the Department of Land.

   1.2 A Temporary Appointed Committee numbering five persons and not exceeding eleven persons appointed by the Minister of Agriculture and Cooperatives, it has advisory capacity on two-year term basis.

2. The Competent Officials, these officials are the same persons as those who are appointed under the Forest Reserve Act, B.E.2507 and the Forest Act, B.E.2518. They are empowered as law enforcement officials under the Criminal Procedure Code.

7.4 The Land Code

In this Code there is a "National Land Allocation Commissions" Chaired by the Minister of Interior and having the Director-General of the Land Department as Ex-Officio Secretary of the Commission, along with not less than 8 and not more than 20 qualified members appointed by the Council of Ministers.

Commission members hold office for 4 years and may be reappointed.

7.5 The Minerals Act

In this Act there is a Commission consisting of :

the Under-Secretary of the Ministry of Industry, (Chairman),
the Director-General of the Royal Irrigation Department,
the Director-General of the Mineral Resources Department,
the Director-General of the Department of Lands,
the Director-General of the Royal Forest Department, and

not more than 3 other persons appointed by the Minister, with the Chief, Mining Concession Division, as Member and Secretary.

This Commission is responsible for giving advice and recommendations to the Minister on subjects relating to the enforcement of this Act. The Minister appoints Commission members to two-year terms.

7.6 The Enhancement and Conservation of National Environmental Quality Act

In this Act there is a Board called the "National Environment Board" Chaired by the Deputy Prime Minister and includes the following members :

the Under-Secretary of State for Defence,
the Under-Secretary of State for Interior,
the Under-Secretary of State for Agriculture and Cooperatives,
the Under-Secretary of State for Industry,
the Under-Secretary of State for Public Health,
the Secretary-General of the National Economic and Social Development Board, and
not more than 5 persons qualified in ecology, and not more than 5 representatives of independent institutions or organizations or other persons appointed by the Council of Ministers, with
the Secretary-General of the National Environment Board as a Member and Secretary.

The representatives of independent institutions or organizations or other persons appointed as members shall not be government officials, officials of state enterprises, or officials of a local government who hold permanent positions or receive salaries.

Members of this Commission remain in office for 3 years and may be reappointed for not more than one consecutive term.

The Prime Minister is in charge and control of this Act.

7.7 Agricultural Land Reform Act

In this Act there is a Committee called "the Agricultural Land Reform Committee" with the Minister of Agriculture and Cooperatives as Chairman and includes :

the Under-Secretary of State for Commerce,
the Under-Secretary of State for Interior,
the Under-Secretary of State for Industry,
the Director-General of the Department of Land Development,
the Director-General of the Department of Agricultural Extension,
the Director-General of the Department of Local Administration,
the Director-General of the Department of Lands,
the Manager of the Bank for Agriculture and Agricultural Cooperatives, plus 7 other members to be appointed by the Minister,

consisting of 4 qualified persons, and
3 representatives of agricultural workers, with the Secretary-General of the Agricultural Land Reform Office as a Member and Secretary.

The Minister of Agriculture and Cooperatives and the Minister of Interior shall be in charge and control of the execution of this Act while the Ministry of Finance shall be in charge of the Agricultural Land Reform Fund and shall effect disbursement of such funds for expenditures in connection with this Act.

7.8 Agricultural Land Consolidation Act

In this Act there is a Committee called "the Central Land Consolidation Committee" with the Minister of Agriculture and Cooperatives as Chairman,

the Under-Secretary of State for Ag. & Coops as Vice-Chairman,
the Under-Secretary of State for Interior as Vice-Chairman,
the Director-General of the Royal Irrigation Department,
the Director-General of the Ag. Extension Dept.,
the Director-General of the Land Development Dept.,
the Director-General of the Agricultural Technics Dept.,
the Director-General of the Coops. Promotion Dept.,
the Director-General of the Local Administration Dept.,
the Director-General of the public Prosecution Dept.,
the Director-General of the Land Dept.,
the Director-General of the Highways Dept,
the Director of the Budget Bureau,
the Secretary-General of the National Economic and Social Development Board,
the Manager of the nk for Agriculture and Agricultural Cooperatives, plus not more than 5 other members appointed by the Council of Ministers, with
the Head of the Central Land Consolidation Office as Member and Secretary.

The Minister of Agriculture and Cooperatives and the Minister of Interior are in charge and control of execution of this Act.

7.9 Analysis of the Legal Officials Duties

The Chairmen and Members along with the duties and powers of the Commissions and Committees mentioned under 7.1 through 7.8 serves to illustrate the wide range of differences and similarities along with the mixture of the levels of activities expected to be resulting from them.

The National Environment Board (7.6) is Chaired by a Deputy Prime Minister while the Prime Minister is in charge and control of the Enhancement and Conservation of National Environmental Quality Act. Thus, it would appear that this Board should be of National Policy Formulation Level with capabilities towards pushing through necessary decisions related towards the Conservation of National Environmental Quality.

Such a Board, therefore, is expected to be composed of key Ministers or Deputy Ministers who are of Cabinet rank and able to formulate policies for finalization and approval by the Council of Ministers before action by the Prime Minister.

However, the Board Members are of Under-Secretary or non-Cabinet rank whose duties and authorities differ to a very large extent and includes non-governmental representatives whose roles would be that of technical experts or opinion representatives whose functions should be at the Ad. Hoc , Working, or Technical Committees or Sub-Committees level.

If viewed against the Agricultural Land Reform Committee of the Agricultural Land Reform Act (7.7) and the Central Land Consolidation Committee of the Agricultural Land Consolidation Act (7.8) there is the feeling that these Agricultural Lands related Committees are given less status by name and the lack of a Deputy Prime Minister as Chairman.

However, these two Committees appear to be attempting to bring about cooperation and coordination of multi-disciplinary inputs through joint responsibilities for these two Acts by two Ministers, the Minister of Agriculture and Cooperatives and the Minister of Interior. However, it becomes apparent that the responsibilities of the Minister of Interior is cosmetic because he does not share in the Chairmanship of these two Committees.

After reviewing the list of Committee members, it will be seen that the Agricultural Land Reform Committee has been given less emphasis because it does not spell out the Vice-Chairmanship in the manner of the Central Land Consolidation Committee.

However, because it is spelled out that there are two Vice-Chairman, the Under-Secretary of State for Agriculture and Cooperatives and the Under-Secretary of State for Interior it appears that the Chairman (the Minister of Agriculture and Cooperatives) is just a figure-head while the Minister of Interior is not expected to actually become directly involved.

On the other hand, the National Land Allocation Commission of the Land Use Code (7.4) sounds impressive and high powered, but the use of the term Commission is mis-leading because it is Chaired by the Minister of Interior and will consist of 20 qualified members appointed by the Council of Ministers.

The weakness of the Commission's technical, sociological, and other meaningful roles related to land resources management is in-built through the loose application of "qualified" members...without any description of the constraints which constitutes becoming qualified. There is a similarity within the Agricultural Land Reform Committee and the National Environment Board, however, this is partly narrowed down through the coupling to result in qualified in ecology for the NEB case.

Thus, the role of the National Land Allocation Commission remains weak and susceptable to credibility gaps, especially where watershed and river basin management insists that land and water resources

are the key components for productive development and utilization for the future security of Thailand.

If we now consider the Forest Reserve Act (7.1) ,the Forest Act (7.2) and the Wildlife Preservation and Protection Act (7.3) we will find that Competent Officials are the same officials throughout, with variations in minor details involving being empowered as law enforcement officials under the Criminal Procedure Code and having the assistance of Forestry Police.

These three Acts, within themselves, cause considerable confusion and frustrations to Watershed Managers because of their similarities and differences...especially when addressing the appointed ompetent Officials with and without law enforcement powers under the Criminal Code.

8. Summing Up

This very brief example analysis of the legal officials duties indicate that Thailand may actually have an over-abundance of laws and committees dealing with land and water resources...and the organic and inorganic resources on the surface or under the surface of the land and water resources which must be wisely and pragmatically shared and utilized for maximum and long-term benefits.

There are other problems with the legal Aspects which presently confronts the Watershed Manager and Planner. The most obvious being the monopolistic trend towards keeping all Codes and Acts in the Control of the Central Government and Government Officials.

There is no allowance for Changwats or Provinces to Legislate and Supervise their specific needs, within the framework of a Central or Federal Code or Act. There is also a limitation of local units of government to carry out the will of the majority of the local people to accomplish local objectives, such as that which existed in Thai government during and prior to the Sukhothai and Ayadhaya Periods.

These legal constraints have to be modified in order to allow the basic concept of a Community Watershed Project to become a viable success. The pilot projects are available and viable from the prägmatic and practical efforts of the Population and Community Development Association (PDA) ; the community fish ponds funded by USAID and given sound technical assistance by the Fisheries Department; ,and the various self-help projects under Royal Patronage.

Such pilot program successes confirms that the Thai peoples are willing and able carry out and make a success of projects in which they participate in as joint beneficiaries...or where they are a part of a community of interest.

It should be remembered that it is always difficult to carry out adjustments and changes, however, it was also difficult for Thailand's former Monarchs to institute the necessary changes which carried Thailand through many stressful situations.

The objective of the Legal Aspects Analysis, however brief and while skimming only the surface, is to indicate that there are changes and innovations needed in the Legal Aspects in order to allow for the successful and widely beneficial completion of Community Watershed Programmes.

With changes in the Legal Constraints the Community Watershed Manager will be able to deliver the development and improved management of the land and water resources in small watershed through project-type undertakings...planned and carried out jointly by the Tambon, Amphur, Changwat and Central Councils and Agencies...and combines the full understanding and support of a large majority of the public and private land owners and operators within a watershed area.

9. Concluding Remarks

With the conclusion of this Watershed Management Training Course, especially this section on the Legal Aspects, we hope that it will only be the beginning of a series of developments which will assist in the preparation of Watershed Managers for their highly important and widely responsible tasks.

Please remember that, Watershed Management is a development activity which will disturb the socio-economic patterns of the people who are supposed to benefit from our actions. Thus, all ideas, plans and projects should be introduced gently...on a small scale..and strive to earn their trusts in the credibility and tangible benefits to them as individuals and communities.

Remember that a small seed has to be nurtured...and...in time will grow into a big and bountiful tree. Thus, if the initial step is accepted, it will generate momentum for the introduction of bigger and more beneficial changes.

V-4 ECOLOGICAL ASPECTS OF WATERSHED RESOURCES MANAGEMENT IN HUMID TROPICAL ECOSYSTEMS 1/

by

Nipon Tangtham 2/

1. INTRODUCTION

1.1 The Need for Resource Management Planning

In recent world situation, the demand for land as a base for producing food for the world's population has been rapidly increasing. As a consequence, the governments of almost every country are preparing plans for providing land for people for living and farming. In countries where lowlands are adequate for food production, the problems of environmental deterioration due to misuse and abuse of land is not significant. However, many countries lack adequate lowland area and they cannot possibly keep the people living and cultivating only on such land, large acres of upland watersheds must necessarily be opened for supplying the people's needs. This leads to serious problems of land use conflicts, water polution., soil erosion and sedimentation, and the change of microclimate. These mentioned problems could results in significant deterioration of the watershed ecosystems, especially the land's long-term productive capacities and the water yield potential.

How can this kind of situation be resolved to satisfy the needs and desires of an ever more demanding society with limited supply of land resource ? Furthermore, how should the watershed resources be allocated to its alternative uses without damaging fragile environments ? In this day of resource shortage, numerous ecologists and the land use planners similarly suggested that, we cannot achieve environmental responsibility, balance against the needs of a dynamic economy, without a rational land use policy (Harvard and Henderson,1974 ; Butz, 1974, and Vink, 1975). Academically speaking, conflicts and the minimization of environmental impairments can be partially resolved

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1/ Prepared for the MAB/NEB/USAID Regional Training Course on Watershed Resources Management and Environmental Monitoring in Humid Tropical Ecosystems, Chiangmai, Thailand. May 25 - June 8, 1981.

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by the knowledge of land characteristics from which various land use opportunities and constraints within a watershed can be interpreted. That is the resolution can be made possible on the basis of a comprehensive appraisal in the inter-relationships between ecological condition, types and intensities of land use and management practices, and problems of environmental degradation.

In humid tropical ecosystems, especially mountainous watersheds where shifting cultivation is becoming more and more marked as population increases, there is special need to protect the environments from all forms of deterioration, particulary, soil degradation, deforestation and the treatening spread of desertification. This is because nearly half of the world's tropical forests have degenerated, thereby affecting climatic stability and its genetic opportunity. Large segments of atmosphere, soils, rivers and seas have been polluted in some ways. Therefore, new enterprise and confisticate technologies are needed to resolve those problems.

1.2 An Ecological Approach to Integrated Resources Management.

In the past, development on the watershed resources was generally based on intuition, although that in turn rested on experiences, some of it learned painfully through mistakes that wasted natural resources. In recent years, confronted with the evidence of past fallacy, and the realization that we can no longer move to new frontier to escape from those we have damaged, interest in the environmental aspects of the natural resources consume and management has, consequently, reached major national and international levels. Most developed and developing countries now pay more attention to the efficiency and long-term stability of modern agricultural and silvicultural systems as ecosystems, particularly in relation to the depletion of resources and deterioration of the environment. This is because the concept of the ecosystem approach to resources management is derived from the recognition of the interaction of the uncountable parts and their functions in any natural system. Also, an ecosystem can be small or large - and is made up of living and non-living components. Within each ecosystem, there is a finite life-supporting capability- a finite natural carrying capacity for living things which can be increased by application of technologies.

A watershed, as well, is an integrated systems that tranforms precipitation, solar radiation, other environment variables, labor and capital into word and agricultural products, livestock products, wildlife, recreational and esthetic satisfaction and water, The forest management subsystem, the grazing subsystem, the recreational use and development subsystems and also the water management subsystem interact to produce the vegetation, animal and soil conditions that govern the yield and quality of its products and services. Any action of resource utilization in watershed area may lead to loss of land capability, disruption of water balance, increased desication which consequently create multitudinous environmental problems. These interrelationships and their interaction can be illustrated as a macrosystem view in Figure 1 , and also as an watershed ecosystematic view subject to development in Figure 2.

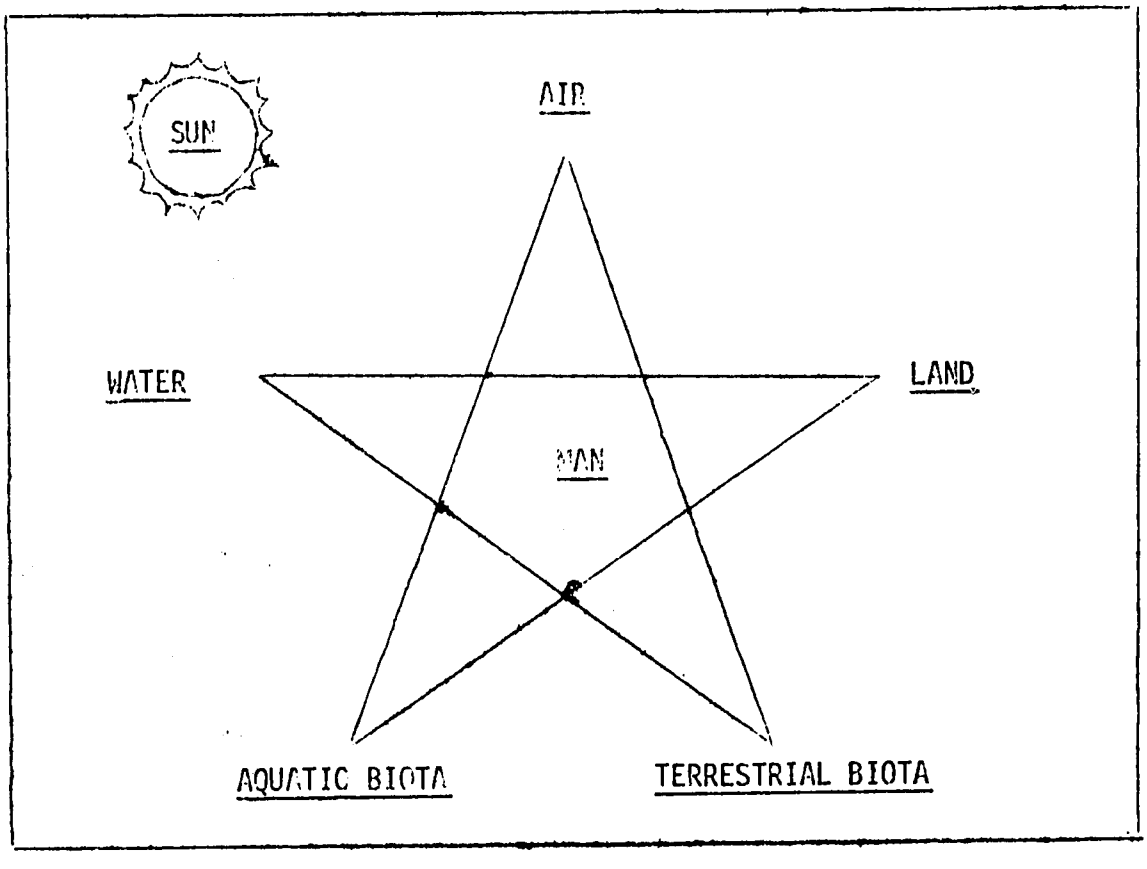

Figure I Macrosystem view of environment components and their basic interrelationships, as in a river basin ecosystem subjected to development... the linkages for each component join it with all other components and show interdependence. (from Figure I.1 in Nam Pong Environmental Management Research Project, [illegible])

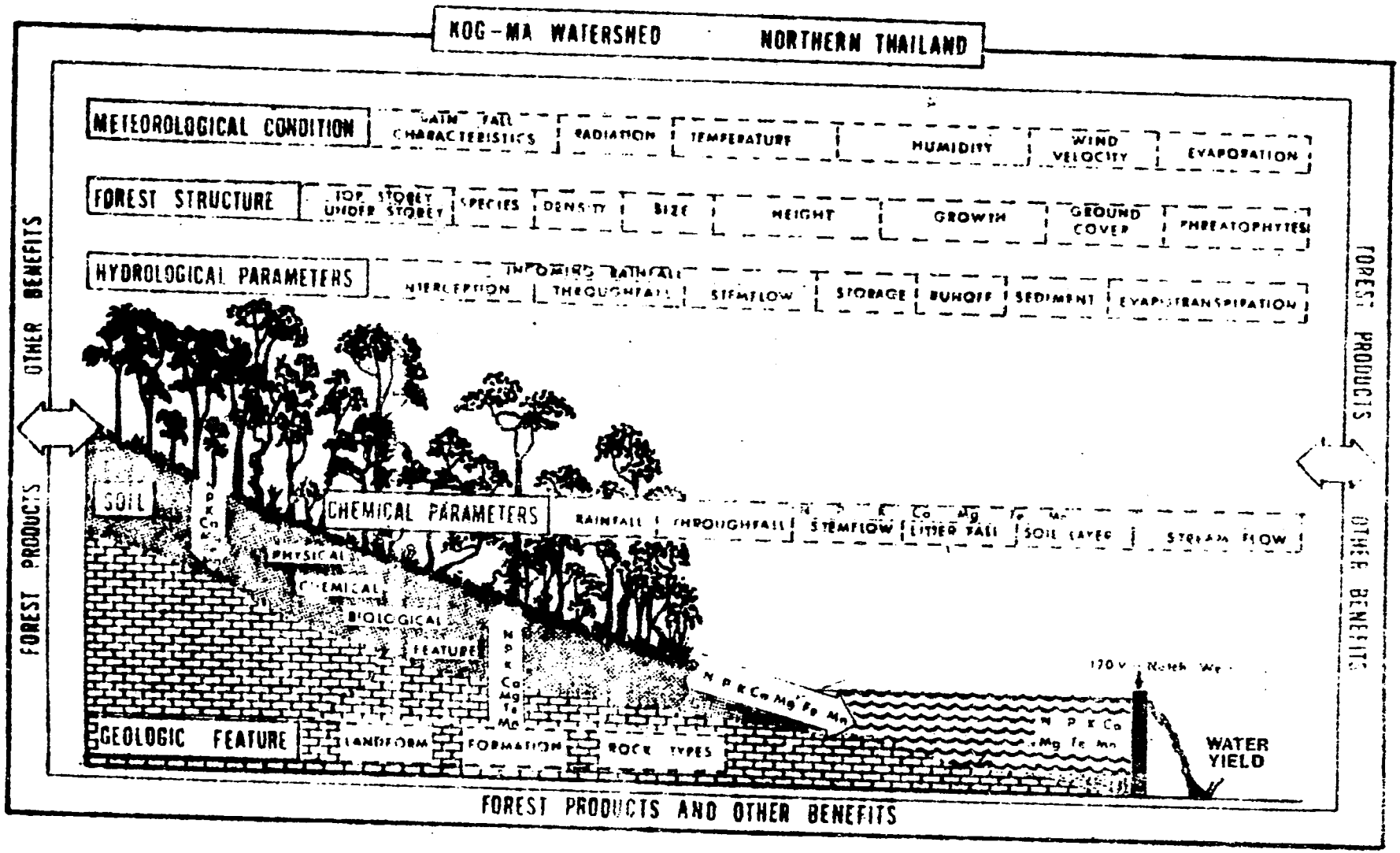

Figure IV-2 An approach to ecosystem study of undisturbed hill-evergreen forest, Northern Thailand.

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General and specific investigation in many developed countries have reached the widely excepted conclusion that understanding of ecosystem concepts and the environment can aid in developing plans for wiser and even more intensive use of the natural resources. Therefore, at present situation, a theory of ecosystem seems to be the only appropriate tool toward a more careful and systematic approach that can effectively guide management for such a complex humid tropical ecosystem.

The intention of this paper is to present, in general view, an ecosystematic consideration in watershed management. Humid tropical ecosystems are described basing on the available information. The possible ecological and environmental effects of forest destruction and conversion in the humid tropics are also denoted. Finally, ecological outlooks of watershed management for the tropical ecosystems, which is the main purpose of this paper, are also discussed.

2. ECOSYSTEMATIC CONSIDERATION IN WATERSHED MANAGEMENT

2.1 The Nature and Behaviors of Ecosystems

An ecosystem is a basic functional unit of nature which includes both organisms and their nonliving environments, each interacting with the other and influencing each other's properties and both necessary for the maintenance and development of the system (Odum,1963). It possesses its own organization which is represented by plant-animal groups in continual interaction and existing in a physico-chemical environment where exchange occurs (Vaissiere, 1972).

Ecosystems can exist on many levels and in many sizes - a small pond, a vast river basin transcending national boundaries, the biosphere itself. Each has its own equilibrium and interdependencies within which energy and matters are circulated. Photosynthesis, decomposition, herbivory, are among the principal biological processes responsible for the transport and storage of materials and energy. In the nonliving part of the ecosystem, circulation of energy and matter is completed by such physical processes as evaporation, precipitation, erosion and deposition (Tansley, 1935). All of these activities take place at varying rates and in different quantities. The principles of carrying capacity,survival threshold, biological succession and resilence can be observed to assure the sustained yield of a particular resources (Inter-agency Committee on Ecological Studies, 1975).

Although A.C. Tansley, who originated the term ecosystem, restricted its application primarily to the community level, in recent years, the concept has been extended to the levels of population and organism. However, major emphasis is still on the cycling of elements; the transfer, utilization, and dissipation of energy; and the rates at which this processes occur, as same as those mentioned in above paragraph.

It was stated by Holdgate (see Holing, 1978) that while links exist between ecosystems, it is, by no means always necessary to possible to trace these behaviors to their ultimate terminations in order to understand the functionings of systems. Moreover, ecosystems, like species, have resilence. They are in a state of dynamic equilibrium, the balance of nature is the result of continuing change.

They have evolved in such a manner as to be able to withstand considerable stress before their structure and integrity are damaged. The natural linkages of energy and/or matter transfer in an ecosystem can be partially or grossly changed by such major environmental alterations for development as take place in watershed management schemes including those that involve man-made activities.

For convenience, ecosystem is usually divided into four separated entities, i.e., agricultural ecosystem, forest ecosystem, aquatic ecosystem, and urban ecosystem. They are, however, isolated only for study or research in particular field. In the actual world there is frequently some movement from one ecosystem to another, whether immediately adjacent or thousands of miles distant.

In searching for the ecological outlocks of watershed resources management in humid tropic ecosystem, the author would like to convey all participants looking at all terrestrial ecosystems as they originated from the primative-humid forest ecosystem. The existing agricultural ecosystem, urban ecosystem and forest ecosystem at the present are the results of the conversion and transformation of primitive forest ecosystem by both the natural events and human activities. The environmental deterioration of all forms that have happened and are happening, are the consequences of those actions.

2.2 Ecological Consideration in Watershed Management

It has been recognized by the watershed scientists and the people involve in water resource development that watershed management is simply an activity of the overall management plan any system to the wildland administrator actively pursuing a multiple land use management. By this multiple use, it refers to production and management of various resource products or resource product combinations on a particular land management unit. The basic objective of multiple land use management is to manage the water resource product complex for the most beneficial combination of present and future uses.

To meet such favorable objective without impairing physical environment, watershed resources must be carefully managed basing on the nature and behaviors of particular watershed ecosystem and environmental constraints. Although, specific criteria for land use planning or for watershed management to serve multiple purposes, and at the same-time, to sustain the ecological balance have not yet been proposed, the following suggestion mentioned in Vink (1975)'s publication, perhaps, could be a principle that one should keep in mind. They are :-

1) Land must be used according to its capacity and its potential, i.e., land of high potential for agriculture should be used to meet this potential through the production of crops. All those lands of low potential for agriculture should be assessed in terms of their possible usage for ranching, forest and wildlife management or multiple land use purposes.

2) Environmental consideration is necessarily introduced into the planning and development. Local environment should be regarded as a functioning ecosystem within which agricultural and other land use development take place and to which those should adapt themselves

3) More attention to the efficiency and longterm stability of modern agricultural and silvicultural systems as ecosystems must be paid, particularly in relation to the depletion of resources and deterioration of the environment.

4) Planning for better forms of land use must involve two related objectives : the first is to raise productivity, and the second is to safeguard the high levels of production attained by adopting appropriate techniques to conserve soil and water. In developing countries, however, form of land use can be changed in time. This is the fact that, as a country develops, patterns of land use are apt to become more varied and intricate.

5) An ecological sound watershed management plan should begin with a comprehensive ecosystem analysis, including an understanding of energy flow, nutrient cycling, population dynamics and other species crucial to successful land management.

6) Industrial development in the tropics has adverse influence on the renewable resources and will eventually cause many problems, such as soil and water pollution , comparable to those now being faced by the more developed part of the world.

3. HUMID TROPICAL ECOSYSTEMS

3.1 Critical Situation of Tropical Ecosystems

In the former day, the humid tropical region is endowed with a well balanced ecosystems. When one speak of tropical ecosystems, one usually refers to the land's rich and distinct natural resources that are made up mostly of virgin forest, wildlife, flora and fauna as well as vast coastal waters and unlimited fishing ground that remained for several years unexploited.The roles of tropical forests in the conservation of soil and water and in mitigating the destructive effects of floods as well as in the amelioration of the microclimate, are too well known. Unfortunately, when man and the so called "civilization" caught up with them, it's nature and behaviors have been progressively deteriorated since then.

According to Richards(1973), the tropical forest ecosystems will virtually disappear from the face of the earth by the end of the 20th century. Lanly and Clement (1979) also reported that the

Asian countries, in which encroachment for agriculture resettlement is likely to result in the disappearance of the tropical forest by the year 2,000 are Malaysia, Thailand, Indonesia, Philippines, Vietnam,, India, Burma and Nepal. Guestimation basing on his common sense as well as using a mathematical model, Spears (1979) indicated that "... by the year 2050 the number of countries containing a significant areas of wet tropical forest might have declined from 36 to 20. It seems highly possible that if nothing is done to control world population and to delay tropical deforestation, there will be about 500 million ha of wet tropical forest by then, and may disappear altogether before the end of the next century."

As has been stated in the previous section that "an ecological sound watershed management plan should begin with a comprehensive ecosystem analysis" , this part is, therefore, prepared for one who lacks of basic knowledge in humid tropical ecosystems. The following sections will be a brief information on geographic distribution, ecological evolution, soil conditions, hydro-ecological balance, biota characteristics, mineral transport systems, and energy flow through the ecosystem of the tropics. All information will provide a crucial fundamental for creating possibility of successful management for the tropical ecosystems which will be discussed later in the last part of this paper.

3.2 Ecological Evolution and Geographic Distribution

It was reported in Esteban (1980)'s article that the tropical rain forest (TRF) is one of the most ancient (300 million year old) ecosystem in the world. Fossil evidence indicates that it has existed continuously since Cretaceous period. About 150 to 200 years ago, a great belt of TRF stretch almost unbroken over the lowland of the humid tropics of Central and South America, Africa, Southeast Asia and the islands of Indonesia. It geographic distribution was shown in Figure 3.

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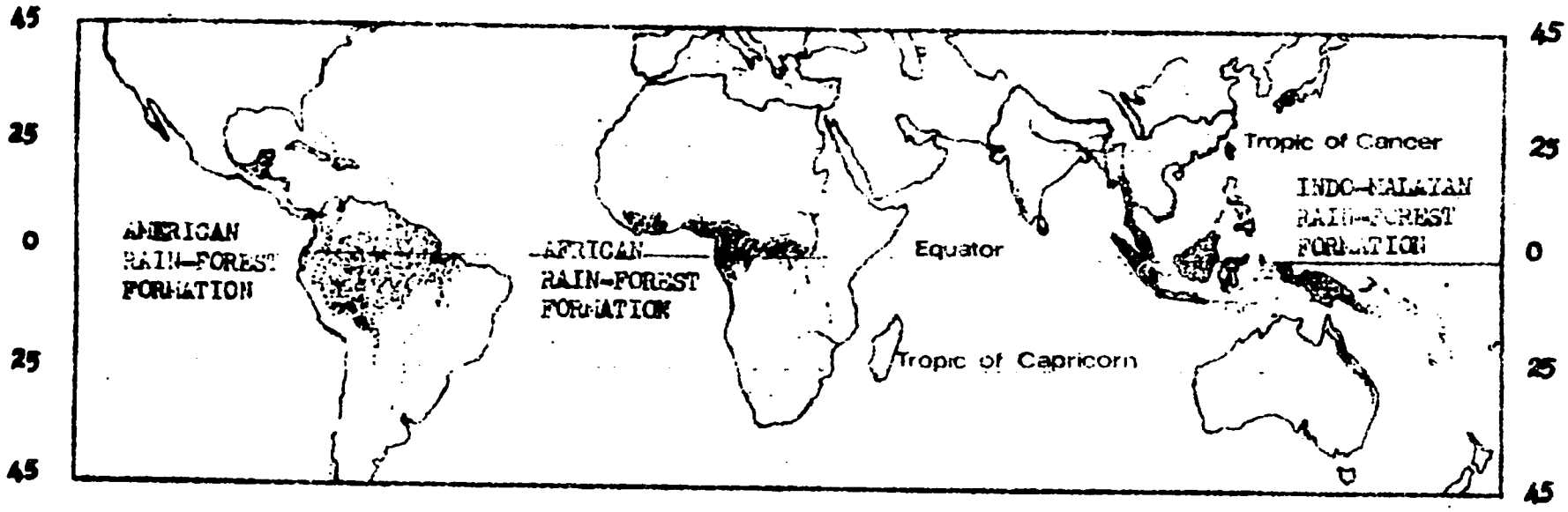

Figure IV-3. Distribution of the tropical rain forest (dotted area)... modified from Richards, 1952 .

3.3 Its Macroclimate and Classification

Due to the particular distribution of continents and oceans, and the circulation of air masses and sea currents, there is wide variation in rainfall, air humidity, temperature, wind and other. Such changes in macroclimate are responsible for the large-scale pattern distribution as illustrated in Figure 3. These characteristics also effect their composition and structure.

When using the phase "tropical ecosystems" we are considering all ecosystem that occupy in the intertropical zone, between the Tropic of Cancer and Capricorn. According to the diagram designated by Holdridge (1967) the "humid tropical ecosystems" refer to the ecosystems in the Tropics but strictly concentrate on the areas of having average annual rainfall greater than 2,000 mm. with mean annual potential evapotranspiration higher than 1,400 mm. but potential evapotranspiration ratio lower than 1.0, and also mean annual biotemperature higher than 24°C. Much of tropical Southeast Asia have rainfall totals surpassing 2,000 or 3,000 mm,which are distributed more or less equally over the year. This is the one of the most powerful factors controlling the nature and behaviors of humid tropical ecosystems.

3.4 Soil Conditions

3.4.1 Soil depth and Fertility

Over large area of tropical ecosystems, the reddish soils; which have been given various names including latasols, ferallitic soils ; kaolisols, oxisols and inceptisols, usually occur. These soils represent the soil climax of the humid tropical under freely drained conditions. The weathering of the rocks to form soil may involve both physical and chemical changes, but in the wet tropics weathering is almost entirely a chemical process. The high temperature and humidity of this region also play important role in activating the rapid rate of rock decomposition. The depth of weathering is extremely deep due to the absence of Quaternary glaciations and the protection of the dense forest. In some certain places, it can be deeper than 20 meters.

In their deeply weathered profile,felspathic materials are decomposed slowly but completely, leaving behind simple clay minerals. The mineral nutrient content is very limited, since weathering and leaching have removed nearly all bases, so that only free Fe and Al oxides, together with small amount of oxides of Ti, Cr and Ni along with fine quartz and kaolinite are left to form the soils (Richards, 1952, Longman and Jenik, 1974). These soils are generally acid and poor in macro-nutrients. Nevertheless, the presence of the forest modifies this; the upper horizon is enriched with organic matter and base through the decomposition of plant litter. Finally, they are

generally well drained and their structure involves good aeration, but once the forest disappears they are very susceptible to leaching (Unesco, 1978).

3.4.2 Soil-hydrologic Properties

1) Soil Porosity

Among various types of tropical soils, a lateritic soils now called "oxisols" seem to be the first one that it porosity was measured (Robert, 1933). Its total porosity equalled 57 percent in the first 12 cm and 47 percent between 75 and 150 cm depth; hence a satisfactory permeability. Bulk density and total porosity of the other soil types occupying in the tropics were shown in Table 1. This high permeability is principally due to a large number of micropores which do not close even when the profile is moistened.

Table 1. Bulk density and total porosity of forest soils within the humic tropics

Soils	Bulk density, gm/cc Area	Bulk density, gm/cc Depth	Total porosity, Area	Total porosity, Depth
Oxisols (Hawaii) 1/ (Low humic latosols)	1.1	1.2	62	59
Inceptisols (Hawaii) 1/ (Humic latosols)	0.8	0.8	70	70
Ultisols (Hawaii) 1/ (Humic ferruginous latosols)	1,2	2.0	60	-
Ultisols (Thailand) 2/ (Tropohumults beneath humid forest)	0.8	1.1	64	54
Soil under 3/ dry-evergreen forest	1.1	1.3	46	43

1/ From Unesco (1978) Chapt. 12 - Water balance and soils

2/ From Udomchock (1981)

3/ From Niyom (1980).

Finally, more intensive analysis made in northern Thailand by Udomchock (1981) indicated that total porosity in A,B1,B2 and B3 horizons of ultisols under hill-evergreen forest in northern Thailand were 64,59,54 and 49 percent respectively, Quick drainage pore (the pores that have

diameter ≥ 30 μm) of this soil was approximately 18 and 10 percent in A and B1 - horizons, and its slow drainage pore (pores that have diameter between 9-30 μm) was about 14 and 16 percent for A and B1 - soil horizons respectively.

2) Soil-hydrologic Capacities

Soil moisture constants in terms of maximum water holding capacity (MWHC), field capacity (FC), available water capacity (AWC) and the permanent wilting point (PWP) play an important role in determining water availability for plant and the potential of subsurface flow. Unfortunately, these kinds of parameter for tropical soils and especially the forest soils are rarely found in the literatures. These soil-hydrologic capacities, certainly, vary with soil texture, organic matter contents and other soil properties. Rough estimation for these hydrologic capacities of soil basing on soil texture classes can be drawn from information published by England (1970) and from Toebes and Ouryvaev (1970).

One of the investigation involving soil moisture constant in the humid tropical forest which the author has in-hand is that from the Kog-Ma Watershed Research Station shown in Table 2. the average values of MWHC, FC and PWP in this ultisols profile under hill-evergreen forest are 67, 30 and 18 percent (by weight) respectively. From these figures, the water freely drained by gravity is therefore about 37 percent which is rather a large capacity. The average AWC is very narrow (equals 30-18 = 12 percent by weight) indicating low capacity of soil water for plant consumption. Fortunately, soil moisture of soil in the humid tropics usually above the PWP since rainfall is ample and almost distribute throughout the year.

Table 2 *Average moisture constants of hill-evergreen soil at Kog-Ma Watershed Research Station, Northern Thailand.

Soil depth, cm	Soil moisture at different atmospheric pressure (percent by weight)							
	0	0.3	1	2	3	5	15	atmosphere
0-5	86	41	38	33	30	28	17	
5-15	80	33	30	27	25	23	20	
15-30	71	30	26	24	24	23	19	
30-45	67	28	25	23	22	21	19	
45-60	62	25	23	22	21	20	18	
60-100	57	26	23	22	21	20	18	
100-150	58	26	24	23	22	21	20	
150+	58	31	29	28	26	23	16	

* From Table 4 of Makarabhirom (1979)

3) Soil-hydrodynamic Properties

It has been recognized that the high rate of permeability or percolation rate of the humid tropical soils is usually resulted from their favorable structure and great stability of aggregates. The mean permeability for lateritic soils in Africa rises to 140 mm/hr at the surface and remains 65 mm/hr at depth (Unesco, 1978). Bonnet (1968), in Pueto Rico, observed infiltration rates of 133,154 and 237 mm/hr for the upper horizons of inceptisols, oxisols and ultisols respectively. Initial infiltration rate of 1,112 mm/hr with a constant rate of 280 mm/hr were measured in the upper horizon of Tropohumults under hill-evergreen of northern Thailand (Chunkao and Naksiri, 1976). The higher values of the final infiltration rate of 480,320 and 264 mm/hr were obtained from field observation of ultisols covered by evergreen forest, Pinus kesiya plantation, mixed deciduous forest and tea plantation, in northern Thailand, respectively. Inceptisols under dry dipterocarp forest gave the lower value of approximately 197 mm/hr as its final infiltration rate (Inthasothi and Chunkao, 1976).

3.4.3 Soil Erosion

It was stated by Richards (1952) that, erosion as well as weathering is rapid, and on steep slope the soil may be very shallow even under a forest cover in a wet tropical climate. This seems to be contrary to that view mentioned by Walter (1971), who described that "under forest, there is no soil erosion even on rather steep slopes, and thus, the weathering products remain in situ".

The nature and behaviors of soil erosion in tropical humid region is now much better understood since the Universal Soil Loss Equation, USLE, of Wischmeier and Smith (1960), and the modified USLE of Foster and Onstad (1973) have been applied to the prediction of soil erosion. The equation gives a better definition of the role of different factors in erosion. The equation states that :

$$A = R.K.C.P.SL$$

and means that the loss of soil (A) is a function of; R-the rainfall factor deriving from the total kinetic energy of annual rainstorms, the erodibility of the soil (K), the vegetative cover (C), the anti-erosion as conservation measures (P), and topography (SL).

K-values for temperate soils, such as in the United States, vary from 0.30 to 0.60 indicating that they are more susceptible to erosion than those soils namely ferralitic soil in the Ivory Coast inwhich their K-values vary from 0.50 to 0.18 (Unesco, 1976). K-values for tropical soil in northern Thailand (classified as Tropohumults) that vary from 0.01 to 0.36

with its average of 0.19 (Thappipidh,1981), and also in Hawaii which their values ranged from a low of 0.0 to a high of 0.55 (Dangler and El-Swaify, 1976) confirm the above statement. It was summarized in Unesco (1978, section 12 : water balance and soils) that, "This conclusion should not be surprising if one looks at the fact soils formed on basic rock are generally very well structured and more resistant and also that the more acid soils always contain sufficient alumina to ensure flocculation of their clay fraction."

In conclusion, soils under tropical forest are relatively poor in nutrients. The wilderness and vigor of the forest is no indication of great soil fertility, as was assumed by the first planters. The living plant mass is a function of the humidity of the climate and seems to associated with intermediate, deep soils, rather than with its soil fertility. Although its erodibility has been proved to be lower than those in the temperate region, the vigor of the dense forest is the only component that dominates all factors in erosion control. It is only when the forest ecosystem is destroyed that erosion intensifies and can reach catastrophic values. Furthermore, since the lushness of the vegetation on deeply weathered, mature soil is inversely related to the nutrient budget in the soil, it is found that cultivated soils degrade most rapidly in humid areas. Therefore, the tropical soils can seldom support a continuous type of farming.

However the young soils with their permanent source of nutrients from slightly-weathered minerals, such as soils on alluvial zone, swamp forest soils, and volcanic sediment deposited soils, can support successful permanent cultivation (Longman and Jenik, 1974).

3.5 Biota Characteristics

Biota characteristics refer to the inter-relationships among plants, animals and micro-organisms living within one site. The following paragraphs are the concise description of all biota consisting in the humid tropical ecosystems.

3.5.1 The Flora and Fauna

It has been recognized that the tropical ecosystem is an outstanding of a complex biocoenosis. No other ecosystem has a larger number of plant and animal than this type of forest ecosystem, The flora of TRF, for example, is roughly estimated to comprise 25,000 species of flowering plant which is about 10 percent of the world's flora. The lowland rainforest often contains more than 50 species in one-hectare. In the Malay Peninsular, more than 100 tree species have been recorded in one-hectare plot. (Esteban, 1980). The stand composition of the undisturbed hill-evergreen forest occupying on highland watersheds of northern Thailand

consists of about 150 species with a four canopy story. The stand density is about 200 trees with volume of more than 120 cu.m. per hectare. The crown cover is approximately over 90 percent (Wasuwanich , 1968).

Animal life is equally abundant and diverse in the tropical forest. In Panama and Costa Rica, about 77,000 ha of rainforest harbored 500 to 600 indigenous species of birds, more than that found in temperate forests. It was also commented by Esteban (1980) that, the wealth of species of the TRF is a product of two factors : a)Environmental stability and b) The Great Age of the TRF.

3.5.2 Man - the Ecosystem Converter

According to Leakey (1964), the evolution of Homo sapiens took place somewhere near the margins of the tropical or subtropical forest, presumably near rivers and lakes in open savanna. Much later, man turned to the closed forest either temporarily as a hunter for food gatherer, or he was forced by inter-tribal conflicts to live permanently. The tropical forest was therefore not a cradle but a refugue. Later, however, sophisticated societies formed within the closed tropical forest areas, for example the Mayan Civilization in South America, well-organized kingdom in Africa and highly developed communities in Tropical Asia. Through his social systems, man was able temporarily or permanently to overcome some of adversities of life in the humid tropics.

The map showed in Figure 3 , therefore, indicates a kind of vegetation which might occur before man's interference. Tropical foresters and environmentalists, however, have recognized that, the agricultural practices so-called "shifting cultivation or swidden cultivation" has been widely profound in many part of the humid tropics.

Recently, the density of population has been increasing rapidly, due to change in agriculture and transport and the infrastructure developments in the tropics. It has been expected that, more than 600 million people will be farming and living in this fragile ecosystem in the coming century. This trend are, certainly, causing new problems to arise in the land and watershed management of this region.

3.6 Hydro-ecological Balance

3.6.1 Rainfall

Rainfall within the tropical zone varies greatly in amount and in seasonal distribution. Over large area, there are annual totals of between 2500 and 4000 mm. (Richards, 1952). The principal regions with a rainy tropical climate including Tropical Southeast Asia have rainfall totals surpassing 2000 or 3000 mm., which are distributed more or less equally over the year (Longman and Jenik, 1974).

3.6.2 Throughfall

Estimates of the amount of rainfall reaching the ground as throughfall are in the order of 70 - 80 percent of annual precipitation in the semi-deciduous forest of Indonesia (Morh and Van Baren, 1954). A study carried out in a lowland tropical rainforest at Pasoh Forest Reserve, Malaysia by Manokaran (1979) indicated that with annual rainfall of 2381 mm, throughfall varies from 0 to 99 percent on single storm and 65 to 96 percent on monthly basis. The annual rate was found to be about 76 percent. The measurement of throughfall of early wet season in 4 forest types of Thailand : hill-evergreen forest in northern highland; dry-evergreen forest in northeastern plateau; natural teak forest, and the dry dipterocarp forest in the north; were found their values to be about 95; 91; 39 and 37 percent respectively (Chunkao et al, 1971).

3.6.3 Stemflow

The amount of stemflow depends largely upon the roughness of the bark. It may vary from as low as 0.01 in. for smooth bark species (vary from 11% to 15% of individual rain storm) or as high as 0.07 in. for rough bark (varying from 2 to 3% of storm rainfall). Annual rate of stemflow measured in the lowland tropical rainforest was about 0.64 percent (Manokaran, 1979). Chunkao, et al (1971) found, for the forest in Thailand that the value of stemflow for the dry evergreen trees with moderately rough stem barks was about 0.97 percent of annual rainfall, 0.52 percent for the hill-evergreen forest. For the very rough barks of natural teak and dry dipterocarp forests more or less of values 0.02 and 0.01 percent were estimated respectively. Intermediate values of 3.3 and 7.1 percent were found in India under *Pinus roxburghii* and *Tectona grandis* (Dabral and Pao, 1968).

3.6.4 Interception

The proportion of rainfall intercepted by tropical forests is very variable. In tropical Southeast Asia, interception measurement in Thailand indicated high values of 03 percent of gross annual rainfall for the natural teak forest;01 percent for dry dipterocarp;

9 percent for hill-evergreen forest; and only 4 percent for the dry-evergreen forest. (Chunkao, et al, 1971). This kind of investigation in the lowland rainforest of Malaysia gave a value of 22 percent. (Manokarn, 1979). It was also stated by Raros (1979) that intercepted water may exceed 60 percent of gross rainfall for the humid tropical forest in the Philippines.

3.6.5 Evapotranspiration

Very few tropical countries have undertaken evapotranspiration studies within the forest. Naturally it can be assumed that there is considerable variation between sites, forests of different structure and species.

Average figures of evapotranspiration from humid tropical forests are between 1200 and 1500 mm (Penman, 1970). The Figures, however, are deduced from very few meteorological measurement. The real figures, surely, are very hard to measure, but seem to be lower than those figures mentioned above. The followings are the estimated actual annual evapotranspiration of a number of tropical forest:-

- Dry-evergreen forest at Sakaerat(North-eastern Thailand):ca. 948 mm (Sabhasri et al, 1970).
- Rainforest (98%) and 2% rubber plantation (Selangor, West Malaysia): ca. 1062 mm (Low and Goh, 1972).
- Combination of 43% rainforest, 44% rubber plantation and 13% settlement area (Selangor, West Malaysia): ca. 993 mm (Low and Goh, 1972).
- Combination of 41% pine forest plus small portion of montane forest, 34% agricultural area, and 23% grazing Land (Agno River Basin, Pangasinan, Philippines ; figures are obtained from Esteban, 1979): ca. 847 mm (Saddam, 1959).
- Hill evergreen forest at Chiang Mai, Northern Thailand: ca. 1037 mm or about 50 percent of rainfall (Suwanarat, 1981).

3.6.6 Surface Runoff and Streamflow

It was stated in the UNESCO (1978) that runoff is probably one of the elements in the water balance of tropical ecosystems for which information is the least well developed and least precise. Among those studies in Southeast Asia, study of Ruangpanit (1971) is the one that shows the importance of 60 - 70 percent vegetative crown cover as well as the role of the intensity and duration of the rainfall on the volume of surface runoff (Figure 4a, 4b and 4c)

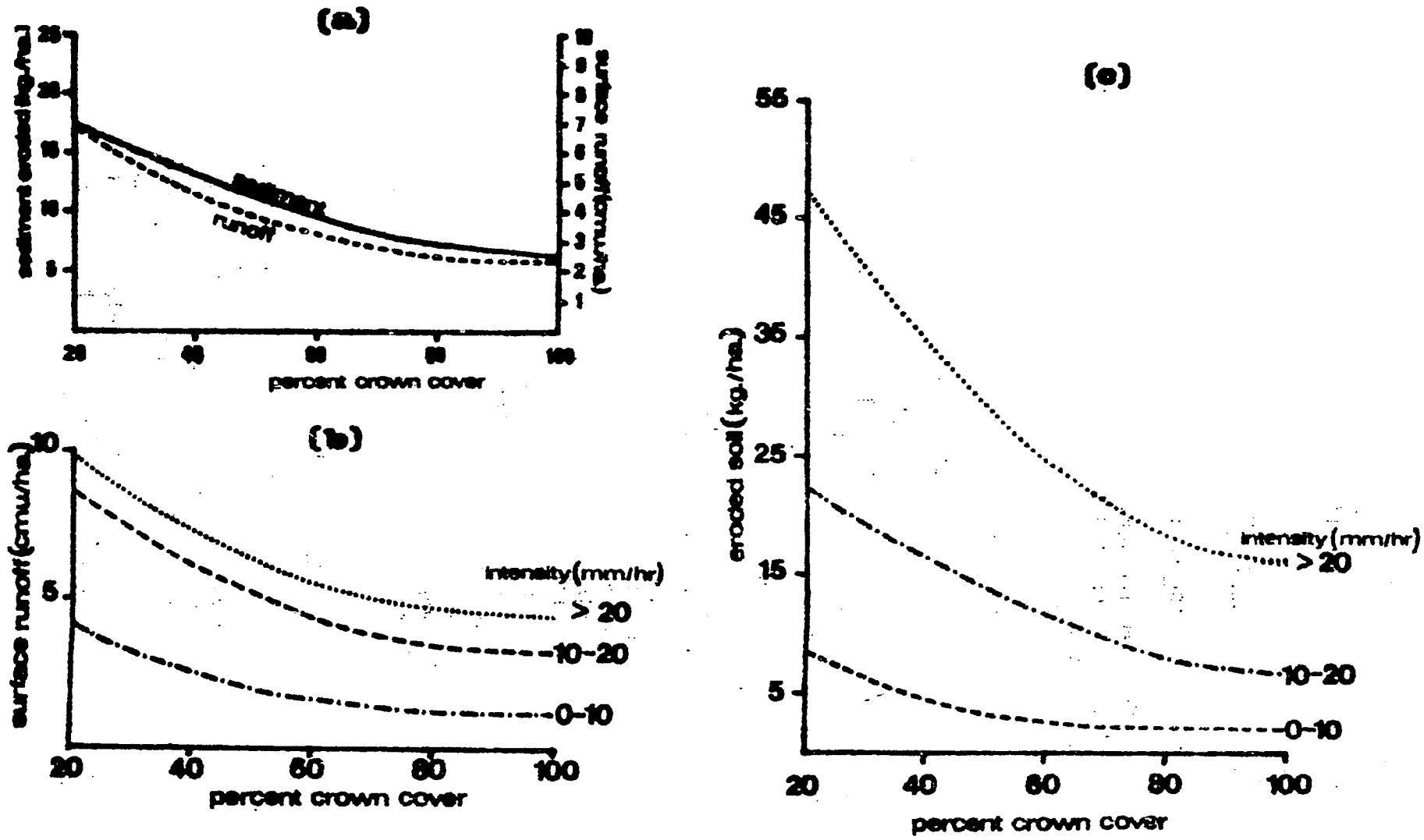

Figure IV-4. Surface runoff and eroded soil in relation to percent crown cover and rainfall intensity measured in the hill-evergreen forest, northern Thailand (from : Ruangpanit, 1971).

1) Surface Runoff

Studies of soil and water losses immediately beneath a forest cover on various slopes undertaken by Chunkao et al (1976) at Lampang, northern Thailand using plots of 2 x 10 meters showed that surface runoff from 31-year old teak plantation, mixed deciduous forest with teak hill slope mixed deciduous with teak and the dry dipterocarp forest were about 0.32, 3.02, 3.60 and 2.44 percent of annual rainfall respectively. Study of Ruangpanit (1971) on the effect of crown cover on surface runoff and erosion in the hill-evergreen forest, northern Thailand, using plots of 4x20 meters indicated that surface runoff varied inversely with percent crown cover. It increased rapidly when the percentages of crown cover were below 70 percent. When percent crown cover was 70 percent or greater, the rates of surface runoff were nearly constant. The annual percentage of surface runoff from the plots having percent crown cover greater than 30 never exceeded 1 percent. This could be an evidence that rain water probably reaches the streams in the dense tropical forest mainly through vertical or lateral flow rather than by surface runoff.

It was also discussed by Ruangpanit that the presence of litter at the ground surface, the high organic matter content and low bulk density of surface soil play more important role than crown cover. The crown cover had little effect on the total volume of surface runoff and amount of eroded soil as well. Therefore, the specific crown cover needed for minimizing surface runoff and erosion and for forest management in the protection watershed should be at least 70 percent.

2) Streamflow

The conclusion that can be made from many surface flow investigation is that, under dense forest, surface runoff is negligible or absent and seepage quick, and storm flow in stream will moderate, except in extreme thunderstorm. High rates of lateral water flow in humid tropical forest ecosystem have been frequently reported by many authors, but few quantitative expression have been made.

The study on soil hydrological characteristics of hill evergreen forest in northern Thailand by Nakarabhiron (1979) indicated that ultisols under this forest has very high absorption especially at the ground surface and tending to decrease with depth due to decreasing in amount of organic matter. Soil also drained water into stream channels rapidly after reaching saturated condition. The rate of release was then slowly decrease when soil water close to field capacity. In quantity point of view, the

amount of total annual flow was approximately 65 percent. Of this amount, 35 percent released as summer flow. In summer, rainfall that higher than 10 mm could effect to streamflow characteristics.

In northeastern Thailand where the geologic formation (sandstone) is different from that in the north (granitic rock), the percentage of annual streamflow is quite small. Only 2.7 percent of annual streamflow averaging from four small watersheds which covered by dry-evergreen, dry dipterocarp forest, mixed vegetative cover, and the shifting cultivation, was found in the drought year. Much higher annual streamflow of 15.4 percent, however, was estimated in the normal year. The quite different percentages of annual streamflow obtained from the northern and northeastern forested watershed, perhaps, due to the difference in the geologic formation rather than climatic condition. Physical soil properties of northeastern watershed largely consist of stone, gravel, and sand, but low quantity of silt and clay. A lot of cracks between rocks, high amount of macropores and rock outcrop in the northeast cause less amount of streamflow. Much of rainwater and streamwater loss by leakage as well as some evaporate to the sky.

Naturally, most lowland forest which receive less rainfall (1600 -2200 mm), usually yields annual runoff below 50 percent (Unesco, 1978). In India, Rao et al (1978) measured a streamflow of 41 percent of rainfall under Shorea robusta where the mean annual precipitation is 2427 mm.

3.3.7 Variation in soil water

Generally, variation of soil water of the profile decreases regularly with depth for the soils that have homogeneous texture, It is higher in horizons where root activity is present. If the lower horizons are clayey, this decrease is less evident. Avenard (in UNESCO, 1976) stated that the processes of soil moisture change are slower beneath forest than beneath savanna and progress downwards, because the root systems slowdown infiltration and water does not penetrate in the deep horizons until after the retention capacity of the surface one has been exceeded.

Three years of soil moisture measurement in ultisols under hill-evergreen forest of northern Thailand indicated that soil moisture fluctuation is depending upon amount of monthly rainfall, soil properties, runoff, evapotranspiration and topography. Moisture storage tended to increase in the rainy month and approximately 60-80 percent of rainfall penetrate into deeper layer. There were no different in soil moisture among soil horizons and among altitudinal location within the study area (Chaicharus and Chunkao, 1978).

3.7 Mineral Nutrient Transport System

Most tropical virgin-ecosystems set up processes tending to counteract soil impoverishment and under undisturbed conditions there is a closed cycle of plant nutrients. In such circumstances, tropical region is a self-sustained ecosystem. The soil beneath its natural cover thus reaches a state of equilibruim in which its impoverishment proceeds extremely slowly. The soil nutrients are absorbed by the plants from the soil and are return again to soil through decay of organic matter (Richard, 1952;Walter, 1971). The plant nutrients, therefore, are tied within the ecosystem resulting in the vigorous vegetation and superative stream-water quality.

Esteban (1966) described nutrient transport system of the humid tropical ecosystem as follows :-

> "The luxuriance of the rain forest is no measure of the fertility of the soil on which it stands. The majority of nutrients are tied up in the forest vegetation and not in the soil. Thus, the rainforest exists only on a very merger nutrient budget and survives only by a near closed nutrient cycle.
>
> The mineral transport system is efficient. Very little is lost from the system due to the root location. The root of tropical trees are generally shallow usually within the top 1.0 to 1.3 meter of soil, and the fine roots where most absorption takes place are just below thin layer of litter in the soil. Because the fungal hyphae(the agents of decomposition) are also in the litter, the nutrients are carried 'door to door' so that almost nothing escapes. Additional mineral nutrients may also come from the weathering of rocks and rainfall".

Preliminary study of undisturbed hill-evergreen forest ecosystem in northern Thailand by Tangtham (1974) indicated that the amount of N and P in the rain-water, throughfall, stemflow and in the stream-water in this area are barely observable. The rate of output K, Ca, Mg, Fe and Mn lost from this ecosystem is a little greater than the rate of those imputs gain from rainfall. Moreover, the annual loss of debris plus soil particle from this type of ecosystem seems to be insignificant difference during a decade of investigation. This is the one of example showing that tropical ecosystem is usually characterized as the near closed nutrient transport system.

3.8 Energy Flow Through Humid Tropical Ecosystems

Generally, forests are very efficient absorbents of visible and infra-red radiation. The reflectivity of forests is 5-10 percent lower than that of other soil covers. The low effective radiative temperature of forests damps infra-red

emission. The high energy intake of forests is used primarily in the evapotranspiration process. Consequently water vapor flow to the air above the stands is intensive, and evaporation cooling avoids overheating of forested land and reduces the tendency to convective air exchanges. Moistening of air without destruction of the atmospheric stratification seems to be characteristics for moist forest areas (Table 3).

Table 3* Energy balance terms in tropical regions (Baumgartner and Reichel, 1975)

Latitude (°)	North 25	15	5	5	South 15	25
kcal/cm^2/annum			Land surface only			
Q, net radiation	69	71	72	72	73	70
H, sensible heat	48	35	9	4	21	42
L, laten heat flux	21	36	63	68	52	28

*from table 4 in UNESCO (1966)

As has been realized that the net radiation input at the earth surface of tropical zone is high. This is due to the sun's elevation being at or near zenith at noon all year round, to the low albedo of forests and the low effective temperature of forest canopies. The discrepancy between high net radiation and low effective temperature is not a contradiction as the absorbed radiation is used for the vaporization of water. It can be, therefore, said that the tropical forest are the intensive converters of energy and of water and, thus, an important link in the thermodynamic system of the atmosphere (UNESCO,1966).

There are, however, regional difference of the energy exchanges and heat flow components, governed by the atmospheric circulation systems (trade-winds,monsoons, cloudiness, precipitation) or by the properties of soil covers. For example,the net radiation of the dry-evergreen forest in northeastern Thailand, where situated at approximately latitude 14°15'N, is about 116-487 langleys/day in the wet season. The reflected incoming short-wave radiation by forest canopy is approximately 11 - 13 percent. The incoming short-wave radiation absorbed by forest stand is about 85 - 95 percent. With higher in both the latitude and elevation, the solar radiation measured adjacent to the hill-evergreen forest located between latitude 16 - 19°N at the altitude of above 1200 meters, ranges from 390 to 527 langleys/day in summer (Chunkao, 1971).

3.9 Influences of Tropical Forest Ecosystems

The influences of tropical forest ecosystem on the regional and global environments has been intensively discussed in terms of state-of-knowledge in Natural Resource Research XIV published by UNESCO (1976). Its influences, however, can be summarized as follows:

3.9.1 Influence on global climatic condition

Although, the river basins in the tropical zone usually receive very high rainfall and sustains the enormous tropical river systems, not all of them discharge into the oceans within the humid tropics but some drain the surface water into the arid zone. The major influence of the humid tropics on the global hydrological balance, hence is not by the rivers, but through the water vapour transported within the atmosphere.

The tropical regions which represent 40 percent of total earth surface contribute 56 percent of water vapour into the global cycle. The share of the tropical ocean surface to the evaporation volume of the globe is 49 percent and that of the tropical land surfaces 9 percent. Tropical forests occupy about one third of tropical land surfaces, so tropical forests influence the global water cycle by the order of 3 percent.

It is assumed that fossil fuel burning increases the CO_2 concentration of the atmosphere by 0.64 ppm/annum. This is partly in the oceans, but partly also fixed by photosynthesis in forests. Accordingly the highly productive forest will serve as effective regulator of the CO_2 balance of the atmosphere.

Aerosol particles from the tropical regions are polluting factors in the atmosphere originate above all from shifting cultivation and savanna burning. Small amounts are released by the exploitation of the forest, permanent agriculture, and by the release of hydrocarbons, pollen grains or spores. Of the world total aerosol of 1670 million tons per year, agriculture and forestry produce 13 percent, of this forest fires contribute less than 0.1 percent.

The importance of tropical forest for the maintenance of climate cannot yet be quantified with any degree of reliance, because neither the changes of climate following changes in the atmospheric composition can be predicted, nor can intensity of the forest influences be related to structural or site properties or to the productivity of the various natural or modified forest types.

3.9.2 Regional influences of tropical forest

It has been realized by the micrometeorologist that each type of land-cover has its typical energy and mass exchanges and balances, and its effects extend for some distance in horizontal or vertical directions. The range of the environmental affects of forests increases with the size of the source area and depending on the kind of the transported factors. Atmospheric contents such as water vapour, Co_2, pollen grains or spore may affect the biosphere at continental scale. Water exchanges influence the functioning of watersheds and the properties of the river sources through overland flow, quick seepage flow, erosion and leaching.

Regional studies of the range to which forest influences make themselve felt, such as precipitation changes after reforestation or forest depletion, are mainly available from the European countries or from temperate regions. The few studies conducted in tropical countries have been much less successful because it is very difficult to separate the effects of climatic fluctuations from the effects of changes of land use.

From the hydrological consideration, precipitation in the equatorial rain belt is more than 3 times as large as the global average of 746 mm. Global average evapotranspiration is 460 mm for the land surfaces, but in the moist tropics it is at least 1200 mm. Global runoff from the land surface average 266 mm or less than 20 percent of annual rainfall but in the equatorial region it is equal to 879 mm or about 40 percent of annual rainfall. This causes the huge tropical rain forest rivers. In the perhumid regions, however, the influence of forest on the water yield is generally less important than on the runoff pattern. The humid tropical forest can prevent flood and high sediment loads.

4. PROBABLE ECOLOGICAL AND ENVIRONMENTAL EFFECTS OF FOREST DESTRUCTION AND MODIFICATION, AND LAND USE EVOLUTION IN THE HUMID TROPICAL ECOSYSTEM

Naturally, the tropical ecosystem are the most productive region of the world. The forest ecosystem, which occupies a great varieties of edaphically and climatologically heterogeneous sites, exhibits a great diversity of architechtural structure and of species and chemical compostion. The high degree of diversity is a major condition for the sustained functioning of the tropical ecosystem. With these factors which cause high productivity, however, make this terrestrial ecosystem extremely sensitive whenever the structural diversity and complexity of this ecosystem is disturbed or impaired, modifications occur in circulation in the boundary layers between atmosphere, vegetation and soil.

In tropical countries where large area of moist evergreen forests have been destroyed by shifting cultivation, logging or agricultural development, it has led to unbalance of the functioning of the ecosystem. As the area of humid tropical forest is rapidly reduced, the effects will be felt at the regional and finally at the global scale (UNESCO, 1978). However, investigations into the impacts of forest destruction, plant cover modification, and land use evolution, on the soil, on micro and macroclimate, and on the ecosystem and its environment as a whole are very rare in the tropics. The following are the ecological and environmental impacts, caused by conversion of tropical forest ecosystem, that the author has reviewed from available information within a limited time.

4.1 Effects of Shifting Cultivation on Soil Deterioration and Water Loss

By nature, the humid tropical ecosystem typically exposes to the heavy rainfall and high temperature. This condition has accelerated the weathering process and the decomposition of organic detritus and resulting in easily leached soils. The consequence is that soil are low in nutrients.

It seems generally accepted that the tropical forest soils are frequently so highly leached, infertile and so fragile, that converting them to sustain agriculture is a lot more difficult than converting those soils which underlay temperate forests into productive agricultural fields (Spears, 1979). Forest destruction in the humid tropics by means of "shifting cultivation" causes a sudden mineralization of the entire capital. Since such cleared and burned areas are denuded of vegetation that could absorb the suddenly - released nutrient capital, it is leached out instead by heavy intensity rainstorms. Only a small remaining proportion is held by cultivated plants and weeds (Walter, 1971).

Available data for whole watersheds show that erosion under dense natural perhumid and seasonal humid forest is usually less than 1 ton/ha/annum. The rate increases up to 20 - 30 tons/ha/annum if the land is cultivated (UNESCO, 1978). Kellman (1969) studied surface runoff characteristics during 227 days in upland Mindanao. Rates in a 10 - year - old abaca plantation were twice as high as in natural mixed dipterocarp forest, 4 times as high in young rice field and about 50 times in a 12 - year - old rice field. Experiment in northern Thailand indicated that soil loss from on - going cultivated area with cash crop like wise rice, maize, bean and sesame was found to be about 3 - 5 times higher than that eroded soil from natural forest. Organic matter content was reduced rapidly from about 10 to 5 percent in the first two year after the hill - evergreen forest has been cleared, and slowly decreased in the third year. It will, however, gradually increase after it has been left as old clearing area.

In almost tropical countries, shifting cultivation has frequently proved to be a too expensive form of agriculture to provide a politically acceptable solution. In addition, as a result of population pressure, it often gives way to intensive food cropping, declining yields, ecological deterioration and abundance of the land. The end results are widely evident and are well known to all foresters, i.e., thousand of acres of eroded hillsides, storage dam full of eroded materials, dried up perennial streams, and lowland agriculture disrupted by flooding in wet season (Spears, 1979).

In Thailand, shifting cultivation has destroyed large area of natural forests which have been developing for thousand of years to reach their climatic stage. Shifting cultivation coupled with fire has reduced million acres of these magnificent - tropical forests to useless scrubs and grassland or secondary growth which may or may not be as economical in value as the original forests. The most serious after effects of shifting cultivation are the degradation environment and the consequences as mentioned above (Kemkris, 1971).

4.2 Impacts of Converting Tropical Forest to Plantation and Agricultural Ecosystem

Cultivation of the nutrient - poor tropical soils can cause severe soil erosion so that unweathering parent rock may appear at the surface. The whole process of nutrient accumulation can start over again provided there is no further interference by man. However, this must involve a very slow process even under the rapid weathering conditions of the tropics. Re-establishment of the primary virgin forest in this manner is conceivable. Converting the tropical moist forest (TMF) in Trinidad to *Pinus caribaea* plantation resulted in several short - lived effects on soil nutrients, but phosporus losses were not regained in 12 years. On steep slopes with high rainfall, 74 percent of the nutrient reserves of the natural forest were lost in 6 years (Cornforth, 1970). Destruction of the undergrowth in the 11-year - old teak plantation by repeated fire causes 8 times of soil erosion compared to that amount eroded from secondary evergreen seasonal forest in Trinidad (Bell, 1973).

Study of soil and water losses in relation to forest fire at Lampang province, northern Thailand by Chunkao et al (1976) indicated that, the 31-year - old teak plantation lost about 3,038 kg/ha/annum of soil meanwhile the mixed deciduous forest with teak at the foot hill, mixed deciduous forest with teak, and dry-dipterocarp forest at bottom land produced about 1,107, 898 and 471 kg/ha/annum respectively. The results implied that conversion of natural tropical forest to forest plantation more or less accelerate soil erosion. However, soil erosion and other observed soil degradation are not entirely the direct results of the plantation, but are connected with

the original status and type of soils, silvicultural practices including fire.

Land use evolution in northern Thailand, especially the conversion of primitive - forest land to agricultural and the tribal settlement areas also contaminated chemical and biological pollutants into stream-water. Nitrate in stream-water drains from agricultural area and Maeo village (a name of tribal settlement area) was found to be 3.5 and 3.8 times higher than that of hill-evergreen forested watershed. As for bacteriological quality, total coliform and fecal coliform in stream-water from Maeo village were 14.3 and 12.6 times greater than those of hill-evergreen forest. Also, total bacterial count of 20°C and 35°C of stream-water drains from agricultural watershed was 4.5 and 3.5 times greater than those of hill- evergreen forest watershed (Nuntapotiseton, 1980).

The impact study of highland agriculture on bacterial content in stream-water drains from tea plantation mixing with natural hill-evergreen forest in northern Thailand indicated that the total viable counts increase at the early part of the rainy season but decrease later by the end of the season. The increase could be attributed to the highland agricultural activities around those watersheds. The total coliform count which were found to fluctuate throughout the year, are over the standard level of potable water (Potchananapasiri, 1980).

The study on bacterial flora in streamflow and spring water drains from the man-made plantation mixed with natural forest and from the various landuse activities at the adjacent watersheds in northern Thailand also found that total viable counts of microorganism in stream-water of each site increase and decrease in the same manner as those studied by Potchananasiri (1980). But, the total coliform counts are higher than the standard level for potable water. However, stream-water from both sites gave excellent water quality and could be used as water supply for any general purposes. But before use it directly as potable water, boiling is recommended. The author, therefore, believe that the changing of the natural forest into man-made forest will not affect the water quality especially in the biological aspect (Sangtaksin and Ruangpanit, 1980).

4.3 Impacts of Humid Tropical Forest Conversion on Hydro-ecological Balance

It has been realized for all foresters in the tropics of how much importance in producing water yield of the tropical-virgin forests. This was supported by the warning of Pereira (1973) that "forests should neither be felled nor planted on a large scale without a study of the potential hydrological changes which may be expected". Effect of converting tropical forests on hydro-ecological changes have been recognized and noted.

Circumstantial evidence of lasting and profound change being initiated by forest clearing is provided by long-term observations of rainfall in private rubber plantations in Malaysia. Large scale forest clearing was followed by substantial changes of rainfall intensity. While the total annual rainfall appeared to remain uneffected, the number of rainfall incidents decreased and the intensity per rainfall increased.

Shifting cultivation which have been practicing on the mountainous watershed of northern Thailand caused infiltration capacity to be changed from 260 mm/hr to 197 mm/hr after the natural hill-evergreen forest has been converted to shifting area for a few years. (Inthasothi and Chunkao, 1976). This implies higher percentage of overland runoff could be produced on shifting cultivation areas.

A radical change as the coversion of tropical moist forest to tea gardens with shade trees indicated no change in annual evapotranspiration of 1300 mm/ann. (Pereira, 1973). His plot experiments where bamboo forest under an annual rainfall of 1260 mm was coverted to Cupressus macrocarpa or Pinus radiata gave almost identical amount of evapotranspiration from all tree covers. Conversion of a whole watershed from bamboo to pine, however, show that after four years when the pine approaching 2/3 height of the bamboo, water loss from the man-made forest had caught up with that from the original vegetation.

Change in lag time of flow due to converting natural hill-evergreen forest to shifting cultivated areas has been noted by Taesombut (1972) and Inthasothi and Chunkao (1976). Lag time, which usually takes 18 hours when watershed was covered by natural condition of vegetative cover reduced to only 4 hours when watershed was converted to old clearing area. Recent finding by Chunkao (1979) denoted that the peak of annual hydrograph of many tributaries in northern Thailand has been shifted from September to August, one month ahead. This can be interpreted that time delay which was usually controlled by interception process, infiltration and percolation processes, has been shortened by heavy destruction of forest and shifting cultivation during the past decades.

4.4 Impacts of Tropical Conversion on Climate

It was said in UNESCO (1978) that changes in the features of the earth's surface will cause changes of meteorological and climatic processes at various scales of space and time. Changes after forest clearing for agriculture with annual field crops or for engineering works have been severe. Less destructive on soil and climate seem to have been natural or plantation silviculture, perennial field crops or rough grazing. Supplementary activities, such as irrigation, drainage, fertilization and pest control affect the environment directly and indirectly and usually accentuate the adverse effect of forest destruction.

Deforestation initiates changes towards aridity. Some climatologists are of the opinion that changes in land use may also effect the dynamics of atmospheric circulation systems. An example is the generation or the dissipation of tropical easterly waves or of local development above forest and absence above clearings of convective clouds. These effects are due to the change of aerodynamic surface roughness, albedo, water vapour flow and stability of thermal air stratification, as a result of the change of surface cover type.

Contrasts in the energy balances of different vegetative cover due to clearing dry-evergreen forest at the Sakaerat Environmental Research Station in northeastern Thailand as studied by Chunkao (1971) perhaps the one of essential evidence of differences in micro-climate relation.

In addition, higher surface-soil temperature after tropical forest has been changed into bare soil or annual crops increase the rate of mineralization of the organic matter. This impairs the stability of soil crumb structure. As a result the shear resistance of the soil surface is reduced and the soil becomes more easily erodible. Hardening of the surface of some soil types on exposure also reduces infiltration which increase runoff and erosion (Hill, 1966).

The most controversial issue about the effect of forest destruction on climate is the change in amount of rainfall. No inconvertible evidence has ever been produced that clearing or converting tropical forests has materially alter rainfall. Pereira (1973) revealed that even clearing high forest from 780 square kilometers of the Nufundi escarpment in Tanzania indicated no measurable change in the annual total rainfal although the number of occasions on which slight rain fell was halved. Observation of rainfall measurement in northern Thailand by P. Wara-asaves (personal communication) during the past ten-year period also produced no significant change in annual rainfall eventhough thousand acres of mountainous watershed have been denuded by shifting cultivation.

Although it has been concluded that the disappearance of a forest has no local effect on rainfall, there is, however, growing evidence that many instances of large scale deforestation could have cumulative effects on global atmospheric cycles of water and energy(Adeyoju, 1980). At the local level, forest influence on lowering air temperature in hot weather, raising humidity and reducing wind speeds at surface level. These effects can mean a substantial improvement in the rate of water loss from field crops and hence an increase in agricultural productivity.

4.5 Effect of Deforestation of the Humid Tropical Forest on the Atmospheric Carbon dioxide Balance.

One of the environmental question stem from the destruction of the wet tropical forest is carbon dioxide issue. This is perhaps not really important issue from the watershed management point of view, but it has recently evoked considerable attention by the environmentalists. The following is brief expression drawn from Stewart (1978) and Spears (1979) articles.

The scientific investigation indicated that the atmospheric concentration of CO_2 release as a result of deforestation is 10 - 35 % of the fossil fuel contribution. It can be, however, as high as 80 - 100 % in some certain places. One model projects the future impact of atmospheric CO_2 concentration near doubling by the middle of the next century implying a raise of global temperature of about 3°C. An unbelievable scenario suggests that this would have benign effects on human welfare. A higher CO_2 concentration increases the efficiency of photosynthesis and raises potential food crop production. While change in rainfall patterns following from moderately higher global temperature would have differing regional effects on agricultural productivity; the net effect on the world's food supply might be positive, although controversy exists on this point. Also, if the earth is entering a natural long-term cooling trend due to gaining less incoming irradiation, then the so-called 'greenhouse' effect could be a valuable compensation.

There are a lot more plausible scenarios about this impact, but one who interested in should read more detail from articles mentioned above. One research worker, however, has recently alearted that :

> "If this process continued until much polar regions no longer feel the deep cold layers of the oceans, enormous quantities of CO_2 would be released. It has been hypothesized that such a positive feedback process caused a catastrophic abrupt increase in planetary temperatures at the transition from the mesozoic and to the cenozoic geological period, a time in which an estimated 1/3 of the earth's species disappeared".

4.6 Impact of Tropical Forest Elimination and/or Conversion on the Losses of Flora and Fauna

Richards (1971) stated for reasons for reserving tropical forest, especially wet tropical forest, that :- 1) indirect economic uses, i.e. water conservation, tourism, etc., 2) unforeseen future value (useful products and genetic resources), 3) scientific value (for research), and 4) aesthetic value. Myers (1978) commented at the 8th World Forestry Congress that elimination of wet tropical forest would automatically mean elimination of many species which would represent an irreversible loss of new unique resources which could offer pragmatic benefits of society, particularly pharmaceutical products. The US National Cancer Institute, for example, believes that if the

tropical forests disappear, this could represent a major setback to its anti-cancer campaign on the grounds that they are a principal repository of anti-cancer drugs.

The deterioration of the fauna when multistory forest is replaced by monocultures has been reported. Choudhury (1974) has criticized the planting of Eucalyptus because of the low value for browse of such stand for cattle and elephant in India.

5. ECOLOGICAL OUTLOOKS OR WATERSHED MANAGEMENT FOR HUMID TROPICAL ECOSYSTEMS

Generally, the aim of ecological planning is to arrive at well-balanced, sensible decisions and to avoid the mistakes which can be caused by concentrating on only one aspect of a problem to exclusion of all others (Vink, 1975). The main objective of watershed management, as well , is to obtain the superative yield of stream-water by a well-balanced management of all resources in the catchment area. Furthermore, impacts caused by the management actions on physical environment, economical and human socio-cultural aspects must be positive not only within the watershed boundaries but also the downstream areas. The ultimate goal of the watershed management in ecological aspects is therefore to help increasing and/or preserving useful and stable ecosystems, in support of the human endeavour which should be to live as well as possible on a sustained-yield basis.

A self-maintaining wet tropical forest which safeguards the fertility of its soil, its genetic composition and its excellent water-yield regulation, is a stable ecosystem. An area of farmland supporting a well balance rotation of crops and livestock maintaining the fertility of its soil with fertilizers and other techniques and preventing erosion also can be stable. Based upon current available information and the ways which the denuded watersheds in Thailand have been and being rehabilitated, the following ecological approaches should be taken into consideration as guidelines for watershed management in tropical ecosystems.

5.1 Preserve High Altitude-Mountainous Watersheds.

As has been repeatedly emphasized, the watershed that covers with the humid tropical forest is an excellent example of an ecosystem in which climate, soil, plant and

animal resources are components in an extremely complex equilibrium. With annual rainfall of higher than 2000 mm and the relatively small amount of evapotranspiration,, the humid tropical ecosystem thus yields adequate amount of good quality streamflow with proper timing. Additionally, the nutrients in stream-water including in the debris and also the sediment loss from these ecosystems seem to be very small whenever they are in undisturbed condition. There is, therefore, no doubt that the preferable hydro-ecological balance and the stability of nutrient flow in this ecosystem are in large part a function of its biological and soil components. The microclimatological condition also plays an essential role in regulating stream-water and limiting evapotranspiration loss. Tropical plant community and organic layers that influence the absorption of rainfall energy and surface runoff thus keeping this ecosystem to produce very small fraction of soil and chemical losses. Accordingly, from the water yield consideration and the ecological point of view, the undisturbed tropical ecosystem especially those which situated in high altitude should be, if possible, preserved permanently as a protection forest. Because this seems to be the only proper form of land use for steep mountainous region to keep the condition of this fragile ecosystem. Any marked reduction of vegetative cover or severe disturbance of soil surface condition would not only lead to greatly impaire hydrological balance, but also accelerated losses of soil and nutrients.

5.2 Provide Lowland for Farming and Living

Under present situation, there is no way to keep large acres of such ecosystem for serving the purpose mentioned above. The facts are at this point in time that over 700 million people in developing world are living in absolute poverty. A condition of life so characterized by malnutrition, illiteracy, disease, high infant mortality and low life expectancy, as to be beneath any reasonable definition of human decency. Taking a realistic expectation of future growth, it seems likely that at least 800 million people will still be-living in that condition by the end of this century (McNamara, 1978). Consequently, the watershed management in tropic especially in Southeast Asia, unavoidably, must be a strategy for rural development, more specifically, a strategy directed against poverty of the landless rural poor as has been stated by Raros (1979).

How could tropical developing countries solve such problems without imparing those fragile ecosystems. This will be,of course, far from easy because shifting cultivation will still be a form of agriculture to provide food as well as a politically acceptable solution. In this case, in which the need for food is high and ever increasing, the land of high potential for agriculture should be used to meet this objective. All those land of low potential for agriculture should be appraised in terms of their possible usage for range management, forest management, wildlife management or multiple land use purposes. Since soil at high altitudes especially on mountainous watersheds are usually subjected to intense erosion and also low fertility due to high leaching, they are not suitable for agriculture. The younger soils of lowlands or at the foot-hill areas where their permanent source of nutrients supposed to support successful permanent cultivation, therefore, should be used as land base for producing food for the people in this region.

5.3 Integrated Land Use and Conservation Farming for Highland Watersheds

As it has been said before that in the tropical countries where lowlands are adequate for farming and living, the problem of ecological imbalance seems to be negligible and any management action can be approached. How about those countries lack adequate lowland, could the management system mentioned above be possibly applied. Certainly not, and surely many acres of upland watershed areas must be opened for serving agricultural purpose. In this circumstance, Konkris (1979) suggested that, these areas should not be allowed over to cultivation, permanent or shifting by the tribal, the local or other people, but should be classified,according to their capabilities into agricultural and forest areas, in the watershed management plans. The latter should include ridge tops, hillside areas of over 20 percent gradient and area along the stream banks. These areas should be afforested, if they have already been denuded, fire protected and kept under perpetual forest or some form of vegetative cover, including grass. This may entail investment in more men and money, but it is the only suitable form of land that can be prescribed for these areas and to conserve the countries' precious soil and water supply, it is an investment that is truely imperative and worthwhile.

However, with ever increasing pressure of population growth, keeping hillslope of over 20 percent gradient for forest area forever is hardly possible. Many tropical countries badly need much of these areas for agriculture. In this case, conservation farming activities are really needed in watershed management. As a general guide, land under 35 percent slope can be used for annual crops, with soil conservation measures where necessary. Slope between 35 and 45 percent can be used for tree cash crops or pasture. Those slopes over 50 percent

should be used for forest plantation. Very steep slopes, over 85 percent, should be kept permanently under protection forest. These guidelines, however, may locally be changed slightly to take account of soil types, demand for land, and so on.

A number of soil conservation measures have been used in northern Thailand as activities of the Mae Sa Integrated Watershed and Land Use Project. The most effective, but by far the most expensive, is complete bench terracing. To reduce costs and labour demands a number of simpler methods have been introduced, including intermittent terraces,, hill-side ditches, contour bunding and for tree crops, orchard terracing. These measures are considered to be about 80 percent as effective in reducing soil erosion as bench terraces are, but only cost between one quarter and one third as much.

Together with those conservation farming activities, monoculture of horticultural species which can be planted on steep slopes, and at the same time will eventually provide a cach income for farmer, such as fruit and nut trees could be introduced. Surely, not all the trials be successful. Some of those varieties which may fail in some countries or some altitudes may be successful at some other countries or altitudes where climatic and edaphic condition are more suitable. Experiment at the Mae Sa Project, northern Thailand showed that coffee seems to be one of the crops that the local villagers are very interested in at the moment owing to the present and perhaps future high prices. Other fruit trees showing promise are loquats, passion fruit, and litchi. Nut trees which so far are promising are Macademia, Malabar chesnut and Chinese chestnut. The results also agree with those experiments carried out at Ang-Kang Royal Highland Agricultural Research Station (Highland Agricultural Project, 1977). It was also suggested by the Mae Sa Project that nut trees seem to be more attractive for remote mountainous areas, since they can be easily handled and stored and transported on mule back without being damaged.

There have been recently introduce varieties of exotic flower into many Highland Agricultural project. They are very impressive and are promising compare to those cash crops which have been tried out. The problem is that they need very much care and more additional artificial fertilizer and pesticide application, which perhaps will create serious problem in ecological degradation in the future.

5.4 Management by Agroforestry Systems

The monoculture with conservation farmings as mentioned in the previous section have indicated very high potential prospect when consider only in socio-economic aspect. Unfortunately, there are at least two problems about that solution. The first is that most wet tropical soils in many Southeast Asian countries such as southern and eastern Thailand, Malaysia and

some parts of Indonesia are highly weathered, leached oxisols (formerly known as latosols) or ultisols (formerly known as yellow podzolic soils) which are unsuitable for some perennial tree crops such as cocoa, coffee and oil palm. Secondly, there are marketing constraints for most of those horticultural crops and exotic flower plants. Besides, those land use alternatives suitable for small farmer settlements such as integrating perennial tree crops with food crops in a mixed farming system, and livestock raising in association with production of annual food crops, have only been tried out in research plots or very small scale pilot project. They have not yet been proved on a sufficiently large scale in well managed small farmer settlement schemes for us to be certain that they can be sustained without risk of diminishing crop yields and serious ecological deterioration on either the red and yellow podzolic soil typical of much of the South Asian tropical forest or on the poorer soils (Spears, 1979).

Evidence from some areas indicated such program of farming systems "may" be possible to ensure a sustained, but relatively low family income, provided adequate soil conservation measures, rotation crop patterns and appropriate fertilizer applications are maintained. These imply a high level of extension input and intensive managment are needed and how much expectation we can ensure of successful in case the farmers have no previous experience of that type of agriculture and inadequate capital for those additional techniques is still a question.

Agroforestry which has gained credence in the last five years is recently a new dimension of system that seems to be very promising action for tropical ecosystem management. It is hoped to be a new concept because it is a sustainable land management system which increases the overall yield of the land, combines the production of crops and forest plant and/or animals simultaneously or sequentially, on the same unit of land, and applied management practices that are compatible with the cultural practices of local population (King and Chandler, 1978).

From the ecological outlook, agroforestry systems will be very beneficial for environmental conservation since land deterioration in terms of soil erosion and nutrient leaching is expected to be decreased comparing to those forms of forest land utilization that have been practices in the tropics. Besides it is not only a bio-ecological mix per se, it is rather a series of management techniques intended to sustain the ecosystem with the latest socio-economic and technological concepts of resources use.

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V-5 ENVIRONMENTAL CONSIDERATIONS IN WATERSHED MANAGEMENT PLANNING : A CASE STUDY OF THE LAM NAM OON WATERSHED IN NORTHEAST THAILAND 1/

by

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1. INTRODUCTION

1.1 Purpose of Case Study

The general purpose of this study is to exemplify environmental or ecological aspects which should be taken into consideration while preparing and implementing a watershed management plan. This planning consideration includes (i) controlling factors of the environment on watershed management and (ii) effects of watershed management on the environment. For many of Thailand's watersheds, watershed management planning and environmental management planning are one and the same. Because of increased population pressure and unsuitable exploitation of watershed resources, many of Thailand's watersheds have been or will soon be environmentally degraded to the point that without environmental management the watershed and downstream populations may not even be able to support themselves at the subsistance level. Such a dilemma is eminent for northeastern Thailand where upland soils are already infertile and are not supporting stable agricultural systems.

The watershed of the Lam Nam Oon Reservoir (LNO watershed) is a good example of one which requires a coupling of environmental management and watershed management planning. The environmental managment of this watershed is critical for the well-being of the watershed residents, the management of the LNO reservoir and the successful operation of the LNO downstream irrigation area.

After the selection and initial assessment of this watershed was made for a case study, a number of very important secondary purposes evolved. The secondary purposes of the case study are to exemplify that (i) watershed management objectives must be balanced to ensure benefits to the watershed residents as well as downstream water users, (ii) to accomplish the balance, natural and human resources must be developed in an integrated or multiple use fashion and the economic organization of watershed management must be such that it ensures environmental stability and contains the capacity for economic growth, and (iii) integrated rural development project planning based on dam/reservoir/irrigation development should include the watershed in the project planning area and should incorporate environmental management of the total water system area of influence as a planning parameter.

1.2 Approach to LNO Watershed Case Study

A description of ecological considerations in watershed management may take several forms. Traditionally such a description would be "fundamental ecology" oriented and would include descriptions such as energy flows in natural systems, carbon cycling, soils ecosystems, nutrient cycling and so on. In recent times ecological evaluation has been modified to incorporate more of the "human factor", especially for project planning, and may now be classified as environmental evaluation. Environmental considerations make for the LNO watershed management are mostly restricted to the ecological relationships between population, natural resources and agricultural technologies, i.e. natural resource management

including conservation and development to support sustained exploitation by humans. With this approach, fundamental ecological evaluations are normally limited to the detail necessary to develop sound management practices and evaluate the interrelationships and effects on the stability of other natural systems as well as the socio-economic systems. For the LNO watershed, many of the quantitative ecological evaluations and systems analyses which should be made for optimum resource use planning were not within the scope of the case study, however, the evaluations which would need to be made for such planning are described. Due to the non-existence of recent and reliable maps for the LNO Watershed, several estimations and "rough mappings" of watershed features were made. Many of the data generated vary significantly from estimates reported in LNO project reports. Consequently the data generated should be considered as representative approximations until sufficient field surveys are carried out.

1.3 Considerations in Environmental/Watershed Management Planning

During the past several years, increased attention has been given to the environmental and economic benefits of watershed management especially for watershed forests. The very first consideration of the role of forestry in development in the Forestry Sector Policy Paper of the World Bank (1978) is given to "ecological effects." In the sector policy paper several ecological effects of forestry on development are described including :

i) microclimatic effects through reduction of the range of daily temperature variation ,

ii) effect on water catchments and regulation of streamflows by retaining water in the roots and humus layers and releasing it as a sustained flow to streams and aquifers over a long period of time and subsequent protection of land from erosion, reduction of flooding and erosion in adjacent areas and, in turn, minimization of silting of rivers, canals and reservoirs ;

iii) the combination of ecological impacts in (ii) above contribute to a stable hydrology essential to downstream irrigated agriculture ; and

iv) habitat for wildlife and recreational outlet for city dwellers as well as places to live for those whose livelihood comes from forests.

The second and third roles of Forestry in development listed in the World Bank policy paper are indigenous consumption and industrial uses. When one considers the management of a forested or partially forested watershed the compatability of the ecological effects role of the forests and the indigenous consumption and industrial uses must be evaluated. The benefits attribute for ecological effects are predominantly to downstream agriculture and non-forest residents. A watershed management plan is often geared to reap these benefits and may not take into consideration the indigenous and industrial demands. Because of this lack of consideration, especially for the indigenous population, many of the "protected forests" are being rapidly degraded to a non-productive level. Thus, when taking into account the "ecological effects" role of forests in watershed management the "management" of indigenous populations must be taken into account

so that they benefit more from supporting management than destructive exploitation.

The role of ecological and socio-economic factors in rural development planning (which encompasses watershed management planning) are becoming increasingly significant as availability of resources decreases. In the evaluation "Ecological Relationships in a Hmong Economy" Keen (1978) identifies several questions which are relevant in considering ecological aspects of watershed management planning especially as they relate to the indigenous population. Similarly important questions which shall be considered in the LNO watershed case study includes :

i) Have the people achieved balanced harmonious and rhythmic subsistence pattern within the watershed ?

ii) Does the system contain within itself elements that could lead to economic growth which might satisfy a population increase (or relocation) or higher expectation of income ?

iii) Is there competition between cash crop and subsistence crop ?

iv) What activity restricts or hinders another ?

v) What role do the forests play ?

vi) Is forest regenerating ? Why or why not ?

vii) What is the role of animal husbandry and does it compete with food crop production ?

viii) What is the capacity for growth (underused land, labor, underdeveloped markdt, etc.)

ix) What are the current or potential environmental instabilities and how are they linked to land use techniques ?

1.4 Background Information on Lam Nam Oon Project

The Lam Nam Oon project, located in Sakon Nakon Province in Northeast Thailand, was initially designed as a Royal Irrigation Department (RID) irrigation and flood control project in 1963. The Lam Nam Oon dam which is located about 45 Km. west of Sakon Nakon near Ban Nong Bua was completed in 1973 (see Figure 1 and Figure 2). The original project feasibility was based on the development of irrigated agriculture for approximately 170,000 rai and reduction of downstream flood damage. The average annual loss in farm production due to flooding was 10.9% from 1951 to 1960 with the most severe damage recorded in 1959 when floods effected a loss of 17.7 % to the total farm area. The estimated flood surcharge storage of the reservoir is 280 million cubic meters. Pertinent data for the Lam Nam Oon Irrigation Project is displayed in Table 1 (RID, 1966 and ECI, 1973) including updated figures for the reservoir and watershed. The inundation of the reservoir caused the displacement of approximately 10,000 people. A resettlement area, King Amphoe Nikom Nam Oon was established in 1969 on the west bank of the reservoir.

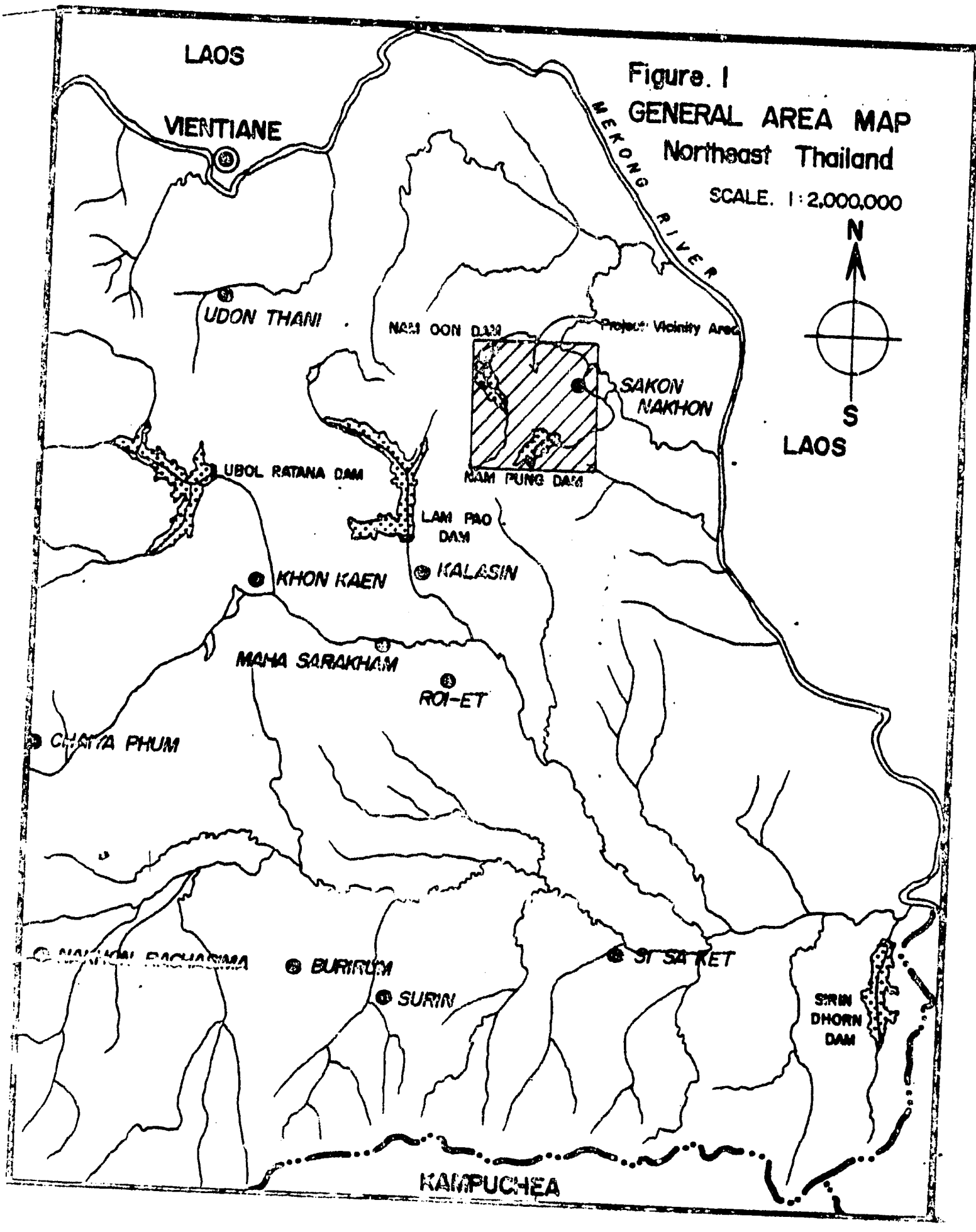


Figure. 1
GENERAL AREA MAP
Northeast Thailand
SCALE. 1:2,000,000

TABLE 1 : PERTINENT DATA FOR LAM NAM OON IRRIGATION PROJECT (ECI, 1973)

Dam Location : On the Lam Nam Oon approximately 120 Km. east of Udorn and 60 Km. west of Nakon Nakon at Ban Nong Bua.

Project Purpose : Irrigation, flood control, domestic water supply and fish production.

Constructed : By the Royal Irrigation Department. Construction commenced in 1968.

Drainage Area : 1,100 Km^2. (900 Km^2. as reported in this study based on measurements of 1 : 50,000 contour maps).

Reservoir : Area-85 Km^2. of water surface at elevation 185.0 MSL (96 Km^2. as reported in this study based on satelite imagery measurement).
Capacity-520 MCM at normal pool elevation of 185.0 MSL

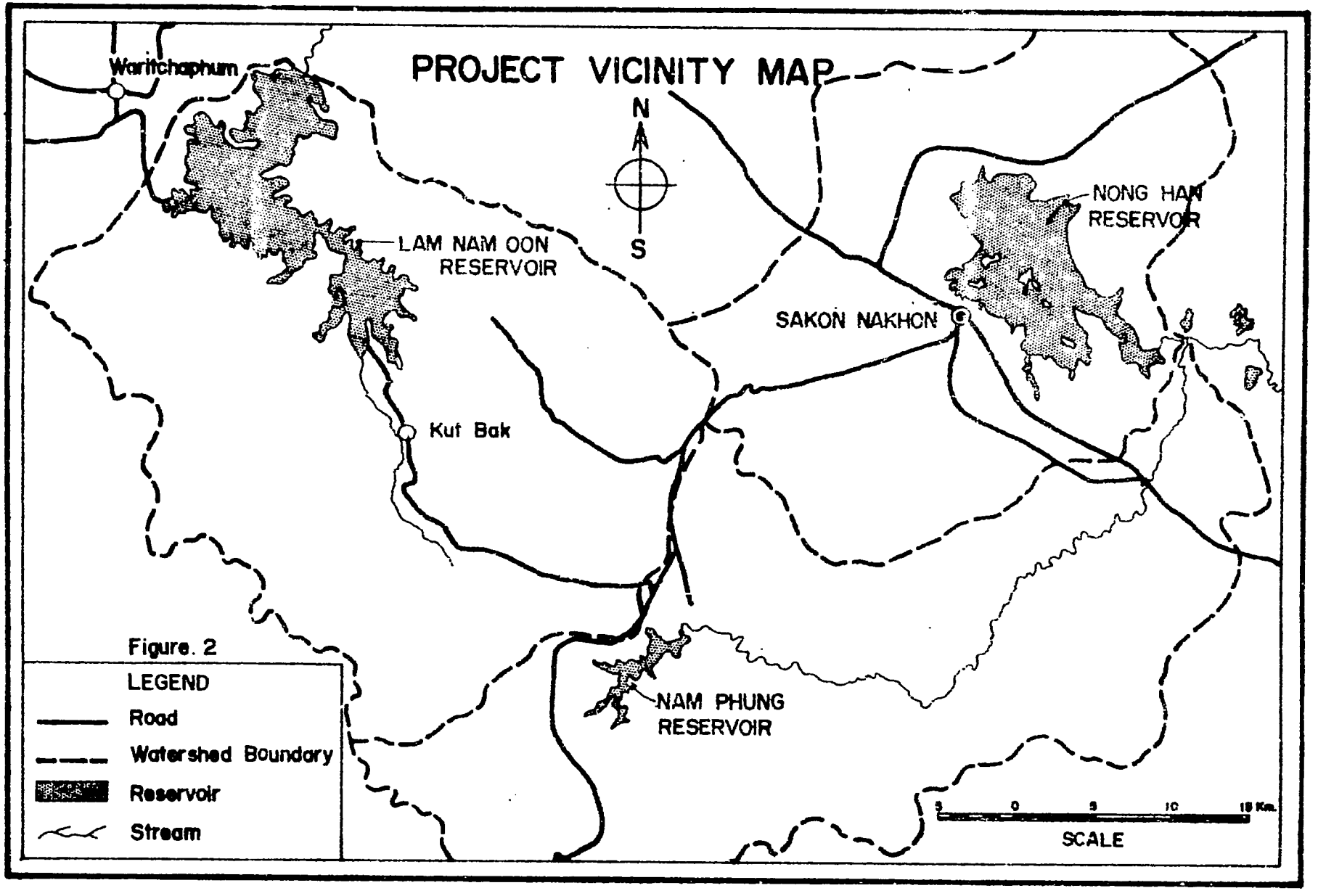
Reservoir Storage Allocations :

Purpose	Elevation	Storage, MCM
Flood Control	185.0-187.3	280*
Irrigation	175.0-185.0	475
Dead Storage	160.0-175.0	45

*Estimated flood surcharge storage

Service Area : Gross area 477.4 Km^2.
Miscellaneous and high lands 75.8 Km^2.
Arable area 345.8 Km^2.
Reclaimable non-arable land 16.32 Km^2.
Net irrigable area 313.8 Km^2.

Maximum Discharge : Service spillway - 380 cms
Emergency spillway - 461 cms


PROJECT VICINITY MAP
N
S
Waritchaphum
LAM NAM OON
RESERVOIR
Kut Bak
SAKON NAKHON
NONG HAN
RESERVOIR
NAM PHUNG
RESERVOIR
Figure. 2
LEGEND
Road
Watershed Boundary
Reservoir
Stream
5 0 5 10 15 Km.
SCALE

Because of inattention to on-farm use of irrigation water and a desire by the RTG to quicken the pace of agricultural development, the original scope of the Lam Nam Oon Irrigation Project was broadened in 1977into an integrated rural development project. The six-year USAID assistance project is an effort to increase the quality of life of proximately 10,000 poor farm families and includes : (i) the completion of construction of the irrigation system in the Lam Nam Oon project areas (ii) construction of a road network for the irrigation system operation-maintenance and doubling as a feeder road system for farmers; (iii) operation of an on-farm water supply system ; and (iv) an integrated program of community development, agricultural research and extension, provision of farm inputs, farm products marketing, health and family planning services, and adult education. A separate element of the project is the introduction of modern sericulture practices to families resettled from the reservoir area to the upstream resettlement area. There is also a fish production program for the LNO reservoir and fish pond culturing downstream. A pump irrigation project has been initiated in the LNO resettlement area using the LNO reservoir as water supply. The integrated project involves participation of over 12 Royal Thai Government agencies as well as local and provincial authorities (AID, 1977).

2. LNO WATERSHED : PHYSICAL ENVIRONMENTAL SETTING

2.1 General

The LNO Watershed is comprised of approximately 950 square kilometers lying within Sakon Nakon Province in Northeast Thailand.[1/]

2.2 Physiography and Drainage

The oval shaped watershed is approximately 45 kilometers long (northwest-southeast) and has a maximum width of 44 kilometers and a total relief of 506 meters. The upland topography of the Phu Phan Uplands varies from rolling to steeply rolling hills with rounded to flat-topped crests 150 to 475 meters above adjacent valley bottoms. Ridge slopes vary from 10% to 30% on the west ridge, 7% to 25% on the south ridge and 5% to 25% on the east ridge. The watershed valley is a portion of the Sakon Nakon Lowlands with interstream areas of rolling and dissected plains between 30 and 50 meters above adjacent valley bottoms. Lowland slopes are largely between 2% and 10%.

The Lam Nam Oon river system source is in the Phu Phan Mountain ridges which form elevated horseshoe shaped perimeter on the west, south and east with the opening at the north. The source of the two main branches

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1/ RID reports the drainage basin is 1150 square kilometers based on 1:250,000 topographic maps. The above approximation of 950 square kilometers is from planimetric measurement of 1:50,000 topographic maps.

of drainage system,namely Huai Nam Oon and Huai I Don, is at the southern most ridge in the watershed. Water flow in these meandering tributaries is generally northern until discharging into the Lam Nam Oon Reservoir. A large number of smaller tributaries with sources in the eastern and western ridges flow into the reservoir. The controlled reservoir release to the Lam Nam Oon River meanders through Panna Nikom District to its confluence with the Huey Pra Harng River. The river then meanders north through the Sakol Nakon Lowlands to its confluence with the Nam Songkhram River which discharges into the Mekong River some 50 Km. downstream.

2.4 Climate

The LNO Watershed climate shows two distinct seasons, namely (i) the southwest monsoon or rainy season, mainly between mid-May and mid-September and (ii) the northeast monsoon or dry season, mainly between mid-October and March. Short autumn and spring transition periods separate the two seasons. The southwest monsoon starts with severe thunderstorms in May and a rainfall pattern of almost daily local showers, occasionally torrential, is established by June. During August and September, developing tropical storms enter the area infrequently with longer lasting and heavy rainfall (ASRCT, 1971). Approximately 80 percent of the annual rainfall occurs during the southwest monsoon. LNO Watershed mean monthly temperatures range from a high of 29.3°C in April during the spring transition period and a low of 21.3°C in January during the northeast monsoon season. Selected climatic data is presented in Table 2.

3. ENVIRONMENTAL MANAGEMENT FACTORS

3.1 Land Resources

The quality of land, its ownership, use, and management, are prime contributing resource factors which affect the environment. Poor land management depreciates the value of the land resource and can be detrimental to environmental values such as the water quality and aquatic habitat of receiving waters. Likewise, social and economic changes result from poor land management. Non-productive degraded forest and depleted agricultural lands in Northeast Thailand are common examples of this phenomenon. Land and its use can be related to nearly every environmental resource or value from wild-life habitat to the economic well-being of a community. Within this matrix of relationships between landuse and other factors are conflicts which must be resolved to ensure a healthy life-supporting environment.

3.1.1 Land ownership Public landownership in the LNO Watershed is estimated to be between 75 to 85 percent including the eastern and southern portions of the watershed which are in the Phu Phan National Park, western forest believed to be forest reserve, the LNO reservoir perimeter, part of the LNO resettlement area, and administrative areas in villages. Average private land holdings in and around the resettlement area is 15 rai per family. There are numerous cases of illegal land encroachment and settlement which shall be discussed in 3.1.3, Dedicated Landuse.

TABLE 2 : PRECIPITATION AND TEMPERATURE DATA AT SAKON NAKON, 20 YEARS

Month	Temperature, °C			Precipitation, mm.				
	Mean max.	Mean min.	Mean	Max	Min	Mean	Highest 24-hour	Ave. No. Rainy days
January	29.4	13.0	21.3	47.3	1.5	5.2	26.0	0.6
February	31.4	16.6	23.9	93.5	0.2	18.3	57.6	1.7
March	33.9	20.4	27.1	112.9	0.2	34.1	52.2	3.2
April	35.7	23.1	29.3	120.1	10.4	70.9	69.7	5.8
May	33.8	23.8	28.8	446.8	48.7	217.4	220.1	12.3
June	32.5	24.1	28.4	439.6	76.7	197.6	98.4	11.9
July	32.0	23.9	28.0	362.8	59.5	197.6	184.2	14.2
August	31.6	23.9	27.7	612.1	82.9	270.0	115.5	17.4
September	31.2	23.4	27.3	451.1	108.3	272.7	214.3	13.3
October	31.2	21.2	26.3	189.3	1.0	59.6	93.9	5.0
November	30.5	17.6	24.1	59.2	0.4	6.4	52.2	1.2
December	29.3	14.3	21.9	44.5	0.2	4.6	35.3	0.3
Mean	31.9	20.4	25.2	2,001.7	779.5	1,414.8 mm.		

3.1.2 Landuse: The first phase of a systematic approach to proper land management and related resource conservation is to determine its present use and capability. LNO Watershed landuse was primarily obtained from the Department of Land Development landuse maps (DLD, 197.) with limited truth-checks using satelite imagery (NRC, 1979), low-level aerial photographs (R.S.D., 1974) and field observations. The basic landuses are identified as paddy, upland crops, LNO reservoir, non-cultivation areas due to stony soils or rock outcrop, forest, and mixtures of paddy-upland crop, paddy-forest, upland crop-rocky soils, upland crop-forest, upland crop-orchard, and orchard-forest. Watershed landuse is displayed on Figure 3. The approximate area and percent of the total watershed for each basic landuse is presented in Table 3. Major upland crops which are reportedly grown in the watershed include : cassava, kenaf, chili, cotton, sesame, pumpkin and tobacco (DLD, 1979 and Sangsingkeo, 1975).

The soil types and their areas were determined from soil survey maps developed by the Dept. of Land Development (1972). Each soil type is associated with two land capability units; one unit beginning with " P " for paddy and one unit beginning with " U " for upland crops. Land capability units are based upon the use limitation or hazards that the land has due to its topography and water characteristics irrespective of its present use. A land capability unit is composed of a class designation and subclasses to indicate the major limiting factor (s). In the LNO Watershed the soils have been grouped according to similarities in land capabilities. The class designations for paddy are either P-III meaning soils are fairly well suited to paddy land or P-V meaning soils are generally not suited to paddy land. The class designations for upland crops are from U-III to U-VI. Each class designation from I through IV demands progressively more careful use for successful crop production. Whereas Class U-III land is fairly well suited to growing upland crops, class U-IV land, which is poorly suited to growing upland crops, must be carefully managed to prevent serious erosion or other damaging processes from occurring. Class designation VI is not suited to cultivation. Subclass designations for limitations of LNO Watershed soils include : " e " for erosion susceptibility, " s " for soil limitations in the root zone due to low soil fertility which are difficult to correct; " m " for lack of moisture for plant growth after short periods of little rain due either to inability of soils to hold sufficient water to maintain plant growth during dry periods, or to lack of water for plants in dry seasons, or both ; " d " for impeded drainage mostly due to slow permeability; and " t " for unfavorable topography. Soil class and subclass limitations are good examples of controlling factors of the environment on watershed planning and management.

Land use by soil type and capability units for the watershed have been determined and are presented in Table 4. The major watershed soils are : (i) Roi Et Series which are utilized primarily in producing rainfed or irrigated rice ;(ii) Khorat Series which are utilized for shifting cultivation and/or upland crop, fruit or vegetable production with some areas still occupied by dry dipterocarp forest , (iii) Borabu Series which are mainly covered with dipterocarp forest , (iv) Nam Phong Series which are

TABLE 3 : LAM NAM OON WATERSHED LANDUSE CHARACTERISTICS

Landuse 1/	Approximate Area (sq.Km.)	Percent of total area (%)
Paddy	122	12.8
Upland crop	12	1.2
LNO reservoir 2/	96	10.1
Forest 3/	580	61.1
Non-vegetated area due to stony soils or rock outcrop	38	4.1
Upland crop in Stony soils	32	3.4
Upland crop-forest mix	57	6.0
paddy-upland crop mix	7	Combined 1.3
paddy-forest mix	3	
Upland crop-orchard mix	2	
Orchard-forest mix 4/	1	
Total	950	100

1/ From Dept. of Land Development (1979) with limited aerial and field check by author in April, 1981.

2/ LNO reservoir surface area taken from Oct. 1979 1 : 250,000 satelite photo when reservoir elevation was 184-185 m MSL-equivalent to design operation elevation.

3/ See text for forest descriptions : western ridge and Valley forests are generally non-productive while eastern and southern ridge and valley forests are relatively productive (Kasetsart, 1980 and Boonnorm, 1979).

4/ Orchards are predominantly coconut, banana and papaya.

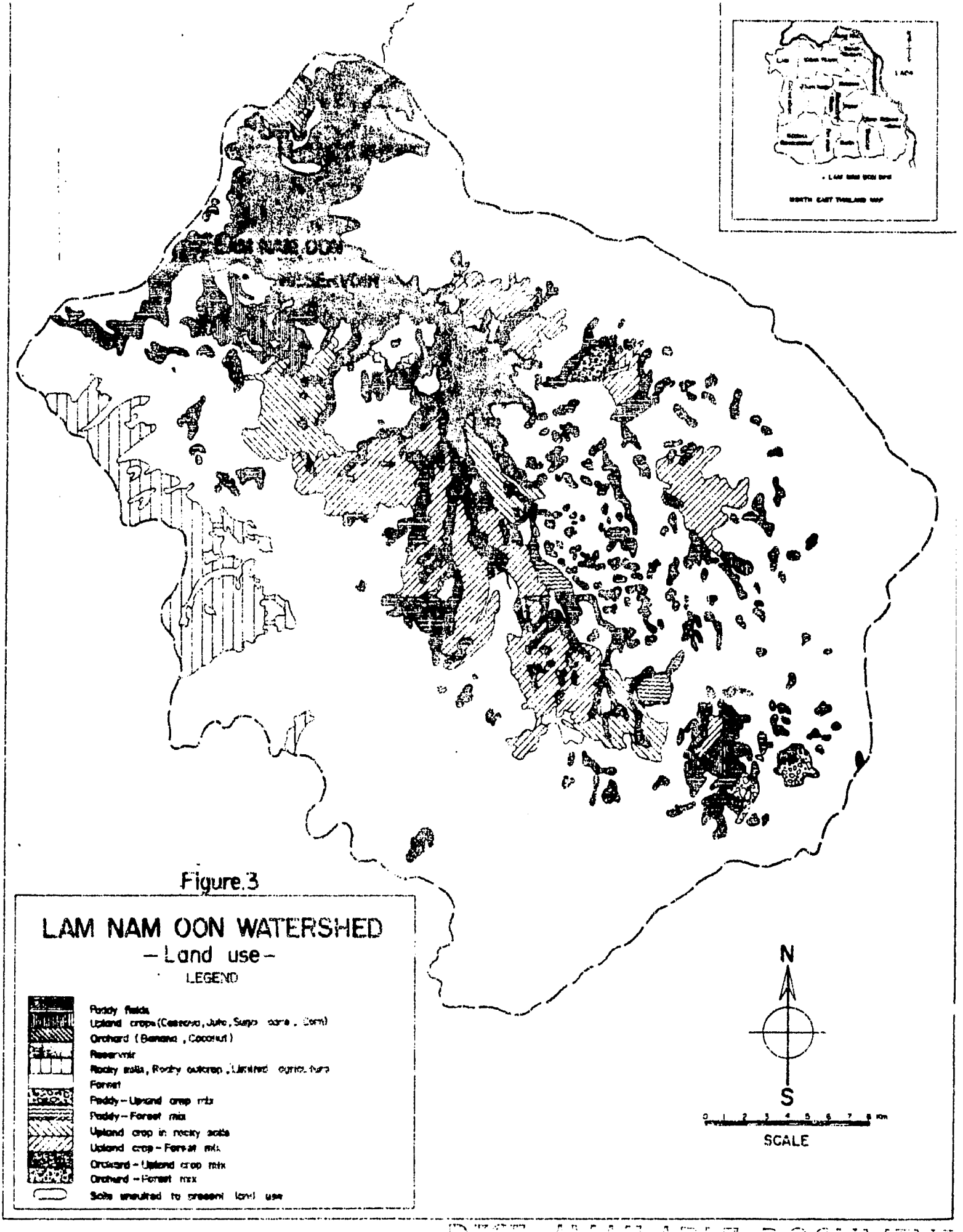
LAM NAM OON
RESERVOIR
Figure.3
LAM NAM OON WATERSHED
—Land use—
LEGEND
Paddy fields
Upland crops (Cassava, Jute, Sugar cane, Corn)
Orchard (Banana, Coconut)
Reservoir
Rocky soils, Rocky outcrop, Unlisted
Forest
Paddy – Upland crop mix
Paddy – Forest mix
Upland crop in rocky soils
Upland crop – Forest mix
Orchard – Upland crop mix
Orchard – Forest mix
Soils unsuited to present land use
N
S
SCALE

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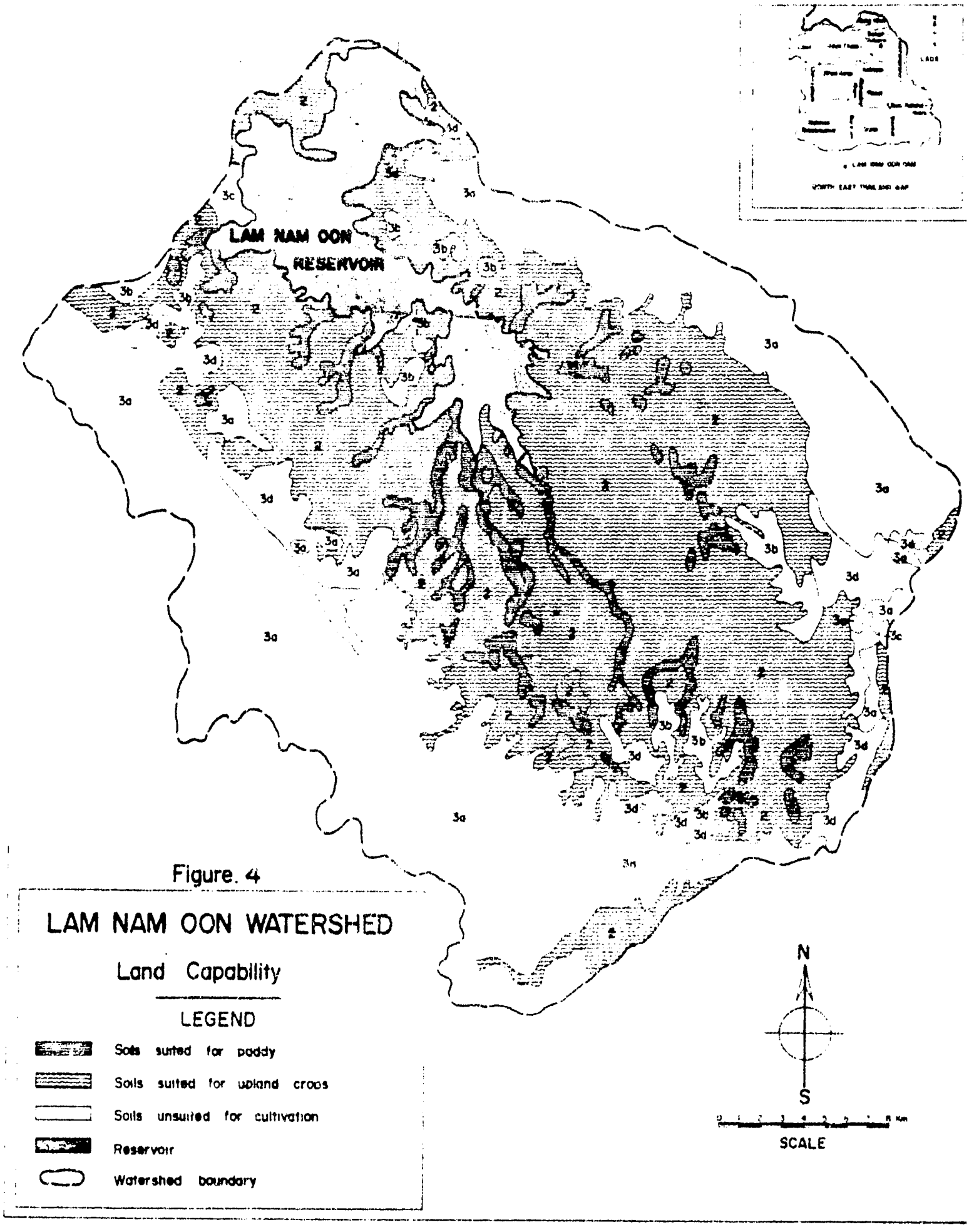
TABLE 4 : LMD WATERSHED LAND CAPABILITY AND LAND USE COMPARISON

(DLD, 1971 and 1978 ; Table V-3)

Watershed Area - Percent - Land Capability (sq.km.) - (soil series-sq.km.)	Capability Groups : Associated Soils Series and Land Capability Units	Descriptions	Limitations, Management Problems	Land Potential	Land Use in Capability group (sq.km.)	Land Use-Capability Comments
8.1% 69 sq.km.	1. Roiet series U-III sm P-III ds	Soils moderately suited for upland crops or paddy. Average rice yields are medium.	Low soil fertility, inability of soil to hold water during periods of little rain, drought in dry season, slow permeability impedes drainage for upland crops.	The potential of this soil is such that substantial yield increases could be realized through intensive management practices such as the use of proper rates and applications of fertilizers, lime where needed, improved seeds and plant varieties insecticides, cultivation method, and irrigation and/or drainage systems. The area, normally too dry for crops during the dry season, could with supplemental water supply be used for additional rice or vegetables and other cultivated crops.	Paddy-(64) Upland-(3) Upland crop-paddy mix-2	5 Sq.Km. could be conve from upland crop or pad upland crop mix to padd
44.4% 379 sq.km. (373) (6)	2. Korat series U -III sm P-V ts 2' Korat high phase U-IV esm P-V ts	Soil moderately suited for upland crops, generally not suitable for paddy. Poorly suited for upland crops.	Low soil fertility, erosion and drought during dry season. Unfavorable topography for paddy.	The potential is such that cultivation could be extended several years in succession by fertilizing, maintaining organic matter and maintenance of surface layers, by erosion protection and weed control. Irrigation would increase yields but cost of pumping water and preparation of land would be high.	paddy-(54) upland crop-(6) paddy-forest mix-(2) paddy-upland crop mix-(5) upland crop-forest mix-(56) upland crop-orchard mix-(2) upland crop in rocky soils-(32) orchard-forest mix-(2) forest-(217)	Many areas in shifting cultivation with kenaf as the major crop.
47.5% 406 sq.km. (328) (17) (4) (57)	3. 3a. Slope Complex 3b. Nam Phong Series 3c. Phon Phisei Series U-VI es P-V ts 3d. Borabu Series or complex U-VI esm P-V ts	Soils have severe limitations that make them generally unsuited to cultivation. 3a.-boulders and rock out crop common 3b.-some sandstone outcrop and poor response to fertilizers 3c.-lateritic gravel 3d.-stony soils	Erosion, low soil fertility and low water holding capacity.	The potential of these soils is such that they are best suited to forest, wildlife habitat, water supply.	Paddy-(4) upland crop-(1) upland crop-forest mix-(1) non-agriculture due to rock-(38) forest-(361) paddy-forest mix-(1)	4 Sq.Km. of paddy within #3 capability group 15Sq.Km. of paddy-forest mix in #3 capability group. 1 Sq.Km. of upland crop within #3 capability group 1 Sq.Km. of upland crop forest mix within #3 capability group.

mostly in open forest with grass understory and some shifting cultivation with kenaf; (v) Phon Phisai Series which is mostly covered with open dipterocarp forest with small areas cleared for cultivation but abandoned after 2 to 3 years due to poor soil fertility; and (vi) Slope Complex which is covered in most areas with open dipterocarp forest with patches of mixed deciduous and scrub forests and unvegetated Rocky areas as displayed in Figure 4. An attempt was made to subdivide upland crop into treated land, that is, land upon which some conservation measures such as terracing or bedding have been practiced, and untreated land that has received no conservation measures. Time and lack of recent aerial photographs prevented analysis of land treatment but such an analysis will be very important for the establishment of a monitoring system designed to determine optimum land uses and treatments for watershed management.

3.1.3 Dedicated Land Use Areas with dedicated landuse are designated areas for which resource utilization is specified and regulated. Dedicated land uses in the watershed include the Phu Phan National Park. LNO reservoir and LNO resettlement area. Phu Phan National Park, established in June 1973, is legally protected by the National Parks Act B.E. 2504 (1961) which prohibits acts within the parks including ownership or cultivation of land, burning, collection of or damage to vegetation, endangering animals and the removal of them or their products, the removal of minerals, damming or interfering with natural flow of water courses, the carrying of weapons and other acts which inhibit preservation of the area in its natural state. Phu Phan National Park cover 699 sq.km. of which 336 sq.km. are within the Lam Nam Oon Watershed or about 39 percent of the total watershed land area as displayed in Figure 5. If the Phu Phan National Park received the protection legally due, the need for a watershed management plan would be reduced significantly. Unfortunately the park receives a great deal of human pressure. While making a one-day hike through a portion of the park in the watershed, the author sighted signs of every illegal act listed above. Boonnorm (1979) reports that forest encroachment has resulted in non-productive forest over 20% of the forest. Types of encroachment include forest products poaching, paddy and upland crop cultivation, land settlement, laterite mining, and road construction. A survey of illegal inhabitants and poachers, estimated at 9,744 persons, showed that they were from 19 provinces and the reasons given for moving to the area and for their illegal actions included; (i) many had come to be fishermen at Nam Phung Reservoir and engage in agricultural activities for supplemental food and income; (ii) easy access for profitable poaching in area where patrolling is inadequate and policies frequently changed because of political sensitivity; (iii) fertile soil along the road (which forms part of the east edge of the watershed) (iv) forced to move out of reservoir areas; (v) dam constructors out of work and (vi) increased land and food requirements due to family expansion. The nature of and ecological effects of forest destruction in the Phu Phan National Park are discussed further in Section 4. Illegal occupation of the LNO resettlement is also a problem resulting from competition for land and water resources.


LAM NAM OON
RESERVOIR
Figure. 4
LAM NAM OON WATERSHED
Land Capability
LEGEND
Soils suited for paddy
Soils suited for upland crops
Soils unsuited for cultivation
Reservoir
Watershed boundary
N
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SCALE

TABLE 5 : LNO WATERSHED RUNOFF-RAINFALL (1961-1968, 1974-1979)

(note : rainfall of 0 indicates none or trace)

Year : Runoff (mm) / Rainfall (mm)	Month: Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1961 Runoff	3.8	45.6	93.5	16.5	72.6	453.3	135.4	0	0	0	0	0	818.7
Rainfall	84.1	301.2	357.4	103.7	334.9	364.8	106.2	0	0	0	0	30.4	1682.8
1962 Runoff	1.3	3.8	20	35.4	92.5	110.5	31.5	4.5	1.2	0.9	0.6	0.6	307.6
Rainfall	74.5	192.8	200.4	188.8	341.8	258.3	53	7.6	0	0	4.3	14.9	1386.4
1963 Runoff	1.5	13.7	38.3	16.7	13.3	73.6	62.4	8.3	2.0	0.8	0.6	0.6	221.8
Rainfall	12.7	181.9	344	354.5	345.2	104.1	26.5	17.4	0	0	0.8	28.2	1415
1964 Runoff	0.3	4.0	42.7	140.0	250.4	111.6	45.9	6.7	1.5	0.8	0.5	0.2	539.6
Rainoff	97.8	320.1	329.5	103.1	297.6	229.8	135.8	5.8	0	0	11.8	38.5	1469.8
1965 Runoff	1.4	15.9	95.7	44.3	72.8	78.2	6.4	2.1	0.7	0.3	0.4	0.8	319.2
Rainfall	74.6	440.2	189.5	119.4	281.1	147.7	27.2	0	0	0	68.1	122.4	
1966 Runoff	0.5	11.9	13.7	15.8	94.2	166.4	9.7	3.5	1.2	0.6	0.4	0.3	318.2
Rainfall	108.7	214.9	148.1	210.7	382.4	108.3	78.7	0	14.4	0	0.8	0.2	1267.2
1967 Runoff	0.7	8.7	24.5	21	33.7	113	47.8	3.2	1	0.4	0.1	0.3	256.4
Rainfall	61.7	195.9	286.6	217.6	186.3	365.5	8.8	61	0.3	6.5	28.2	62.9	1437.3
1968 Runoff	2.3	3.2	11.5	18.6	43.0	144.3	15.1	1.2	2.0	0.4	0.8	1.4	245.1
Rainfall	189.1	206.9	162.3	232.8	86	103.6	65.6	14.9	0	7.4	0	61.5	1220.1
1974 Runoff	8	2	10	11	208	85	11	0	0	0	4	7	346
Rainfall	109.1	208.8	262	155.2	999.2	128.7	22.9	16.3	0.6	13.6	23.2	15.9	
1975 Runoff	4	13	[illegible]	107	127	103	31	0	1	4	11	9	469
Rainfall	18.7	192.5	320.1	355.1	413.7	266.6	25.6	3.3	0	0	0	0	1598.6
1976 Runoff	17	21	29	30	37	50	37	2	0	3	1	2	259
Rainfall	27.5	25.7	84.6	92.9	104.9	150.9	74.3	0	0	0	0	4.8	565.6
1977 Runoff	6	15	0	18	29	89	0	0	0	0	2	8	169
Rainfall	87.1	95.8	64.1	141.9	195.3	232.5	0	0	0	0	0	0	816.7
1978 Runoff	15	12	25	76	206	97	0	0	0	2	10	7	450
Rainfall	0	61.3	63.7	199.8	416.9	202.5	9.6	0	0	0	1.1	22.2	977.1
1979 Runoff	17	90	140	58	133	66	9	0	11	8	5	7	544
Rainfall	65.8	361.0	239.9	51.4	258.3	130.4	0.0	0	0	0	1.3	7.2	1165.7
Runoff : mean	5.8	19.5	42.2	43.5	102.3	124.5	30.2	2.3	1.5	1.5	2.6	3.2	378
max	17	90	140	140	250.4	453.3	135.4	8.3	11	8	11	9	815.7
min	0.3	2	0	11	13.3	50	0	0	0	0	0	0	169
% distribution (approximate)	1.34	5.2	11.2	11.6	27.2	33.1	8.0	0.6	0.4	0.4	0.7	0.8	

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3.1.4 Mineral Deposits-Construction Materials: The removal of subsurface materials may significantly effect the environmental quality of a watershed as well as watershed management efforts. The LNO Watershed does not have any known mineral deposits. It does have several operating or spent laterite pits as well as untapped 0-80 cm. thick lateritic gravel deposits which occur 20-60 cm. below the surface (ASRCT, 1971). Lateritic gravel is used extensively for road building in the watershed vicinity. During field reconnaissance in Phu Phan National Park large abandoned and untreated laterite pits were viewed along with obvious gully erosion.

3.1.5 Water Management: Taken within the context of land resource management, water management involves the addition or removal of water to facilitate increased agricultural production. The only land capability limitations which may require removal of water as a management practice (ie. drainage measures) exists in the Roi Et soil series if used for upland crop. However, these soils are the only suitable watershed soils for paddy with 92 percent presently in paddy. It is unlikely that the Roi Et soils will be used for upland crops and consequently soil drainage measures are unlikely to be an important part of watershed management until irrigation water supply is available and used for more intense cropping.

The other aspect of water management involves the addition of water to facilitate increased agricultural production, i.e. irrigation. Most of the cultivated watershed lands are rainfed. There is reportedly a pump irrigation project development in Amphoe Nikom Nam Oon for LNO resettlers with wet season irrigation for 28.8 sq.km. and dry season for 8 sq.km. but lack of water supply for agriculture is still a problem (Sangsingkeo, 1975). The potential of Roi Et soils is such that substantial yield increases could be realized through intensive management practices including supplemental water supply. Irrigation would also significantly increase yields of the Korat soils. Intensive management practices include application of fertilizers and pesticides as well as water, and consequently water management such as irrigation drainage must become an increasingly important component of land resource management. A study by AIT (1978) concludes that the only way the future year round food and water requirements will be met will be through small-scale water resource developments. In order to maximize production using small-scale irrigation and enhance the economic viability of such projects, efforts should be included in planning a watershed management program to identify effective water management for both increased agricultural production and environmental protection. Such a program is discussed further in Section 4, Watershed Management Needs.

3.1.6 Upland Erosion Sedimentation and Flooding Damages: The upland soils of the LNO Watershed are highly erodible. The quantity of soils lost due to erosion, the severity of erosion types (sheet, streambank, gully, roads, floodplain scour) or soil losses relative to various landuses have not been established for the watershed. Because of the very significant long-term environmental effects of erosion and sedimentation on resources, it is very important to identify, quantify, typify and map sediment sources so that watershed management measures can be designed to eliminate

or control the sources. Emphasis must be placed on soils conservation such as contour banking for cultivation of the Korat series which previously was described as suitable for upland crops. Middle terrace Korat soils have traditionally been the areas used for shifting cultivation and will likely be more intensively cultivated in the future. Because of the dispersive soil surface, massive subsurface material and restricted infiltration, heavy rains can result in significant soil loss and damage if the soil has been disturbed by cultivation even if the area is fairly level (Charley, 1978). Surprisingly, water in the LNO reservoir is quite clear (not turbid) and relatively weedless indicating insignificant sedimentation. Sedimentation may be taking its toll of damanges to crop production upstream of the reservoir. Flood damage does not appear to be significant in the watershed. Some low lying areas in the floodplain are flooded periodically and farmers surveyed in the lowlands listed flooding as one of six problems inhibiting agricultural production and marketing (Sangsingkeo, 1975).

3.2 Water

3.2.1 Streams

3.2.1.1 Discharge : Streamflow characteristics are important for consideration in a study of water problems and requirements for an area like the LNO Watershed. Average flow and seasonal variations of flow indicate the availability of surface water. The effects of alterations in stream-flow due to the presence or lack of watershed management may be far-reaching economically and ecologically. Detailed runoff evaluations are available for the watershed (USAID, 1977). Streamflow data for the watershed is presented in Table 5.

For watershed management planning it will be important to understand the subwatershed drainage characteristics. Methodologies are available for estimation of reach runoff based on data available. However, to enable runoff characterization with upstream land use and other characteristics and to facilitate correction and correlation of erosion-sedimentation information to runoff and land use, monitoring stations need to be established at sites identified on Figure 6.

3.2.1.2 Seasonal Variations in Streamflow: Figure 7 displays the seasonal variations and relationships between rainfall and runoff.

3.2.1.3 Regimen: In the process of developing a management scheme to supply upper watershed water requirements, it is important to understand subwatershed characteristics, especially the stream regimen. Classification usually includes perennial and intermittent and sometimes ephemeral. During field reconnaissance to the LNO Watershed at the peak of the dry season, several streams were flowing in the ridge areas but not in the valleys. The classifications of the 1965 : 50,000 contour maps are not accurate enough to rely on for any level of planning where stream regimen is a disign or management factor. Consequently, dry season field classification should be made. The author has found that stream walks are extremely useful for regimen classification, as well as evaluation of bank

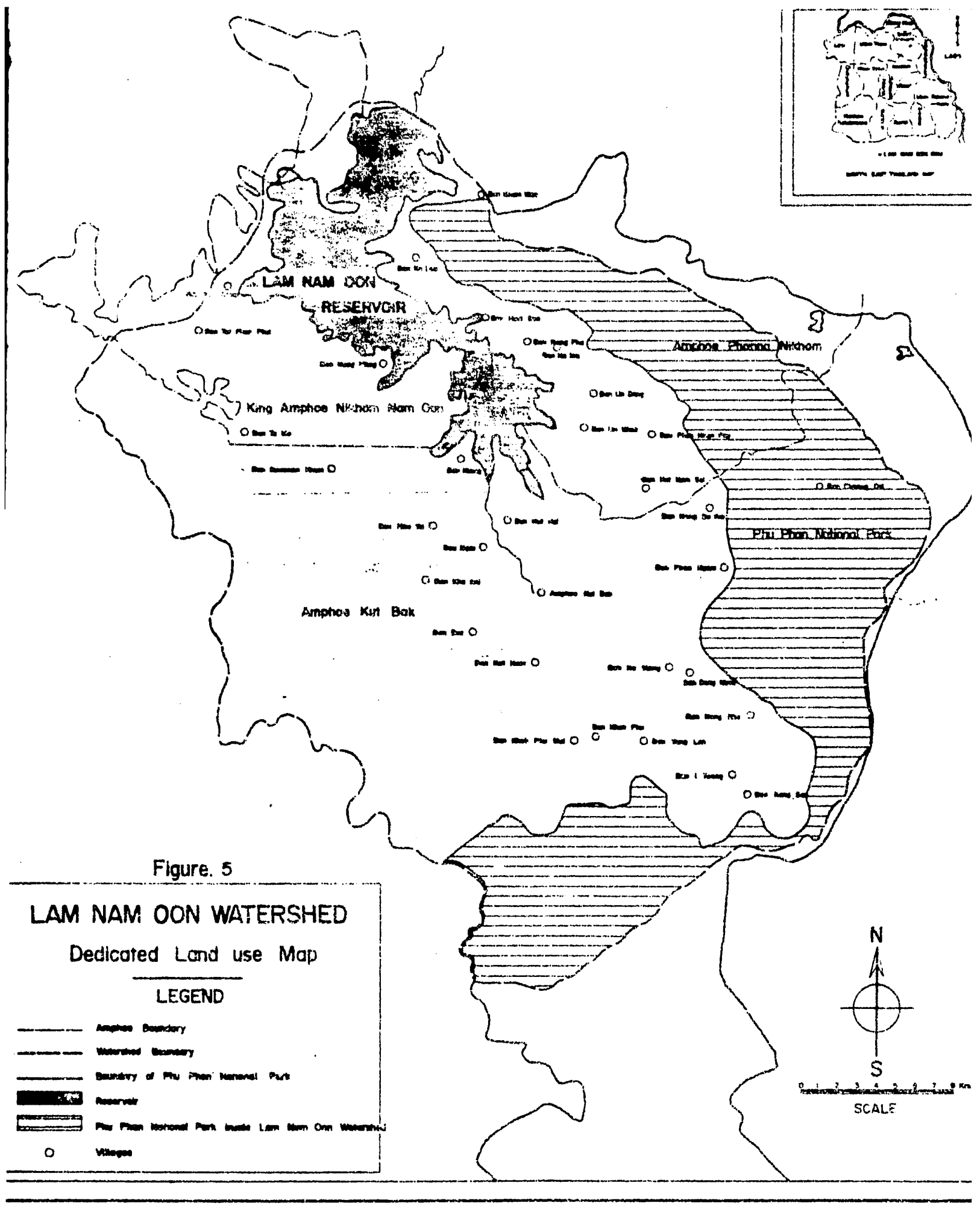

Figure. 5

LAM NAM OON WATERSHED

Dedicated Land use Map

LEGEND

- Amphoe Boundary
- Watershed Boundary
- Boundary of Phu Phan National Park
- Reservoir
- Phu Phan National Park Inside Lam Nam Oon Watershed
- Villages

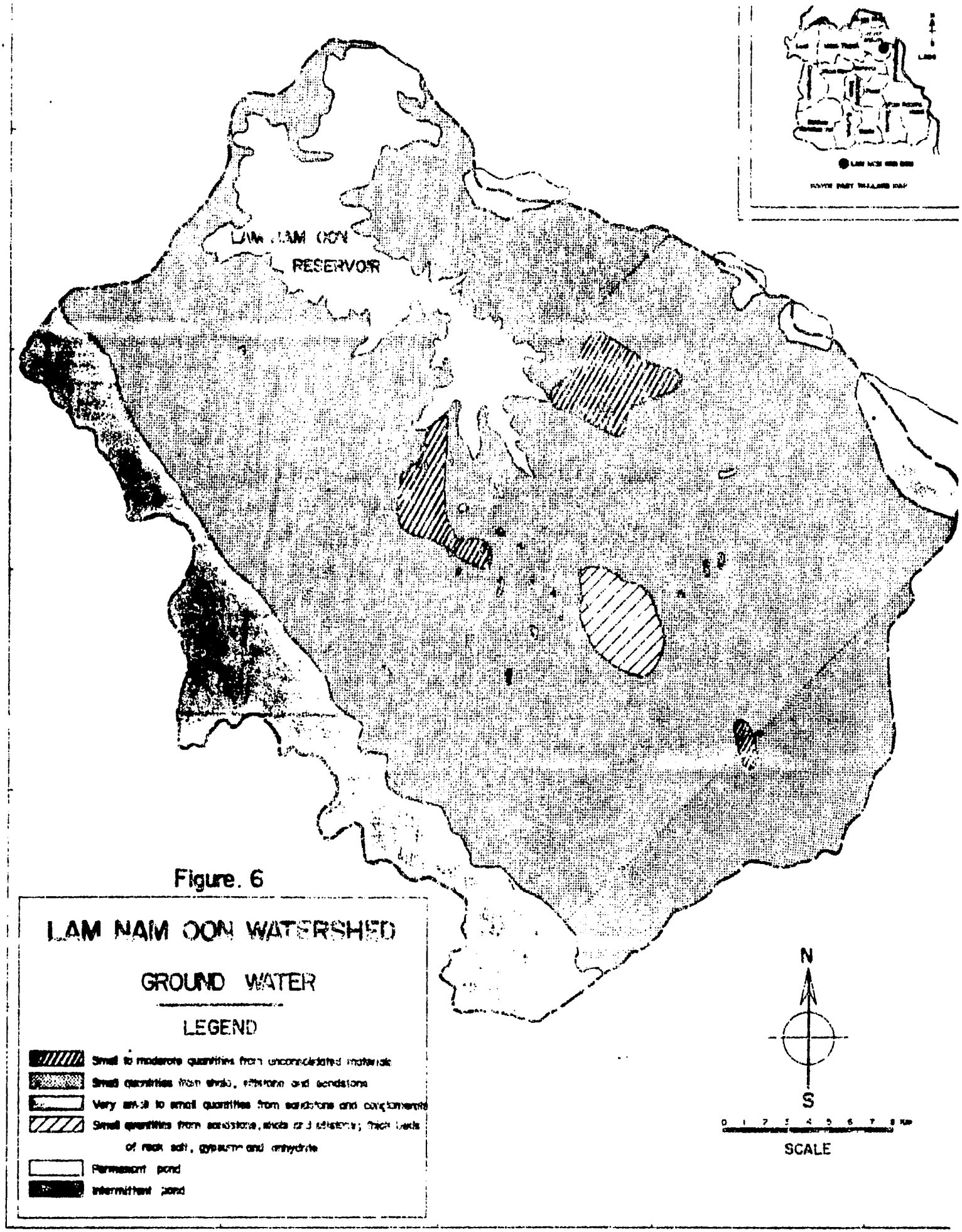
LAM NAM OON
RESERVOIR
LAM NAM OON WATERSHED
GROUND WATER
LEGEND
Small to moderate quantities from unconsolidated materials
Small quantities from shale, siltstone and sandstone
Very small to small quantities from sandstone and conglomerate
Small quantities from sandstone, shale and siltstone; thick beds of rock salt, gypsum and anhydrite
Permanent pond
Intermittent pond
N
S
SCALE

Figure. 6

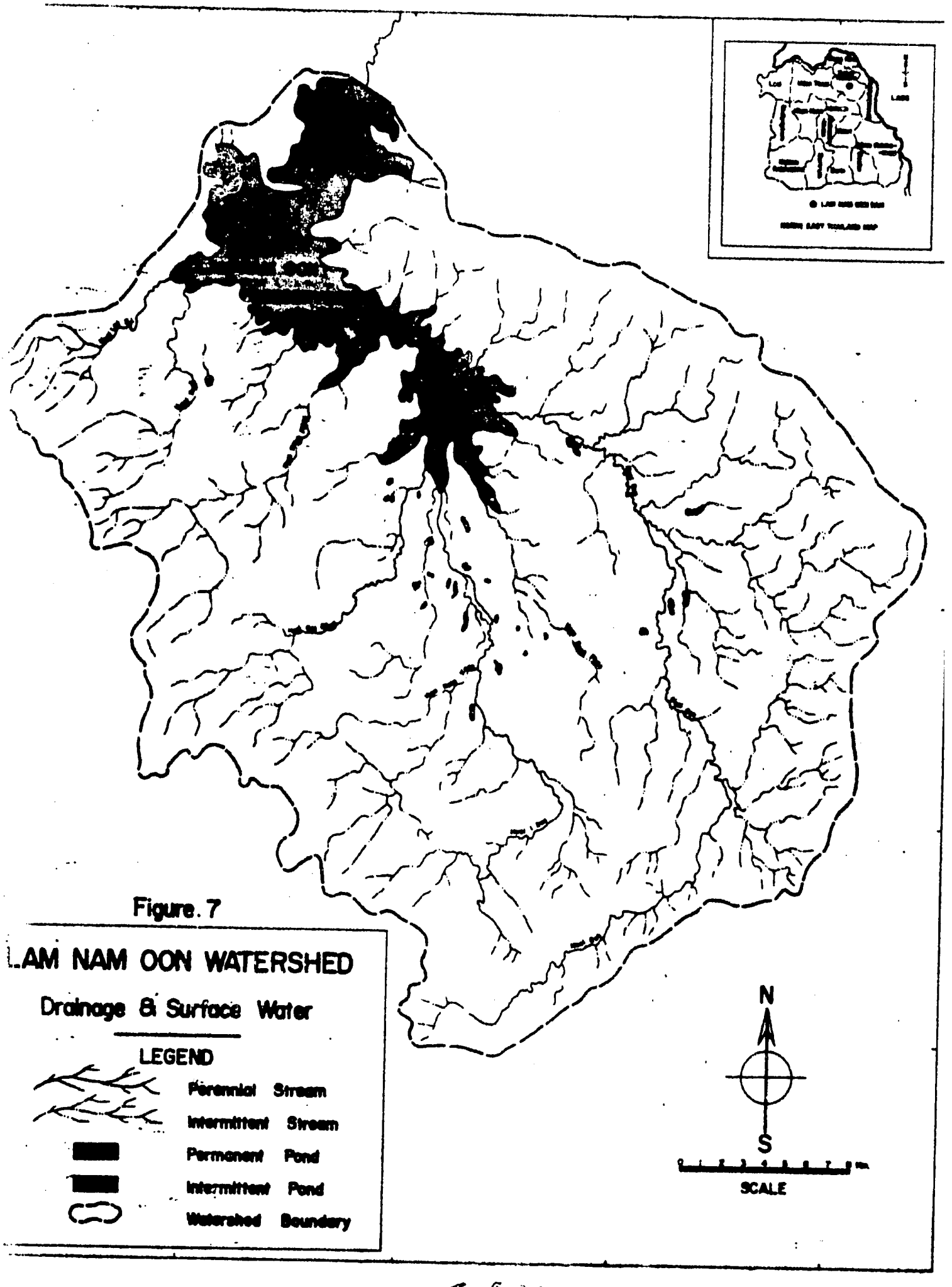
Figure. 7
LAM NAM OON WATERSHED
Drainage & Surface Water
LEGEND
Perennial Stream
Intermittent Stream
Permanent Pond
Intermittent Pond
Watershed Boundary
N
S
SCALE

Stability, bed gradation changes, aquatic habitat, potential grade-stabilization flood control or other structure sites, and reparian land use.

3.2.2 Lakes and Reservoirs : Several small permanent and intermittant lakes and reservoirs exist in the lowlands of the watershed. These natural impoundments are now recognized as valuable assets for water resource development but descriptive information will be necessary to utilize them in a rural development or watershed management scheme. The potential is very good that small structures could be built for sediment-erosion flood control and the resulting impoundments used for various water supplies. Hydrologic information adequate for watershed management planning is limited to LNO reservoir. The pertinent storage and yield data is displayed in Table 1; Monthly discharge from LNO reservoir is presented in Table 6.

3.2.3 Groundwater : The majority of the LNO Watershed has good quality groundwater with small water yielding capacity from shale, siltstone and which ranges from 54,500 to 545,000 liters per day. The west ridge and portions of the east ridge yield is very small, from 5,450 to 54,500 liters per day. Small pockets of moderate yields, 545,000 to 5,450,000 liters per day, can be obtained from unconsolidated materials in the lowland along stream courses. Most of the drilled wells are between 20-50 meters in depth (ASRCT, 1971). Locations and descriptions of groundwater resources are displayed in Figure 7.

3.2.4 Water Quality : Water quality is a complex environmental parameter. The chemical composition of water varies geographically, seasonally, and diurnally and is influenced by such natural factors as flow rate, ambient air conditions, and surrounding terrestrial conditions to name but a few. Obviously all of these factors are interrelated. Because of the complexity of influential factors it is impossible to establish a universal "good" water quality. For purposes of this report, good water quality is defined as that composition of water that contains no pollutants to a specific environment. Pollutant is defined as a substance in excess, damageable, or foreign to a specific environment. Very little data is available which allows one to assess the water composition and related quality within the LNO Watershed. The surface water quality data available for the watershed is limited to parameters which indicate suitability of water for irrigation. This data is presented in Table 8. Additional water quality analysis should be made for other water uses including domestic water supply, partial or full body contact, aquatic habitat (both reservoir and stream) and other agricultural uses. Many of the parameters which should be measured are the same for at least two of the uses (or classifications). The results of the water quality analysis can be compared to water quality criteria, when available, or other similar watershed developments to determine suitability. Water quality monitoring should be carried out to determine and manage changes in water quality caused by the watershed management projects. Some of the parameters commonly evaluated in a systematic sampling program in addition to those in Table 8 include : dissolved oxygen, temperature, total dissolved solid, suspended solid, nitrates, phosphates, and, depending on the degree of agricultural development and reservoir use, sampling parameters in certain areas may include B.O.D. fecal coliform, and residual pesticides.

TABLE 6 : MONTHLY DISCHARGE FROM LNO RESERVOIR (RID, 1981)

Month	1974	1975	1976	1977	1978	1979	1980
Apr.	-	31	53	1	5	51	24
May	-	47	60	3	0	33	12
Jun.	1	63	56	4	10	47	
Jul.	1	55	55	10	23	67	
Aug.	1	62	30	11	12	63	
Sept.	1	35	3	4	25	65	
Oct.	1	18	2	14	9	66	
Nov.	0	0.4	0.8	7	1	7	
Dec.	8	2	1	5	6	20	
Jan.	21	6	1	6	15	22	
Feb.	29	12	1	4	45	19	
Mar.	33	49	2	4	63	32	
Annual	96	380.4	264.8	73	220	492	

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TABLE 9 : WATER QUALITY OF LBO RIVER

(RCI, 1973-sampling for irrigation suitability)

Location	Sampling Date	pH	Ecm10^6	Turbidity ppm.	SSP 1/	SAR 2/	RSC meq./l 3/	Iron, ppm. Total	Iron, ppm. Dissolved	Ion in solution, meq./l Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4
Lam Nam Oon (above road works)	Jun. 6/71	7.8	<100	37	14	0.20	0	1.25	0.70	0.27	0.21	0.08	-	0	0.40	0.03	0.13
	Sep. 13/71	7.0	<100	29	14	0.20	0	0.40	0.20	0.27	0.27	0.08	-	0	0.44	0.02	0.11
	Dec. 28/71	7.3	<100	29	23	0.35	0	0.10	0.70	0.46	0.20	0.20	-	0	0.61	0.08	0.11
	Apr. 28/72	7.4	100	<25	27	0.30	0	0.10	0.00	0.55	0.27	0.31	-	0	0.81	0.15	0.06
	Sep. 17/72	7.0	<100	<25	14	0.20	0	0.40	0.30	0.62	0.15	0.13	0.06	0	0.75	0.10	0.07
	Dec. 20/72	7.2	<100	28	21	0.30	0	0.07	0.05	0.50	0.21	0.20	0.05	0	0.70	0.30	0.10
	Mar. 19/73	6.8	120	<25	12	0.20	0	-	0.00	0.73	0.42	0.16	0.08	0	1.12	0.23	0.02
New Phum Bikan (Lam Nam Oon)	Jun. 6/71	7.1	<100	47	26	0.30	0	0.90	0.30	0.23	0.14	0.13	-	0	0.37	0.06	0.08
	Sep. 13/71	6.9	<100	31	19	0.20	0	0.40	0.30	0.25	0.23	0.11	-	0	0.38	0.06	0.14
	Dec. 28/71	7.3	380	33	39	2.00	0	1.20	0.70	0.66	0.35	1.49	-	0	0.70	1.44	0.10
	Apr. 28/72	7.4	3400 6/	<25	83	16.00	0	3.20	0.00	1.31	3.78	33.00	-	0	0.32	30.10	0.08
	Jun. 17/72	8.0	<100	70	36	0.60	0	0.80	0.60	0.30	0.21	0.29	-	0	0.50	0.08	0.17
	Sep. 17/72	6.5	400	50	68	3.20	0	0.60	0.20	0.80	0.36	7.45	0.12	0	0.50	2.95	0.15
	Dec. 20/72	7.4	300	34	60	2.10	0	0.07	0.04	0.67	0.36	1.46	-	0	0.71	1.66	0.10
	Mar. 19/73	6.8	6500 6/	<25	84	24.00	0	-	0.30	5.10	5.40	56.00	1.30	0	0.58	66.36	0.39
Lam Phak Tai (Lam Nam Oon)	Jun. 6/71	7.5	160	<25	64	1.70	0	0.90	0.70	0.29	0.13	0.30	-	0	0.35	0.86	0.13
	Sep. 11/71	6.7	<100	<25	35	0.40	0	0.60	0.40	0.17	0.15	0.17	-	0	0.29	0.15	0.07
	Dec. 28/71	7.1	250	30	34	1.70	0	0.70	0.30	0.67	0.37	1.20	-	0	0.69	1.35	0.14
	Apr. 28/72	6.9	340	88	70	3.40	0	0.60	0.20	0.64	0.39	2.45	-	0	0.62	2.12	0.75
	Sep. 17/72	6.3	140	44	62	1.70	0	0.70	0.50	0.27	0.30	0.93	0.07	0	0.34	0.80	0.26
	Dec. 20/72	7.3	260	31	54	1.70	0	0.05	0.02	0.66	0.38	1.22	-	0	0.69	1.36	0.20
	Mar. 19/73	6.7	380	<25	65	2.90	0	-	0.20	0.69	0.37	2.32	0.12	0	0.57	2.53	0.38

1/ SSP = soluble sodium percentage

2/ SAR = sodium adsorption ratio

3/ RSC = residual sodium carbonate

General descriptions of some of the key parameters indicative of suitability of water for different uses are described below.

i) Temperature : Temperature of surface water is a major determining factor of the aquatic biota present and the rate of chemical reactions. A rough approximation commonly make is that a 10°C change in temperature changes the rate of reaction by a factor of 2. This approximation includes biochemical processes as well as inorganic reactions.

ii) Dissolved Oxygen : The solubility of oxygen in water is mainly a function of temperature and pressure. Oxygen is available to water both from exposure to the air and as a by-product of photosynthesis. Dissolved oxygen levels in streams fluctuate due to daily temperature fluctuation, biological oxygen demand, velocity, and photosynthetic production.

iii) pH : pH is a logarithmic expression of hydrogen-ion activity. The pH of natural water is related in one way or another to many other equilibria and many nonequilibrium reactions which occur in natural water among solute, solid and gaseous, or other liquid species.

iv) Turbidity : Turbidity is caused by the presence in the water of suspended matter such as clay, silt, finely divided organic matter, bacteria, plankton, and other microscopic organisms.

v) Bicarbonate Alkalinity : Alkalinity is defined as the capacity of water to neutralize acid. Alkalinity is primarily produced by anions or molecular species of weak acids which are not fully dissociated above a pH of [illegible]. The bicarbonate content of water is dependent on the calcium content of the earth and on the carbon dioxide content of the water. It is very seldom that alkalinity in the form of hydroxide calcium carbonate occurs in natural waters because it requires a pH of 9.5 or above for stability. Carbonate alkalinity occurs when the pH is above 8.2, however it is difficult to detect until the pH raises to 8.7 or above. Bicarbonate content is important due to its effect on pH, and therefore is linked to the species composition of aquatic communities and their life processes. Bicarbonate is actively broken down by plants in the assimilation process of photosynthesis and is consequently the source of the most important nutrient.

vi) Nitrogen : Nitrogen occurs in surface waters as ammonical nitrogen, organic nitrogen, nitrite and nitrate. Nitrogen in the form of dissolved nitrate is a major nutrient for vegetation and is essential to all life. Nitrate is available to streams via soil leaching and surface runoff. High nitrate concentrations

resulting in algal blooms can be ecologically harmful. Nitrate nitrogen, in general, is the most significant form of nitrogen in surface water both in importance and quantity.

vii) Phosphate : Phosphorous is an essential nutrient for plant growth. Phosphate is made available for solution in water from several kinds of cultural applications of phosphates by man. These pollution sources probably are the most important causes of high concentrations of phosphate in surface water. High phosphate levels in conjunction with high nitrate levels can result in algal blooms.

viii) Total Dissolved Solids : All natural surface waters carry a certain amount of dissolved solids in the ionic form which may or may not be electrically charge. The concentration of dissolved solids in the water of a stream is related to many factors such as ionic solubility and anion-cation exchange, however the most direct affect is the volume of water available for dilution. The dissolved solids concentration is an inverse function of the rate of discharge of water over all of the recorded range.

ix) Suspended Solids (fixed and volatile) : The suspended solids in surface waters are important because of their effect on light penetration, temperature, solubility products, and aquatic life. Suspended particles also serve as a transport mechanism for pesticides and other toxic substances which are readily readily adsorbed into or onto clay particles.

x) Electrical Conductivity : Electrical conductivity or specific conductance is the ability of water to conduct an electric current measured in micromhos per centimeter at 25°C. The presence of charged ionic species in solution makes the solution conductive. As ion concentrations increase, conductance of the solution increases; therefore, the conductance measurement provides an indication of ion concentration.

xi) Five Day Biochemical Oxygen Demand (BOD) : BOD is the quantity of oxygen utilized in the biochemical oxidation of organic matter in five days at 20°C. It is generally considered the most useful way of expressing stream-pollution loads and for comparing one set of conditions with another. Chemical Oxygen Demand (COD): COD determines the quantity of oxygen required to oxidize the organic matter in a sample. This is a much quicker method of determining the oxidizable material loads than BOD and is an aid in estimating organic pollution loads.

xii) Fecal Coliform : Fecal coliform is reported in the number of organisms per 100 ml. The fecal coliform count is indicative of the organic pollution load of a stream. The primary sources of fecal coliform are areas where livestock have

access to streams or village wastes are discharge untreated to streams.

Ground water quality in the watershed is classified as generally good according to ASRCT (1971) (see Table 7).

3.3 Aquatic Habitat and Fisheries : Aquatic habitat in the LNO Watershed can be divided in to streams, small ponds and one reservoir. Aquatic habitats can be classified as to their relative degree of importance as fisheries resources. One possible classification system is displayed in Table 9.

The only significant fishery resource in the LNO watershed is the LNO reservoir. As is typical of other impoundments (dams, tanks) constructed in N.E. Thailand the Lam Nam Oon reservoir was not cleared of vegetative growth prior to flooding. As a result the nutrients derived from submerged vegetation is expected to support biological activity and aquatic plant growth which in turn will support a high fish density. The fish density and harvest reported in 1977 for the reservoir was 8 kg./rai and 5 kg./rai, respectively. Under the LNO integrated development project, the target reservoir fish density is 30 kg./rai, to be accomplished by annual stocking of one million fingerlings.

Fish farming is carried out to a limited extent in small artificial ponds in the watershed. Subsistence fishing is fairly intense in streams capable of supporting even small fish populations. A great deal of potential exists for fishery development as one component of a rural development oriented watershed management project as shall be discussed in Section 4.

3.4 Forests and Wildlife In 1963 Gartner and Beuschel reported that 46 percent of N.E. Thailand was covered with forest and 11.3 percent in shifting cultivation. Based on the average growing stock characteristics they concluded the forests were already depleted. One of the main problems was the lack of small trees (due to cutting preference for firewood and charcoal) resulting in unsatisfactory regrowth. The 1963 annual cut of approximately 2.2 percent was considered the maximum sustainable extraction. In 1961 the forests in the Udon Thani Forest Division including the LNO Watershed were in much better condition, covering 59 per cent of the district with valuable species accounting for 53 percent of the total stock. The authors stated that a 60 percent increase over the 1961 removal of 187,000 cubic meters could be sustained (Gartner and Beuschel, 1963).

Forests in the LNO Watershed are dry evergreen, mixed deciduous, dry dipterocarp, scrub and disturbed non-productive. The estimated areas within the total watershed and Phu Phan National Park and descriptions are provided in Table 10.

The estimated LNO watershed forest coverage of 61.1 percent is strikingly high as compared to the coverage reported in 1963 and the general deforestation trend throughout the country. The high percentage

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TABLE 7 : IMO WATERSHED GROUND WATER RESOURCES (ASRGT, 1971)

MAF UNIT	SOURCE	DEPTH	QUALITY	DEVELOPMENT PROBLEMS
1	Water occurs in pore spaces in lenticular beds of sand and gravel (aquifers) interbedded with unproductive layers of silt and clay 1/. In many areas, several potential aquifers exist at different levels any may be tapped by a single well. Many artesian aquifers but water does not flow at the surface. Some areas too small to be shown at the scale of this study.	Aquifers in drilled wells range from 20 to 45 m. in depth. Water commonly rises above the aquifer. A seasonal drop in water level in shallow dug wells has ranged from 1 to 3 m. during the several years of record.	Mostly good quality water but high in dissolved iron; total dissolved solids generally less than 500 p.p.m. (parts per million); water generally soft*, but moderately hard to very hard and high in total dissolved solids in some wells. Risk of bacterial contamination high in shallow wells.	Wells easily sited. Easily constructed by digging, drive point, jetting or drilling. Casing and screens generally required. More than 90 percent of wells successfully completed. Moderate quantities obtained only under favorable condition by experienced personnel needed; batteries of closely spaced wells at some site may be required.
2	Water occurs in bedding planes and various kinds of fractures in alternating beds of shale, siltstone and minor sandstone; quantity of water available depends on the number of openings, size of opening, and degree of interconnection. Some aquifers under high hydrostatic pressure, when first tapped lose pressure rapidly.	Most drilled wells be between 30 and 50 m. in depth. Incomplete data indicate a seasonal drop of water level between 1 and 7 m. in dug wells; greater seasonal drop probable if withdrawal rate increased.	Mostly good quality water but high in iron; total dissolved solids are generally less than 500 p.p.m.	Wells must be carefully sited to anticipate favorable geological conditions for development of fractures and accumulation of water. Drilling required. Casing and screens necessary in most cases. Very rarely may encounter salty water and require plugging to prevent contamination of overlying fresh water. Generally high drawdown, may extend to 40 m. Hand pumps commonly not feasible.
3	Water occurs in bedding planes and fractures of shale and in pores between the particles of sandstone and conglomerate. In general, pore partially filled with mineral matter or incompletely interconnected and will yield contained water very slowly. Some sources may be artesian.	Shallow dug wells possible in small pockets of alluvium; very small springs in mountains. Most productive zone generally within 60 m. of surface; increase in depth generally does not yield greater volumes.	Only one water analysis available. Good quality water with total dissolved solids of less than 500 p.p.m. probable. In zones of calcareous conglomerate, water moderately hard to very hard. In places, water high in iron compounds.	Very difficult to site wells in areas of steep slopes. Drilling relatively slow. Casing and screens may be necessary locally. Abundant quantities not likely. Drawdown generally high, may be more than 30 m. locally. Hand pumps generally not feasible.
4	Water occurs in bedding planes, cracks and fractures in alternating beds of siltstone, shale, minor sandstone, gypsum, salt and anhydrite; in addition, water may be in solution cavities in gypsum, salt and anhydrite.	Depths range from 15 to 460 m. Possible production from solution cavities. Water level in dug wells ranges from 1 to 9 m. with seasonal drop of more than 7 m. in some wells.	Deep drilling expected to yield fresh water in siltstone-shale-sandstone rock sequence; brackish** to salty water where interbedded with gypsum, salt, and anhydrite beds. Water from drilled wells likely to contain more than 250 p.p.m. of chloride, sulfate or both; total dissolved solids range from 1,000 to more than 2,500 p.p.m. Water generally moderately hard or very hard; impotable in many areas. Dug wells, dependant on rain water for recharge, generally of fair quality. Shallow wells subject to bacterial contamination.	Exploratory drilling required to predict presence of contaminating mineral or water in potential fresh water zones. About 15 percent to 50 percent of deep wells expected to provide fresh water. Dug wells furnishing quantities adequate for family units readily sited anywhere in place, contaminated by mineralized water from rains. Under certain conditions wells must be plugged and cased to shut out objectionable water.

*Hardness Terminology :

- Soft - 0-55 parts per million (p.p.m.) of $CaCO_3$
- Slightly hard - 56-100 p.p.m. of $CaCO_3$
- Moderately hard - 101-200 p.p.m. of $CaCO_3$
- Very hard - More than 200 p.p.m. of $CaCO_3$

1/ Three of the 4 existing drilled wells were sited in unproductive layers of alluvium and produce from the underlying bedrock.

**Qualitative Terms :

- Brackish - Contains more than 250 p.p.m. either dissolved chlorides or sulfates; contains less than 2,500 p.p.m. total dissolved solids; tastes somewhat unpleasant to most people.
- Salty - Contains more than 2,500 p.p.m. total dissolved solids; generally impotable.

TABLE 9 : AQUATIC HABITAT CLASSIFICATIONS

Class	Importance	Origin of Use (in LNO watershed)
1	National	Throughout Thailand (no waters in this class in LNO watershed)
2	Regional	Throughout Northeast Thailand (possibly LNO reservoir)
3	Provincial	Sakon Nakon (possibly some fish farms)
4	Local	Tambons or boardering Tambons (most perennial streams and ponds, some pools inmentermittent streams)
5	Degraded	Waters of potentially higher class but presently little used because of water withdrawal or pollution. (no known waters in this class in LNO watershed)
6.	Nonproductive	Waters not supporting a fish population because of natural factors such as intermittence or water chemistry. (most of intermittent and ephemeral streams)

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TABLE 10 : FOREST VEGETATION IN LBO WATERSHED (ASRCT, 1971 and Boonmarm, 1979)

Forest class	Description	Evaluation	Area in Watershed	Area in Phu Phan National Park in Watershed
Dry Evergreen Forest :	Consisting of a two-or three-storied, dense canopy. The forest profile is normally composed of trees of small to medium sizes with straight stems. Although larger trees occur, the median height is from 9-11 m. with a diameter of 12 cm. at breast height (dbh). Average stocking of the main strata, 28 cm. (dbh) and greater, is 56.2 $m.^3$ (43.4 $m.^3$ Hoppus) per hectare. Average tree density, 5 cm. dbh and larger, is 571 per hectare. Undergrowth is generally dense, 3-4.5 m. high, and composed of seedlings of the primary species; epiphytes, and some climbers also comprise the understory. Dominant species are Hopea ferrea and Dipterocarpus alatus; the tallest Hopea do not exceed 40 m. high and the Dipterocarpus, 45 m. Numerous other species occur, the most common of which are Hydnocarpus ilicifolius, Walsura trichostemon, and Memecylon species. Additionally, because more moisture is available, Shorea obtusa and Pentacme siamensis occur locally over a small area in the southern tip of the watershed.	Abundant hardwood timber of good quality for construction. Based on an inventory in 1963, the volume of timber in this forest type, 70 cm. and greater in diameter, is an estimated 3,186,540 $m.^3$ (2,460,780 $m.^3$ Hoppus). Aside from sawn wood, forest products include wood-oil obtained from the Dipterocarp spp. This oil or oleo-resin is intensively used for making torches, caulking boats, and for waterproofing basketware. Regrowth of the principal species is inadequate to replenish cuttings under current logging practices. Indiscriminate cutting in the past and shifting agriculture has reduced this forest type to a remnant of a once luxuriant and extensive forest.	20 sq.km.	15 sq.km.
Mixed Deciduous Forest :	Stands range from open to moderately dense with a generally open canopy composed of one or two stories. Almost complete disappearance of the leaves during the dry season and lush foliage in the rainy season. Often these forest are contiguous to the Dry Dipterocarp forest, and transitional types exist in many places. The undergrowth is generally sparse, consisting primarily of grasses, herbs, bamboo and some climbers. Seedlings of the primary species are limited in occurrence. The dominant species is Lagerstroemia calyculata which reaches heights of 30-35 m. Associated species include Xylia kerrii, Pterocarpus macrocarpus, Afzelia xylocarpa, Adina cordifolia, and Dalbergia cochinchinensis. Average tree density, 5 cm. dbh and larger, is 660 per hectare. The median tree height is 9 m.; the median diameter (dbh) is 18 cm. Average stocking for trees, 28 dbh and greater, is 57.6 $m.^3$ (44.5 $m.^3$ Hoppus) per hectare.	Timber of good quality for construction and veneer for plywood manufacturing. Based on an inventory in 1963, the volume of timber in this forest type, 28 cm. and greater in diameter, is an estimated 3,810,240 $m.^3$ (2,643,675 $m.^3$ Hoppus). Minor forest products include tannins and dyes and crude drugs which contribute to the well-being of the Province. Regrowth of the most important species is inadequate to replenish cuttings. Bamboo, although not extensive, is also significant in the farmers daily life. It is widely used for housing and a large number of articles and implements such as baskets, fences, fishing poles, rafts, fish traps, animal snares, and food containers. Split, the bamboo is used as troughs or roofing materials.	70 sq.km.	50 sq.km.

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Forest class	Description	Evaluation	Area in Watershed	[redacted]
Dry Dipterocarp Forest :	Forests are open, generally consisting of uniformly spaced trees forming two-story canopies covering 40% of the area. The upper story ranges from 10 to 20 m in height; the lower, 7 m. Trees drop their leaves during the dry season. On very dry sandy soils which are subjected to extreme leaching and erosion, trees are smaller in size and have a reduced form class with a corresponding reduction in their quality and volume. Undergrowth is chiefly grasses often replaced by bamboo and scattered thorny shrubs. Annual fires degrade the stands and during primary stages of growth the trees are stunted because of these ground fires. Common species are Shorea obtusa, Dipterocarpus tuberculatus, Pentacme suavis, and Dipterocarpus obtusifolius. Average stocking of the forest stand, 20 cm. dbh and greater, is 10.8 m.^{3} (11.0 m.^{3} Hoppus) per hectare. Median tree heights are 8-11 m; diameters are 14 cm. dbh. Average tree density, 5 cm. dbh and greater, is about 345 per hectare.	Trees of commercial importance have boles with merchantable lengths of 8 to 20 m. The logs are of good quality and are suitable for construction grade lumber. Based on an inventory in 1963, the volume of timber in this forest type, 25 cm. and greater in diameter, is estimated at 4,286,520 m.^{3} (3,316,950 m.^{3} Hoppus). Firewood, poles railway ties, and fenceposts are normally cut in exploited areas. Minor forest products include damar resin from Shorea obtusa and wood-oil from the Dipterocarps. Bamboo is used for a number of articles and utensils as well as for piping, troughs, and roofing.	165 sq.km.	[redacted]
Scrub :	This forest type develops as a phytocenoses of secondary species following clearcutting by logging or from shifting cultivation practices. The woody vegetation is usually of the sunclimax type, consisting of shrubs and thickets up to 2 m. high, generally with spiny climbers. Eupatorium odoratum plant is common ground cover and grows to heights of 1.25 to 1.65 m.	Scrub forests will require many years of natural, undisturbed growth before reaching economic significance. If properly managed, by excluding man's intervention and controlling ground fires, the climax forest that once grew on these areas will again prevail. In its current state, the area is practically devoid of many commercial species. Fuelwood is the main yield to be obtained from this forest type.	340 sq.km.	[redacted]
Disturbed-nonproductive Forest :	Species are essentially the same as either dry evergreen mixed diciduous or dry dipterocarp except the trees are stunted because of environmental factors or affected by uncontrolled exploitation by local residents, charcoal or other forest industry. Average tree density 5 cm. dbh and greater is approximately 290 per hectare.	Commercial value is limited to individual scattered trees of large diameter and fairly straight boles. Smaller trees are utilized locally for firewood, charcoal production or poles.	185 sq.km.	[redacted]

of forest in the watershed is unfortunately not indicative of its productivity or value. Much of the area classified as forest is highly disturbed and unproductive. The forests in Phu Phan National Park are of the best quality of the watershed but even in this legally protected area degradation and destruction due to poaching and shifting agriculture are significant. The problems facing forestry management are even more intense in the remainder of the watershed where most of the forest is degraded to the point of being nonproductive (Kasetsart, circa 1980). The successional time required for a second growth forest to have a similar species richness as nondegraded natural forest is estimated at 100 years for the dry evergreen forest (Drew, et. al, 1978). In the early 1960's the shifting cultivation reportedly followed a cycle of cultivation for 2 to 3 years and follow for 5 years. The soils were limited to producing crop yields for only 2 to 3 years after which the plant nutrient content could not be restored in the poorer quality soils resulting in secondary growth of nonproductive dry dipterocarp, dry evergreen, mixed deciduous or scrub forest. Such agricultural practices are still carried out as observed during field reconnaissance by the author. Detailed forest inventories are needed to determine potential development and management alternatives as well as to determine quality and intensity of use of wildlife habitat. In 1979 approximately 9.5 sq.km. of forest was illegally cleared in the LNO resettlement even though it has a designated land use of forest.

The roles and values of wildlife in relation to watershed management are not really well understood. Many would argue that wildlife is not a factor and, although it is beyond the scope of this paper to argue against this point, the fact is that the Phu Phan National Park and its wild inhabitants are protected by law and thus a signficant factor for LNO Watershed management planning. Several people are currently attempting to identify and quantify some lesser appreciated values of wildlife and hopefully in the future such values will be incorporated in planning and management. Spectacular mammals reported in Phu Phan National Park by SriKhosamart (1981) are listed in Table 11. Numerous species of spectacular birds, reptiles and amphibians also inhabit the park. All of the wildlife are seriously threatened due to poaching and habitat destruction throughout the park which is the last area inhabited to any measurable degree by a diverse population within LNO watershed. Even in certain areas of the park such as the northern portion, poaching and habitat destruction has all but wiped out the local wildlife populations (Nethin, 1981).

3.5 Social and Economic Factors : For the purposes of this case study, social and economic data collection was limited to enable general descriptions of population and socio-economic characteristics and relationship to land and water use as well as development needs. The data presented is indicative at least. A survey and monitoring program similar to the LNO resettlement survey(Sangsingkeo and Pinutai, 1975) is needed for the entire watershed. Selected relevant data are presented in Table 12. It is very difficult to estimate the population changes of the watershed because of the numerous physical and political changes which have occurred over the past 10 to 15 years. A gross estimation based on data from 1970 to 1977 in Kut Bak District, considered indicative of watershed population changes, is

TABLE 11 : SOME MAMMALS OF PHU PHAN NATIONAL PARK (Srikhosamart, 1981)

Order	Common name	Genus species
Primates	Slow loris	Nycticebus coucang
	Rhesus monkey	Macaca mulatta
	pig-tailed monkey	Macaca nemestrina
	Silvered langur	Presbytis cristata
Pholidota	Malayan pangolin	Manis javanica
Rodentia	Porcupine	Hystrix sp
Insectivora	Tree shrew	Tupaia glis
Carnivora	Asian wild dog	Cuon alpinus
	Asiatic black bear	Selenarctos thibetanus
	Malayan Sun bear	Helarctos malayanus
	Javan Mongoose	Herpestes javanicus
	Common Palmcivet	Paradoxurus hermaphroditus
	Leopard cat	Felis bengalensis
	Tiger	Panthera tigris
Proboscidea	Wild elephant	Elephas maximus
Artiodactyla	Wild pig	Sus scrofa
	Barking Deer	Muntiacus muntjak
	Sambar	Cervus unicolor
	Bentang	Bos javanicus
	Gaur	Bos gaurus
	Mouse deer	Tragulus javanicus

TABLE 12 : SELECTED INDICATIVE SOCIO-ECONOMIC CHARACTERISTICS-1979-80

	Sakon Nakon Province 1/2/	Amphoe Kut Bak 1/2/	Amphoe Nikom Lam Nam Oon (LNO resettlement) 3/4/	Watershed (extrapolated estimate)
Population	741,391	25,381	8,552	40,300
Population density (persons/ sq.km.)	78.3	25.1	52.8	47.7 (79.2 Adjusted)
Average family size	6.6	5.4	5.2	6.0
Average Land holding (rai)		9.2	15	-
Percent income depending on rainfed agriculture		20.5		
Average paddy crop production (kg/rai)		30	30 (18-22 in 1974)	
Average annual income per family (baht)*	16,000	8,360	12,900 (7,560 in 1974)	

Total income includes cash income and income in kind (consumption)

1/ Panpiemras, 1981
2/ Census Bureau, 1979
3/ Sangsingkao, 1975
4/ DPW, 1980

3 percent per increase year. This compares to an estimated annual rate of increase in Sakon Nakon Province of 2.8 percent from 1960 to 1979. The LNO Watershed population in 1979 was approximately 40,300. This results in an overall watershed population density of 47.7 persons per sq.km. (40,300 people in 845 sq.km.). This figure is relatively low when compared to population densities elsewhere in N.E. Thailand. It is also inaccurate f consideration is made that "legally" no one can reside in Phu Phan National Park, the available land is reduced to 509 sq.km. and the calculated population density is 79.2 persons per sq.km. Since it is known that some persons illegally inhabit the park, the actual population density is probably between 47.7 and 79.2 persons per sq.km., most likely closer to the higher value.

The population is dispersed throughout the watershed in three districts including about 35 villages (see Table 13). The average family size is 6.6 and average land holding ranges from 9.2 rai per family to 15.3 rai per family in Kut Bak and King Amphoe Nikom Lam Nam Oon (LNO resettlement), respectively, as compared to an overall average land holding of 30 rai per family in N.E. Thailand.

Kosit Panpiemras (1981) has developed a formula to determine the degree and density of poverty in N.E. Thailand. The key variables are (i) average production of rice per family and (ii) degree of dependence on rainfed rice farming. Based on the evaluation by Panpiemras, the severity of poverty in LNO Watershed is classified as medium relative to the rest of N.E. Thailand. This may not actually reflect the actual severity of impoverishment in most of the watershed since density is an evaluation factor. As previously mentioned the population density may actually be much higher than supposedly representative district calculations. Also one must take into account that practically all of the paddy in the watershed is rainfed. Panpiemras also identified a direct correlation of increased poverty density to increased ratios of paddy to upland crop in rainfed agricultural areas. The ratio is very high, 9:1 in the totally cultivated land and about 1.4:1 for total crop land including mixtures (see Table 3). Within the LNO resettlement area the ratio of paddy to non-paddy cultivation is approximately 7.1 but the rainfed ratio is not known. For upland paddy and other upland crops the ratio is 1.6:1

For the sake of water and land management planning, it is important to understand the local agricultural and other labor patterns and productivity. Paddy is transplanted in the lowlands and broadcast in the uplands in May followed by upland crop planting in June. Paddy is harvested in October with reported 1974 yields of 18 tang per rai for upland and 22 tang per rai for lowland paddy in the resettlement area. Upland crop harvest follows in November. After harvesting paddy and upland crops there is back-gardening of vegetables and about 3 to 4 rai of upland paddy for daily consumption until the next season. Single cropping of paddy leaves farmers a great deal of time to participate in other occupations including land clearings, wood sawing, firewood cutting, charcoal production, carpentry, gathering miscellaneous forest products and fishing. The non-farm occupations account for about 70-75 percent of the farmers cash income

TABLE 13 : DISTRICTS AND VILLAGES IN LNO WATERSHED

District (Tambom)	Village (Ban)
Phana Nikon	Kut Nam Sai, Un Khok, Pak Kham Phu Un Dong, ham Was, Na Lao, Huai Sun Nong Phu, Na Nai, Nong Bua Ban
Nikom Nam Oon	Nong Pling, Ta Mo, Tat Phon Phai, Kut Takap
Muang Sakon Nakon	Lat Krachoe
Phang Khon	Suwannakham
Kut Bak	Nong Sa Nai, Choeng Doi, Phon Ngam, Na Mong, Yang Lon, Dong Nimit, Nongkha, I Toeng, Nong San, Kut ak, Yang Lon, Kut Hai, Ngin, Klang Kho Yai, Kho Noi, Bua, Kut Haet, Khok Phu Mai, Khok Phu.

(Sangsingkeo,1975). The time between harvesting and planting of paddy, October to May, is probably when most intense forest degradation occurs.

Livestock raised in the watershed includes cattle, water buffalo, chickens, ducks and pigs. Cattle and water buffalo are used mainly as draft animals while chickens, ducks and pigs are used both for consumption and sale. In the LNO resettlement, 75-80 percent of the families own livestock.

4. LNO Watershed Management Needs and Associated Environmental Effects

4.1 Management Strategies : Three somewhat related but independent management strategies have been reviewed during the course of this case study which are directly associated with the LNO Watershed. Gartner and Beuschel in the 1963 FAO sponsored forest inventory of N.E. Thailand recommend forest and watershed management be established for economic development in general and an increase in valuable lumber production in particular (Gartner and Beuschel, 1963). USAID, in the 1981 Country Development Strategy Paper, refers to watershed resource degradation as the key environmental problem in N.E. Thailand and proposes watershed management as an integral portion of the high priority assistance program for integrated rural development in N.E. Thailand. The Conservation for Thailand-Policy Guidelines (IUCN, 1979) presents a broad natural resource management scope of watershed management strategies which is justified because the national development strategy of Thailand relies on sustained development of living natural resources. The policy guidelines urge management of significant watershed areas on a unit watershed basis and include land outside forest reserves that forms the upper catchment of rivers. Management activities emphasised by IUCN include forest protection, the rehabilitation of degraded areas , and the implementation of the necessary soil conservation measures on land allocated on the basis of land capability, for agricultural or tree crops. Guidelines are recommended as well for protection and rehabilitation of water catchment forests and for cooperation of local people to help minimize poaching and encroachment.

A watershed management strategy for the LNO Watershed would depend on the primary objectives or target area. Once the target area is identified, alternative management measures can be scrutinized to develop the most environmentally sound watershed management plan.

4.2 Target Areas for Management : Management planning for the LNO Watershed would most likely be for three target areas (i) protection of downstream LNO reservoir/irrigation and/or (ii) rural development/poverty eradication of watershed residents. In addition the management plan should include measures to improve ecological conditions in Phu Phan National Park. All three objectives are justified below.

4.2.1 LNO Reservoir/Irrigation : A large amount of investment has been made in time and money to develop the LNO reservoir and irrigation system. In the LNO integrated rural development project paper (USAID, 1977) it states that the Lam Nam Oon is short of water and every use of the

available resource will ultimately be necessary. Resource use in the LNO Watershed will have an effect on the LNO irrigation water supply as well as reservoir operations and consequently a watershed management program should be designed to maximize water available for downstream irrigation. Such a program would require catchment protection and soil conservation to control runoff and siltation and provide stable irrigation water supply. Thus the primary management measures would probably be forest protection and rehabilitation especially for areas with highly erosive soils and installation or use of soil and water conservation measures in cultivated areas in the watershed.

V.2.2 Rural Development Poverty Eradication : The LNO Watershed is within the target areas of the "Regulations of the Prime Minister's Office on Determining the Target Areas for Rural Development under the Fifth National Economic and Social Development Plan (1982-1986)." These regulations direct the National Economic and Social Development Board (NESDB), Budget Bureau, Civil Service Commission and all other government Offices to allocate as much budget and as many projects as possible for the target areas for rural development. As described previously, the natural resources of the LNO Watershed have few alternatives for sustained rural development unless an environmentally sound resource cum watershed management program is implemented. Such a program would include land and water use planning and may employ a variety of agricultural management methods to sustain and maximize yields of products most effective in reducing poverty. As stated earlier Panpiemras (1980) has shown that in N.E. Thailand, rainfed paddy cultivation is associated with poverty and the strategy to reduce poverty should be to shift production away from rainfed upland cash crop. In the LNO Watershed about one-half of the paddy cultivation is in Korat soils which are not generally suited to paddy. Upland crop cultivation covers less than one-tenth the area of paddy. Approximately 44 percent of the watershed is capable of supporting upland cropping extended several years in succession with application of on-farm watershed management measures such as fertilizing, maintaining organic matter and structure of surface layers, erosion protection and weed control.

The main reason farmers in N.E. Thailand have been reluctant to switch from paddy to upland crop production is due to uncertainty regarding the amount and timing of rainfall. The farmers prefer to use their land for paddy to ensure enough staple food for their own consumption in dry years, however in good years this results in a surplus of low-income yielding rice as compared to profitable upland crops. Reduction of farmer reluctance can possibly be accomplished with an integrated on-farm watershed management program which includes extention and research efforts geared towards increased rainfed paddy productivity and establishing supplementary sources of staple food, such as fish farming. Provision of a reliable domestic water supply for villages in parts of the watershed could also be incorporated in the management scheme. Utilization of interface teams for extension as proposed in the Mae Chaem Watershed Development Project in Northern Thailand would help program operations.

4.2.3 Phu Phan National Park : Consideration of management needs of this national park are justified because of its protected status and the inclusion of policy guidelines for conservation in the Fifth Five Year Plan. Conservation for Thailand-Policy Guidelines (IUCN, 1979) identifies the following general management measures as necessary for the national park :

i) increase in personnel, buildings, communications and equipment to improve protection ;

ii) preparation of management plan taking into account needs for fire protection, eradication of exotic species, etc;

iii) promotion of cooperation from settlements that are adjacent to the park, through the provision of employment and rural development schemes and public education;

iv) reafforestation of degraded areas especially where erosion has occurred;

v) initiate inventories of animal and plant communities and monitor changes in vegetation types and species populations, and

vi) undertake studies of ecological succession and habitat manipulation by man, including fire ecology; population sizes, dynamics and trends of selected animal and plant populations, including identification of limiting factors.

There is some doubt whether the past efforts made to obtain local populations cooperation (as compared to protection efforts) in national park management are sufficient to prevent irreversible damage to plant communities and wildlife through encroachment and poaching (Brockelman, 1981). The problem is very evident in Phu Phan where 140 of the total 699 sq.km. is non-productive (20 percent of the park) including paddy and upland crop cultivation, one village and several homestead squatters, as well as disturbed non-productive forest. These local residents become hostile when denied this traditionally free source of fuelwood, wildlife, and other forest products as well as an area for agricultural expansion. Intensive management efforts in the form of integrated rural development need to be designed which allow the potential poacher/encroacher to benefit more from preservation of the park than from destructive illegal exploitation. Several potential forms of integrated rural development need to be examined and tested to design an effective management scheme.

4.3 Selection of Development and Management Components : A single watershed management plan designed to encompass the three strategies and target areas described above would most likely involve integrated planning since the optimum resource uses for each target area are not necessarily compatible. In order to evaluate the compatability of some potential resource use and management alternatives; an interaction matrix was developed (see Figure 9). While the interaction matrix allows one to eliminate non-managable conflicts in resource allocations, the planner must still make several resource development and environmental management

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FIGURE 9 : COMPATIBILITY OF SOME RESOURCE USE AND MANAGEMENT OPTIONS-LNO WATERSHED

Competability of Options
(numbers correspond to resource use)

S. Supplemental or complimentary

C. Competitive or harmful

	Resource Use and Management Options	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Poverty eradication	1. Increase cash income opportunity target area population																												
	2. Decrease reliance on rainfed paddy	S																											
Landuse of Ba' Et soils	3. Existing use and management (rainfed paddy)	C	C																										
	4. Agricultural intensification (irrigated paddy with intensive management)	S/C	S/C	-																									
Landuse of Kerat soils	5. Existing multiple use and management	C	C	-	-																								
	6. Rehabilitation of degraded forest	S	-	-	S	C																							
	7. Agricultural intensification (upland cropping) (outside P.P.N.P.)	S	S	-	S	C	S/C																						
	8. Forest plantation replacement of non-productive forest	S	-	-	-	C	S/C	C																					
	9. Conservation of productive forest	-	-	-	-	C	S	C	S/C																				
Landuse of Class VI soils	10. Existing land use and management	S/C	-	-	-	C	-	C	-	C																			
	11. Rehabilitation of degraded forest	S	-	S	S	S	S	S	S	S	C																		
	12. Agricultural intensification	-	-	-	C	C	C	C	C	C	-	C																	
	13. Forest plantation replacement of nonproductive forest	S	-	-	-	-	-	S	-	S/C	S/C	S/C	C																
	14. Natural regeneration of disturbed forest	C	-	-	-	C	S/C	S	C	S/C	C	S/C	C	C															
Watershed Protection	15. Soil conservation (ag.mgmt.)	-	-	-	C	C	S	S/C	S	S	C	S	C	S	S														
	16. Gully stabilization-flood control structures	-	S	-	S	S	-	S	S/C	C	C	S/C	S/C	S/C	C	S													
The Pulu National Park Protection	17. Law enforcement for protected area	C	C	-	-	C	S	-	-	S	C	S	C	-	S	S	-												
	18. Employment of locals, squatters and poachers in protected area	S	-	-	-	-	S	-	-	S	C	S	C	M	S	S	-	S											
	19. Fire control-protection	S	-	-	-	C	S	C	S	S	C	S	C	S	S	C	-	S	S										
	20. Increase intensity and productivity of land use outside park	C	S/C	-	S	S/C	C	S	C	C	S	C	S	C	C	C	C	S	S	S									
	21. Integrated rural development outside protected area	S	S	S/C	S	S/C	S/C	S	S/C	C	S/C	S/C	C	S	C	S	S	S	-	S	S/C								
	22. Limited forest farming in buffer zone locals	S	-	-	-	-	S	C	C	S/C	S	S/C	C	C	C	S	-	S	-	S	C	S/C							
	23. Reforestation, rehabilitation, gully erosion control in park	S	-	-	S	S	S	S	-	-	-	-	-	-	-	C	-	-	S/C	S	S	S	-						
Forest use	24. Traditional uses (firewood, charcoal, timber)	C	-	-	-	S	C	C	C	C	S/C	C	S/C	S/C	C	C	-	C	-	C	C	S/C	S/C	C					
	25. Forest farming-villages	S	S	-	-	C	S	C	S/C	S/C	C	S	C	S/C	C	S	S	-	S	S	C	S/C	S	S	S/C				
	26. Wildlife habitat	-	-	C	C	C	S	C	S/C	S	C	S	C	S/C	S	S	S/C	S	S	S	S/C	S/C	S/C	S	C	S/C			
	27. Conservation reserve area	C	-	-	-	C	S	C	S	S	C	S	C	C	S	S	-	S	S	S	S/C	S/C	S/C	S	C	-	S		
	28. Agricultural development	S	-	-	-	S	C	S	C	C	S	C	S	S/C	C	C	-	-	-	C	S	S/C	S	C	C	C	C	C	
Water use and quality management	29. Fish ponds	S	S	-	-	S	C	S	-	-	-	-	C/S	-	S	S	S	-	-	-	-	S	-	-	-	S	S	C	S
	30. Water supply	-	S	-	S	S	C	S	-	-	S/C	-	S	-	S	S	S	-	-	S	S	S	-	-	-	S	-	C	S

decisions. Probable components of a watershed management plan for the LNO Watershed are presented in Table 14. A review of the interaction matrix shows that conflicting resource use may result from (i) intensification of agricultural development on class VI soils and ridges (conflict between 1.1.1.1 and 3.1.2.2) and (ii) clearing of degraded forest on Korat soils (conflict between 2.1.2.1 and 3.1.2.2).

Several resource and environmental decisions are required for conservation and development planning. When conflicts in resource use arise alternatives should be developed for the optimum development or management goals in Table 14. For sustained resource use there is a critical level of management which must be met. The critical level of management should be evaluated and included as a resource use-management option. Alternative development or management goals can then be reweighted. For the conflicts in resource use mentioned above the establishment and enforcement of environmental standards for land use based on land capability would resolve the first. For the second conflict decisions must be made for the choice of new farming areas and selection of permissible forest uses by forest type.

4.4 Significant Environmental Considerations for LNO Watershed Management Planning

Several of the decisions on resource use and management will have potentially profound effects on the environment. Some of the more significant potential environmental effects which should be considered in the selection of alternative resource use and management are described below.

4.4.1 Upland cropping on Korat soils : Assuming the decision is made to limit intensification of upland cropping to Korat soils several management considerations must be made in order to develop a stable agricultural economy on normally infertile and erosive soils. First the area and sites of crop expansion must be determined. The agricultural expansion into forested areas should be limited to nonproductive areas which are common on the Korat soils in the west side of the watershed.

The clearing of forest vegetation and upland cropping of middle terrace soils such as the Korat series in the LNO Watershed will significantly effect erosion, soil biology, and soil nutrient status. Because of dispersive soil surfaces, massive subsurface material, and restricted infiltration, the infrequent heavy rains of the wet season can cause serious erosive damage. Conservation cropping including timing of forest clearing, initial cultivation with adequate ground cover, and soil conservation measures are essential for protection of these soils. This landuse change-removal of all trees and tree regrowth potential from shifting cultivation and nonproductive forest-constitutes a fundamental ecological modification with far reaching implications for subsequent cropping. Destruction of the larger deep rooted trees and shrubs which were essential for fertility restoration, elimination of the chemical inputs of bush fallow, and elimination of nutrient redistribution from litter turnover demands a search for other means of maintaining soil fertility.

The initial cropping may provide a surprising yield of upland rice without addition of fertilizers. Physical disturbance, lang-continued drying, and high temperature influence the promotion of biological activity when the soil is wetted. The biological activity of the first physical breakup of the Korat soils may result in enhancement of mineral nitrogen production early in the rainy season with excellent first year rice yields. The next year will require addition of fertilizers which may be purchased with the cash surplus generated as a short-term reward of the first year (Charley and McGarity, 1978). There are three main methods by which man adds nutrient fertilizers to soils : (i) by animal manures which is feasible only on small plots because of the large amount of manure required per unit of land; (ii) chemical fertilizers which require a high cash input (thus for upland cropping schemes in N,E, Thailand based on continuous cash-cropping with high fertilizer inputs have not met with success): and (iii) symbiotic fixation of atmospheric nitrogen by crop legumes. Consideration should be given to ley farming as an applicable approach to symbiotic fixation of nitrogen. Ley farming involves inclusion of a legume-based ley (possibly pasture legumes, fodder legumes on legume shrubs) in a definite rotation with crops and usually involves the integration of crops, pastures and livestock. Ley farming is also useful for protection of Korat soils in that it provides ground cover and addition of organic matter to the soil. Ley farming may allow a diversification to soil depleting cash crops such as cassava and kenaf (Mekong, 1970).

4.4.2 Lowland Irrigated Cropping : Even though the irrigated agriculture potential in the watershed is limited to small pump irrigation in the LNO resettlement area, the potential effects and environmental management alternatives are worthy of short discussion. Irrigation water supply in the watershed allows a cultivation change to double cropping resulting in increased potential for plant disease and pest infestation thus requiring increased application of pesticides and fungicides. The LNO irrigation project environmental assessment identifies several low toxicity insecticides and fungicides which may be used in the watershed irrigation area together with fertilizers and other agricultural chemicals to optimize crop yields. The environmental impacts of this land-water use change will be very dependent on on-farm management and water management. The 1975 World Bank Irrigation Sector Policy Paper states that insect damage in Thailand is not a serious problem for rice (comparatively) because the combination of relatively low use of fertilizer, a wide spectrum of plant varieties used in wet seasons, small areas of dry season cropping and limited use of pesticides has allowed natural pupulation dynamics of predators and parasites to maintain a reasonable balance. An integrated approach to pest control will require monitoring and research for development of resistant seed varieties as well as studies of life cycles and strategic spraying and studies of predator parasite relationships. In the meantime the use of a broader spectrum of varieties, moderate use of fertilizer, restriction of wide spread use of powerful broad spectrum pesticides and strategic spraying may be a better policy than blindly following high yield technology (World Bank, 1975).

Water quality degradation from irrigation may effect several water uses in the resettlement including deterioration of the ground water (which is the domestic water supply), decreased aquatic productivity locally in the reservoir, and damage to other irrigated systems. Pollutants from surface runoff (tailwater runoff from paddy fields) are usually sediments, crop residue, phosphates and biocides. Subsurface flows from seepage losses, canals and percolation losses from paddy field may pollute groundwater with mineral salts, nitrates from fertilizer, and other water soluble constituents. Proper local water management, proper land use and proper application of agricultural chemicals are necessary for an influent control approach to water quality management, i.e. irrigation return flow quality control.

4.5 An Example of Optimum Resource Management Planning : Water resource management is very important for N.E. Thailand. In many areas remote from available water resources, water is insufficient for meeting the minimum requirements of domestic supply for people and animals, subsistence agriculture and related activities. This case exists to some degree in the upper reaches of the LNO Watershed. There are on-going programs for water resource development in and around the Watershed. The following conceptual integration of these developments presents an interesting case for environmentally sound integrated and multiple use resource development.

Several agencies are developing village water supplies, including well drilling, small reservoir and tanks, dug ponds, diked natural ponds and various stream diversions. The LNO dam/reservoir is one of the large water resource developments in the Northeast. LNO reservoir water is being used for irrigation, some domestic water supply and some fisheries production. One water demand which needs to be met is as supplemental domestic public water supply for Amphoe Sakon Nakorn because the public water supply of Nong Harn Lake is inadequate and taste and odor problems prevail.

Several LNO Watershed villages are located on intermittent stream courses at the base of the west, east and south ridges. The runoff at these points (though not gaged) probably fluctuates significantly and depending on landuse and forest quality upstream of the villages, may contain heavy suspended sediment loads. In the previous description of watershed management needs, provision was made for grade stabilization-flood control structures which if located near village sites would serve soil and water conservation purposes (dampen flow fluctuations, prevent down-stream flooding and trap suspended sediments) and the structure reservoirs could also be utilized as domestic and limited agricultural water supply.

Another ongoing water resource development project in the LNO Watershed vicinity is the USAID-Dept. of Fisheries (DOF) Village Fish Pond Development Project (USAID, 1979). Natural swamp depressions near villages are being diked to provide community operated and community determined water uses, usually domestic and animal water supply, perennial fish production, and supplemental agricultural water supply. Seed

fish are normally Tilapia or Puntius. The Ban Nong Dear, (A Phanna Nikom) village fish pond has a surface area of 110 rai (17.6 ha) and storage capacity of approximately 140,000 cu.m. and serves 800 people from two villages. This fish pond, which is very close to the LNO Watershed is a possible project site for introduction of integrated systems of multiple use. The most promising opportunity of this type which could be readily applied in LNO Watershed small water resource developments including grade stabilization-flood control reservoirs is an integrated fish-livestock system whereby poultry or pigs are raised in pens built over the pond and their droppings fertilize the pond for fish feeding.

Another related water development project which could be adopted at the LNO Reservoir is a preliminary scheme developed by the Mekong Committee for development of fish seed production and research facility next to Lam Pao Reservoir using the reservoir as water supply. The seed production will be used to stock village fish ponds and fish farms. At the same time cage culture development is planned in the reservoir. The combination of these water development projects gives hope for alleviation of critical water shortage, money shortage and protein shortage in Northeast Thailand, especially if they are managed as integrated developments with multiple use.

5. Conclusions

The overall environmental effects of watershed management are beneficial if management planning is based on sustained use of natural resources. In the LNO Watershed and many similar watersheds in Northeast Thailand, one of the objectives of watershed management should be to enhance and protect environmental quality. However, the ultimate objective should be to alleviate the severe poverty. In fact one of the reasons the Northeast is so impoverished is due to mis-managed exploitation of water catchment resources. Resoreces problems of deforestation, erosion, soil nutrient depletion, and so on, should be managed from a unit watershed basis. Once a grasp is made on the watershed management measures required for a given area, integration of rural development can be made to maximize long term benefits of sustained exploitation of natural resources.

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V-6 HUAI THUNG CHOA

A CASE STUDY ON ENVIRONMENTAL RESTORATION

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1. Introduction

As a consequence of forest destruction in the past, as much as 3% p.a. for the period 1973-1977, now only 25.35% of the national forest remains. This has an adverse effect on the environmental conditions of the watershed areas. Moreover, in the dry season of every year, the dwellers of these watershed areas deliberately set fire to the forest in order to clear the land for cultivation. This practice destroys most of the seedlings sprouted during the rainy season. It is beyond hope that the forest can restore itself and that the environmental can ever return to its natural state of equilibrium.

Many government departments, especially the Royal Forest Department, have tried to tackle the problem by reafforestation and by making arrangement for the dwellers of the watershed areas in such a way that they do not have to disturb or endanger the environment. However, the main effort of these departments is directed towards providing a permanent settlement for the peoples on the hills and this involves not only agriculture but also development of education, health care and communication.

Huai Thung Choa is one of the site, on which personnels from the Royal Forest Department have been working jointly with personnels from Chiangmai University in an attempt to solve the environmental problem. This work started in 1975.

2. Location

Huai Thung Choa is situated North-West of Chiang Mai City, at latitude 10°10'N and longtitude 98°35'E, at a distance of about 90 km. from Chiang Mai City. The area under the responsibility of this project is approximately 220 km^2.

3. Geographical Characteristics

The majority of the Huai Thung Choa area has an altitude between 1,000 and 1,300 m, with a maximum of 1,456 m and a minimum of 800 m. From a detailed study on a chosen typical slope covering about 10 km^2 it has been found that 1.4% of the land has an inclination of 10% or less, 5.0% for an inclination of 10-15%, 13.6% for an inclination of 15-20%, 49.0% for an inclination of 20-40%, and 30.0% for an inclination of more than 40%.

The rain water from this area collects and flows down south-eastward pass Chiang Mai City.

4. Demographic Characteristics

When the project started in 1975 a preliminary survey was carried out to find out about population. A detailed study followed in 1979 in order to gain full understanding about the dwellers within the area of this project. The result of this study can be summarized as follows :

4.1 Tribal composition

In the Huai Thung Choa area, there were 23 villages of many different tribes, viz : 2 Lisu villages, 6 local Thai villages, 14 Karen villages, and 1 Chinese village. Table 1 and 2 show the distribution of ethnic groups in these villages. At the time the survey was made there were 254 households in the area, 27 being Lisu, 173 Karen, 5 Chinese and 49 Thai, or in term of percentage for households there were 68.1% Karen, 19.3% Thai, and 10.6% Lisu.

The total population amounted to 1,438 with 740 male (51.5%) and 698 female (48.5%).

4.2 Age Distribution

Nearly a third of the population (31.6 percent) being children under the age of 10, while more than half of the population (54.9 percent) being persons under 20 years of age. If labour force is defined here as persons between 13-54, there was 57.9 percent labour force and 39.2 percent of the population being young dependents and about 2.6 percent being elder dependents.

26.8 percent of the heads of the households were between 30-39 of age 24 percent were between 40-49 , 20.4 percent between 50-59 years of age respectively. Most heads of households were male (88.2 percent) and married(97.2 percent)

A closer examination of the profile of the population found the general fertility rate in the surveyed area during 1978-1979 being 285.7 per thousand of female population aged between 15-44 years. Although it is expected that the birth rate in the area is high seeing from the high proportion of children in total population, the birth rate cannot be ascertained in this study because information on infant deaths was unknown. In a similar manner, the rate of population growth cannot be estimated since information on migration is lacking. Admittedly, population study is not planned when this project is taken up. (see Table 3-4).

4.3 Size of Household

On the average, the household size in the surveyed area is 5.57 persons per household. The Lisu were found to have bigger sized household than the Karen and Thai. The average household size for the Lisu, the Karen and the Thai were 6.24, 5.64 and 5.05 persons per household respectively. From field observations, it was found that the Lisu and the Karen had stronger system of extended family than the Thai. During the first few years of any young couple's marriage in the Lisu and the Karen villages, the husband would come to live with his wife's parents. (See Table 5)

4.4 Education

It was found that most heads of households could communicate in Northern Thai dialect. Only about 10-12 percent of the heads of households had difficulty in communicating in Northern Thai dialect. Very few heads of households of Karen, and Lisu, however , received any kind of education. 100 percent of Lisu heads of household and 95.4 percent of Karen heads did not have any education. As for the Local Thai heads of households, 45.0 percent of them received 1-4 years of education. For younger generation, 1-4 years education was more common. 33.3 percent of the Lisu households, 36.2 percent of the Karen and 73.5 percent of the Local Thai had their members in 1-4 years of education. (See Table 6-7 - 8)

4.5 Settlement

The settlement period in the village of the households have been investigated. 63.4 percent of the households reported to have settled in their villages for 10 years or more 16.5 percent of the households were those newly settled within 1-3 years. The Lisu were shown to be the most newly settled group in the area with only 47.4 percent reported to have settled in their villages for 10 years or more while as much as 29.6 percent of them had settled 1-3 years ago. (See Table 9)

4.6 Marriage Custom

A Lisu wife costs some Baht 30,000 to a Lisu man who has to pay the marriage due in cash and silver coins to the wife's parents. On the contrary, a Karen wife costs a Karen man a few hens and pigs which will be used in the marriage and celebration ceremony. After staying in the wife's parents' house and helping them with their work for a period of time, the couple would then get the approval of the parents to build their own house and farm their own land. This custom supports the extended family system in the Lisu and the Karen villages to a greater extent than in the Thai villeges.

5. Resources Utilization

The pattern of resources utilization has significant impact on the environment of the area. Detailed study have provided an understanding in this issue.

5.1 Materials for Dwellings

In the area, 79.1 percent of the houses were one-storey built on stilts, while 18.5 percent of them were one-storey house built on the ground. Most of the Lisu houses were found built on the ground. The Karen and the Thai houses usually were built on stilts. Those houses built on the ground were also those with earthy floor. The floor would be hard earth

neatly swept. 61.4 percent of the houses used bamboo stalks as flooring material and 14.6 percent used wooden planks. 63.8 percent of the houses used flattened bamboo stalks for walls, 13.8 percent used sheets of woven bamboo strips and 18.5 percent used wooden planks. Most houses were roofed with Tong Tung Leaves (64.6 percent) while some 28.3 percent of them were roofed with Imperata leaves. 18.9 percent of the houses were not divided into rooms. (See Table 10,11,12-13)

5.2 Firewood Consumption

The majority of the population (98.75%) obtained their firewood from fallen trees. Only 1.25% cut down live trees for this purpose. Firewood is used for cooking, house warming, keeping away insects, steaming Miang leaves (for fermented tea), boiling opium and sugar syrup. Among the three ethnic groups of this area, Lisu consumes more firewood than others, amounting to 24.40 m^3 per family per year. (see Table 14)

5.3 Land Use for Agriculture

It was found that among the 254 households in the surveyed area in 1979, 83.5 percent were rice farmers 3.9 percent of the households engaged fully in wage employment. Other 3.9 percent engaged in fermented tea (Miang) production. Exotic flower growing was found among 4.3 percent of the households i.e. 11 households. 89 percent of the Karen households were rice farmers compared to 66.6 percent for the Lisu households. The Lisu households grew flowers to greater extent than the Karen households. Miang production was an important occupation among the Thai households in the area while wage employment and flower growing were not available occupations for them.

The cropping pattern in the surveyed area can be summarized as follows Lisu households planted upland rice to a greater extent than the Karen or the Thai households. Maize and opium were grown mainly by the Lisu whereas Miang production was an occupation for the Karen and the Thai households. Most households had more than one plot of land for cultivation. The average number of plots cultivated per household was 1.5.

There were roughly 2 types of land utilization. One was permanent and the other swidden. Nearly a third of the plots of land in use in this area was swidden farm land having been used 1-2 years and would be deserted. With the present level of technology, most swidden farmers thought it is not possible or rational to use the farm land more than 1-2 years. The yield of crops was reported to be decreased enormously if the same piece of land was repeated. However, at least half of the land in use in this area was permanent farm land. (See Table 15 , 16, 17)

6. The Population's Needs

It was found that most of the highlanders spend more of their income on rice than on other foodstuff and clothing. This indicates the low yield of rice production.

The average yield of rice per household was 120.8 tang per planting season. Since it was not possible to obtain reliable information on average area planted per household, average yield of rice per rai could not be obtained. The Lisu as noted above obtained their household rice production mainly from upland rice production. They could produces as much as 139 tang of upland rice on average compared to 56 tang for the Karens and 28 tang for the Thais. As for paddy rice production, the Thais produced 143 tang on average, the Karens 109 tang and the Lisu 36 tang.

This study has attempted to make estimates of average rice adequacy for the households in the surveyed area. On the whole whether by the estimation method I or II, the households in the surveyed area produced 69 percent of their home rice consumption. In this respect, self-sufficiency in terms of rice consumption on the part of the households in the surveyed area was not attained. The estimation method I defined rice adequacy as household milled rice production divided by the household milled rice production plus annual household reported purchase of milled rice. The estimation method II defined rice adequacy as household milled rice production devided by household reported consumption per annum. Although errors of the estimation were possible, it is believed that the estimates of rice adequacy obtained can be useful for policy formulation. By both methods of estimation, the Karen households are shown to be the most self-sufficient in terms of their rice production with rice adequacy being 74 percent by Estimates I and 82 percent by Estimates II. The Thais grew 70 percent of their rice requirement by Estimates I and 76 percent by Estimates II. The Lisu grew 64 percent of their rice requirement by Estimates I and 49 percent by Estimates II. The Lisus were the least self-sufficient in terms of rice production. From the observation in the field survey, the Lisus were more commercial-minded and engaged themselves more in trade. This may be because they originally were the ethnic group which actively participate in opium producing while the Karens and the Thais have been more of subsistence farmers. Milled rice production was estimated roughly by weighting the paddy or upland unmilled rice production by the proportion reported by the households being milled rice from a tang of unmilled rice. 8-10 litres was reported as being milled rice from a tang of unmilled rice and the average of 9 litres in 22 litres of unmilled rice was used in this study. Also note that 'milled rice' here is loosely referred to the rice treated by the households both by means of milling and pounding in rice pounders.

7. Efforts for restoring the environment

Attempts have been made in various ways as detailed below :

7.1 Reafforestation The Royal Forest Department have been replanting 400 areas of forest per year from 1975.

7.2 To Reduce Forest Destruction and Swiddening. The hill tribes in this area have now stopped these destructive practices completely.

7.3 To Introduce Permanent Farming Methods An agro-forestry system have been introduced at the experimental level. This system is made up of 3 main components : a food crop, a cash crop, and forest trees, intermingled in such a way as to reduce soil erosion.

7.4 To Reduce the Area of Agricultural Land This is done by introducing high-priced crop such as flowers (Statice, Gladiolus and Carnation).

8. Conclusion

Once the natural equilibrium in the environment has been upset it cannot be satisfactorily restored within a short period of 5-10 years. It is necessary to use various measures both direct and indirect in order to bring about any improvement. Direct measures are exemplified by reafforestation, prevention of forest fires, and reduction of land use for agriculture. Indirect measures include persuation to stop further destruction. Such a development scheme must necessarily have many obstacles of all kinds and it is essential to bring in high technology for solving some of the problems. This in turn implies that the population must be given basic education up to the level that they can appreciate and accept these technology. Such a task will take generations to fulfil and will require much endurance and self-sacrifice on the part of the researchers and developers.

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Table 1 Distribution of Ethnic Group by Village in Huai Thung Choa Area in 1979.

Village	No. of Households being				Total
	Lisu	Karen	Chinese	Thai	
1. Lisu Mae Muang Luang	13	-	-	-	13
2. Lisu Lum	14	1	1	-	16
3. Klang (Chinese)	-	-	4	-	4
4. Kee Lek	-	-	-	13	13
5. Lai Tung	-	1	-	9	10
6. Huey Rai	-	1	-	10	11
7. Hua Pong	-	-	-	3	3
8. Pang Kam Pom	-	-	-	5	5
9. Kum Sa	-	7	-	-	7
10. Pra Jesus	-	7	-	1	8
11. Pong sa	-	5	-	2	7
12. Pang Tong	-	22	-	-	22
13, Pong Tag	-	17	-	-	17
14. Kun Huey Non	-	12	-	-	12
15. Huey Non Pang Nai	-	2	-	1	3
16. Huey Nong Pang Nog	-	-	-	2	2
17. Huey Pra Chao	-	26	-	-	26
18. Huey Mae	-	6	-	-	6
19. Huc Loa	-	15	-	1	16
20. Pang Tong	-	4	-	-	4
21. Ban Nue	-	2	-	-	2
22. Karen Mae Muang Luang	-	29	-	1	30
23. Ban Mai	-	16	-	1	17
Total	27	173	5	49	254
Percentage	10.6	68.1	2.0	19.3	100

Source : Field Survey, 1979.

Table 2 Age distribution and sex of the Population in Huai Thung Choa Area in 1979.

Age	Number	%
< 5	238	16.5
5 - 9	217	15.1
10 - 14	189	13.1
15 - 19	147	10.0
20 - 24	107	7.4
25 - 29	123	8.5
30 - 34	82	5.7
35 - 39	71	4.9
40 - 44	53	3.7
45 - 49	62	4.3
50 - 54	45	3.1
55 - 59	34	2.4
60 - 64	31	2.2
65 and over	37	2.6
No answer	4	0.3
Total	1,438	100.0
Sex		
- Male	740	51.5
- Female	698	48.5

Sources : Field Survey, 1979.

Table 3 Distribution of Age of the Population in Huai Thung Choa Area in 1979.

Age	Number	%
< 10	453	31.6
10 - 19	336	23.3
20 - 29	230	16.0
30 - 39	153	10.6
40 - 49	115	8.0
50 - 59	79	5.5
60 and over	68	4.8
No answer	4	0.3
Total	1,438	100.0

Sources : Field Survey , 1979.

Table 4 Distribution of Age of the Heads of Households in Huai Thung Choa Area in 1979.

Age	Number of Households	%
15 - 19	1	0.4
20 - 24	6	2.4
25 - 29	35	13.8
30 - 34	30	11.8
35 - 39	38	15.0
40 - 44	25	9.8
45 - 49	36	14.2
50 - 54	26	10.2
55 - 59	26	10.2
60 - 64	13	5.1
Over 65	18	7.1
Total	254	100.0

Source : Field Survey, 1979.

Table 5 Distribution of the Household Size and the Average Household size in Huai Thung Choa Area in 1979.

Household Size	% of the group			
	Lisu	Karen	Thai	Total*
1-2 members/household	7.4	6.9	14.2	9.0
3-4 members/household	22.2	28.3	28.5	27.6
5-6 members/household	22.2	28.9	32.6	28.3
7-8 members/household	25.9	23.7	16.3	22.4
9-10 members/household	14.8	9.2	6.1	9.4
Over 10 members/household	7.4	2.9	2.0	3.1
Total	100	100	100	100
No of cases	27	173	49	254
Average size/household	6.24	5.64	5.03	5.57
SD	2.597	2.32	2.29	2.37

Source : Field Survey, 1979.

* Including 5 Chinese household.

Table 6 Ability of Communicate in Northern Thai Dialect of the Head of the Household in Huai Thung Choa Area in 1979.

	%
Cannot communicate in northern Thai Dialect	3.9
Understand simple Northern Thai	1.2
Can communicate in Northern Thai Dialect with some difficulty	8.3
Can communicate in Northern Thai Dialect	86.6
Total	100

Source : Field Survey, 1979.

Table 7 Education of the Head of the Households in Huai Thung Choa Area in 1979.

	% of the Group			
	Lisu	Karen	Thai	Total
No education	100	94.5	54.2	88
1-4 year education	0	3.5	45.9	11.2
More than 4 year education	0	1.2	0	0.8
Total	100	100	100	100

Source : Field Survey, 1979.

Table 8 Highest Level of Education of the Members in the Household in Huai Thung Choa Area in 1979.

	% of the Group			
	Lisu	Karen	Thai	Total
No education	59.3	57.3	2.0	46.4
1-4 year education	33.3	36.2	73.5	43.2
More than 4 year education	7.4	6.4	24.5	10.1
Total	100	100	100	100

Source : Field Survey, 1979.

Table 9 Settlement period in the Village of the Households in Huai Thung Choa Area in 1979.

Period of Settlement	% of the Group			
	Lisu	Karen	Thai	Total*
1 - 3 years	29.6	15.9	16.3	16.5
4 - 6 years	14.8	4.0	8.1	5.9
7 - 9 years	3.7	3.5	4.1	3.5
10 years and over	41.4	66.5	63.3	63.4
No answer	0.4	10.9	8.2	10.6
Total	100	100	100	100

Source : Field Survey, 1979

* Including 5 Chinese households.

Table 10 Type of the Houses in Huai Thung Choa Area in 1979.

	Frequency	%
One story built on the ground	47	18.5
One story built on stills	201	79.1
Two stories	1	0.4
No answer	5	2.0
Total	254	100.0

Source : Field Survey, 1979.

Table 11 Type of the Roofs of the Houses in Huai Thung Choa Area in 1979.

	Frequency	%
Imperata Cylindica	72	28.3
Tong Tung	164	64.6
Galvanized iron	5	2.0
Tiles	8	3.1
Other materials	2	0.8
No answer	3	1.2
Total	254	100

Source : Field Survey, 1979.

Table 12 Type of the Walls of the Houses in Huai Thung Choa Area in 1979.

	Frequency	%
Besten Bamboo	162	63.8
Woven bamboo strips	35	13.8
Wooden planks	47	18.5
Bricks	5	2.0
Other meterials	1	0.4
No answer	4	1.6
Total	254	100.0

Source : Field Survey, 1979.

Table 13 Type of the Floors of the Houses in Huai Thung Choa Area in 1979.

	Frequency	%
Earth	25	9.8
Some part being earthy and some being bamboo	23	9.1
Bamboo	156	61.4
Wooden planks	37	14.6
Other materials	8	3.1
No answer	5	2.0
Total	254	100

Source : Field Survey, 1979.

Table 14 Fire wood used by ethnics Group in Huai Thung Choa Area in 1981.

Tribes	Volume (m^3)/household/year
Karen	17.12
Lisu	24.40
Thai	11.94

Source : Field Survey, 1981.

Table 15 Main Occupation of the Households in Huai Thung Choa Area in 1979.

Occupation	% of the Group			
	Lisu	Karen	Thai	Total*
Rice farming	66.6	89.0	79.6	83.5
Wage employment	7.4	4.6	0.0	3.9
Flower growing	14.8	4.0	0.0	4.3
Wiang production	0.0	0.6	18.4	3.9
Others	11.2	1.8	2.0	4.4
Total	100	100	100	100
No. of cases	27	173	49	254

Source : Field Survey, 1979.

*Including 5 cases of Chinese households.

Table 16 Cropping Pattern in the Surveyed Area in 1979.

Cropping Pattern	% of the Plots Cultivated			
	Lisu	Karen	Thai	Total*
Upland rice only	21.3	19.9	22.5	20.6
Paddy rice only	8.5	51.7	55	47.3
Maize only	12.8	0	0	1.5
Upland rice + Maize	14.9	1.9	0	3.1
Upland rice + Garden crops	2.1	6.9	0	4.9
Upland rice + Maize + garden crops	4.2	5.0	1.3	4.1
Flowers	23.4	3.1	0	4.9
Miang	0	8.0	15.0	8.5
Opium	6.4	0	0	0.8
Others	6.4	3.5	6.2	4.3
Total	100	100	100	100
No of plots cultivated	47	261	0	389
No of Households	27	173	49	254
Average No. of plots cultivated per household	1.7	1.5	1.5	1.5

Source : Field Survey, 1979.

*Including 1 plot cultivated by a Chinese household

Table 17 Periods of Present Land Utilization in Huai Thung Choa Area in 1979.

Years that Present Piece of Land Have Been in Use	Frequency	%
1-2	115	29.2
3-4	26	6.5
5-6	23	5.8
7-8	12	3.0
9-10	20	5.1
11-12	5	1.3
Over 12	193	49.0
Total	394	100

Source : Field Survey, 1979.

Table 18 Distribution of Total Household Expenditure by Ethnic Group in Huai Thung Choa Area in 1979.

Total household expenditure (baht)	Lisu	Karen	Thai	Total*
0 - 6,000	29.6	71.6	55.1	63.9
6,001-12,000	40.7	20.2	30.6	24.5
Over 12,000	29.6	5.9	14.3	10.0
No answer	0	2.3	0	1.6
Total	100	100	100	100
Average expenditure/household	11,177.8	4,819.3	7,109.0	6,081.5

Source : Field Survey, 1979.

*Not Including 5 Chinese households

Table 19 Pattern of Household Expenditure in Huai Thung Choa Area by Ethnic Group in 1979.

	Average Expenditure on Milled Rice per annum	Average Expenditure on other food per annum	Average Expenditure on clothing per annum	Average Expenditure on medical care per annum	Average Expenditure on ceremonial junction per annum	Average Expenditure on Liquor, gambling, cigarettes etc per annum	Average Other Expenditure per annum	Average Expenditure on Fixed Assets per annum	Average Total Expenditure per annum
Lisu	1,[illegible].5	3,443.0	1,041.7	195.0	1,577.4	773.0	190.8	1,421	11,177.8
Karen	1,359.3	1,282.4	593.5	207.0	297.0	651.0	51.2	562.2	4,819.3
Thai	1,702.0	1,337.7	990.8	167.0	300.0	700.0	137.5	1,380.9	7,109.0
Total	1,409.8	1,537.4	807.0	198.0	450.1	687.0	82.80	816.4	6,081.5

Source : Field Survey, 1979.

Table 20 Average Rice Production (tang) per household for the Households in Huai Thung Choa Area in 1979.

	Upland Rice Production (tang/household)	Paddy Rice Production (tang/household)	Total Rice Production (tang/household)
Lisu	139.0	36.67	127.80
Karen	56.13	109.75	118.67
Thai	28.67	143.23	133.95
Total	74.60	96.55	126.80

Source : Field Survey, 1979.

Table 21 Estimates of Average Rice Adequacy for the Households in Huai Thung Choa Area in 1979.

(Per cent)

	Estimate I [1]	Estimates II [2]
Lisu	64.0	49.0
Karen	74.0	82.0
Thai	70.0	76.0
Total	69.0	69.0

Source : Field Survey , 1979.

1 Rice Adequacy = $\frac{\text{Milled Rice Production}}{\text{Milled Rice Production + Reported Purchase of Milled Rice}}$

2 Rice Adequacy = $\frac{\text{Milled Rice Production}}{\text{Reported Rice Consumption}}$

Table 22 Material Possessing : (Standard of living)

Assets	Frequencies	Percentages
1. Blankets	247	98.4
2. Aluminum pots	244	97.2
3. Clearing knives	242	96.4
4. Galvanized iron plate/bowls/cups	236	94.8
5. Wooden mortars and pestles	224	89.2
6. Hens/cooks	201	80.0
7. Silos	187	74.5
8. Pigs	177	70.5
9. Threshing mats	176	70.1
10. (Sleeping) mats	162	64.5
11. Buffaloes	135	53.8
12. Home-made guns (Black Powder loader)	129	51.4
13. Rakes	126	50.2
14. Pillows	124	49.4
15. Radios	117	46.6
16. Matresses	107	42.6
17. Small canned lamps	92	36.7
18. Porcelain plates/bowls/cups	90	35.9
19. Mosquito nets	58	23.1
20. Cows/Bulls	45	17.9
21. Watches	36	14.3
22. Revolvers	34	13.5
23. Stone mortars and pestles	30	11.9
24. Horses	20	7.9
25. Sewing machines	16	6.4
26. Motor bicycles	1	0.4

Sources : Field Survey, 1979.

V-7 HIGHLAND AGRICULTURAL AND COMMUNITY DEVELOPMENT

by

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1. Introduction.

An upland watershed in remote northern Thailand has long known as critical area reflecting the national agricultures, socio economic and national security. The basic objective of the watershed management is thus, to keep or maintain those areas as permanent completed watershed as possible. This would be included a maintenance of optimum quantity and quality of water regime and protection of soil erosion.

Generally, the area of good watershed has to have sufficient plants covered with density of 70% or more in the area. Varieties of plant could be any kinds ; forest, agricultural fruit trees or even grasses. The forest however, is considered as the best for good watershed, though such completed watershed may find with difficulty in this part of the country. This is just not only because of problem on deforestration for illicit timbers, but also the problem on rapid growth in minor group of people known as 'hilltribes' , who have in the main migrated south from China and eastwards from Burma. The northern hilltribes population also live from all kinds of agriculture include a swidden opium poppy cultivation. They would cultivate all unoccupied land that it was capable of using for as long a period as it desired. When the fertility of the land has been exhausted after a number of crops had been cultivated on it, the tribal growers would move to a more fertile areas for their cultivations. Such typical move in the hilltribe people would lead to the problems not only on reduction of land fertility and erosion of the soil surface, but also on watershed and national resources destruction as a whole. It comes to the question of how to stop those people doing so and bring them together to live in one particular area farming on whatsoever the states recommendation to implement a programme on watershed management. These would be included the development of individual villages land and their socioeconomic pattern. Modern technical-knowledge on agricultural extension could be used as a tool applying to the areas urgently and seriously in hope of to stop deforestration and watershed destruction.

2. General conditions of northern Thailand.

2.1 Geopraphical conditions.

The northern area of Thailand lies between 15-21 °N

latitude and 97-102°E longitude covered the area of 170,000 Sq.Km. which is accounted for one-third of total area of the country.

The specific boundary is as follows :

The north boundalies along the River Khong, Petcha Boon and Thanon Thong Chai mountain ranges are the east and west bound, respectively, while the south bound reaches the area of Chainat Province.

The northern area may further be devided physically into 2 parts ; lower north and upper north, in which only the latter will be concerned in this paper.

The covered area of the upper north comprises 9 provinces namely ; Chiangmai, Chiangrai, Mae Hong Sorn, Tak, Lum Poon, Phrae, Nan, Lum Pang and Phayow. The total area of all 9 provinces is about 105,000 Sq.Km. or 62% of the total area in the whole northern part.

The area may be devided into 3 different parts ; Low land, Upland and Highland, with an estimated area of 9,365 Sq.Km. for Lowland; 31,432 Sq.Km. for Upland and 64,296 Sq.Km. for Highland. It is cleared that majority of the land area is in Highland part, in which most of the mountainous watershed located in. Usually those Highland has an altitude of more than 700 metre with degree of slope above 20 and mostly are rolling. The principal uses of the land are orchard, pasture and economic forest unless effective structure of soil and water conservation being applied. The higher elevation area would be left as watershed and/or economic forest, national park and wild life conserving area.

Most of the highland in this part is considered as the most important watershed particularly for major rivers in Thailand; Ping, Wang, Yom, Nan, Kok, Khong, Khum, Lao, Salwin, Lamard, Pye and Youm. The total area of such watershed is about 40% of the total upper north.

2.2 Weather conditions.

Because the mountainous area of the upper north comprises of many mountain ranges lie in a north-south direction which are barriers to block the path way of the south-west monsoon originated in Indian Ocean. Moreover, a depression from Tungkia, southern China would bring in a continuous rain to the area. Consequently to become high rainfall prevailing over the whole area.

In general, the rain is more than 50 mm. during April and October with a monthly average of more than 250 mm. during May and September. The average annual rainfall would be 1,550-2,600 mm. in which approximately of 500 mm. higher than those in adjacent southern area.

An average monthly temperature is 9°C in December and 13°C in February which are both considered lower than those in other part of the country. The temperature however, may go down to zero or

even under zero in some spots particularly in the bottom of the valley having no wind. An average temperature during March and May is under 24°C with maximum daily under 35°C, while those in other parts of the country, the monthly average is 30°C and 44°C for maximum daily temperature.

2.3 Population in the upper northern area.

The population of the upper northern was 4,739,855 recorded in 1979 with birth rate of 2.4 per annum and the population density was 45 per Sq.Km.

In regard to the population of the highland which are mostly identified as hilltribes; Mae, Yao, Lisu, Lahu, Egor and Karen. Those tribesmen may be considered as the most six major tribes with total population as large as 80% of all hilltribes in Thailand. A report made by the Hilltribe Research Centre in 1975, concludes a total population of 286,448 ; 49,074 households and 2,048 villages. Which of those, Karen was the biggest group with its population of 159,092, the other were Mae, Thin and Yao with their population of 30,519 , 23,397 and 21,074 respectively.

The provinces that have largest number of hilltribes are Chiangrai, Mae Hong Sorn and Chiangmai. In fact, the hilltribe peeple are being scattered over 58 different districts ; Mae Chan district of Chiangrai, Mae Sarieng of Mae Hong Sorn and Om-Koy in Chiangmai in which each of these having tribal population over 25,000. The areas that have hilltribes population between 10,000 and 25,000 are; Muang district of Chiangrai, Mae Jam (Chiangmai), Pou (Nan), Muang and Fye (Mae Hong Sorn), The Song Yang (Tak) and Lee (Lampoon).

It is not unusaul that the move in many hilltribes oftenly occurs both within and from outside country, making difficulty in surveys for precise number of population. However, the Hilltribe Welfare Centre in Chiangmai has recently reported a total population of 6 tribes in 9 provinces of the upper north as shown in table below.

Table - 1 Number of villages and population of six major hilltribes in northern Thailand recorded in 1979.

Tribes	No. of Village	Total population	Percentage
Karen	1,385	161,664	64.25
Mae	134	30,519	12.13
Yao	144	21,074	8.38
Lahu	140	16,960	6.74
Lisu	31	11,200	4.47
Egor	30	10,152	4.03
Total	1,934	251,629	100.00

Since a large number of hilltribe population lives scatterly over the remote mountainous area with a low standard of living ; poverty, poor health, lack of education, etc. which is therefore leading to the problems on national resources destruction, national security and illicit opium poppy production. These problems are indeed needed to be recovered urgently and seriously by states authorities.

One can imagine that with a large number of as many as 300,000 hilltribes in the watershed area living from all kinds of agriculture including shifting opium cultivation would lead to a land resources ruination. The provinces that have biggest problem on shifting cultivation behaved by the hilltribes are Mae Hong Sorn, Chiangmai, Chiangrai and Nan. The use of shifting cultivation method however, tended to be incrased in the area of other provinces; Lumpoon, Lumpang, Phrae and elsewhere. A report made in 1969 by the Royal Forest Department has pointed out that the deforestration for agricultural purpose was as high as 2.3 million rais (1 rai equal 0.395 acre or 0.16 hectare) per annum with waste cost of 200 million Baht.

It has been known that a consequence of watershed destruction always followed by reduction in total amount of water and its quality. This is evident from deficiency of water regime during dry season, **while excessive** water prevails in wet season. The amount of water from Ping, Wang, Yom and Nan that flown into the Chao Phaya River recorded in 1970 was 21 Billion cubic metre which is compatible to the average of 23 Billion cubic metre recorded at Chainat Dam during 1957-1968. It is believed that the reduction in the water quantity being suffered from hazard deforestration as the main. Flood is another problem attacking agricultural growing crops, physical land status and socio-economic not only in the region but also in other parts of the country. The excessive water and soil erosion that basically caused by deforestration also induce water pollution with low water quality, a deficiency of oxygen. Consequently to make troublesome over in land aquatic lives.

3. Programme for individual watershed development based agriculture.

Perhaps a deforestration and watershed destruction in remote northern Thailand that caused by hilltribes may seriously induce problems not only on land resources ruination, but also on the nationwide socio-economic disaster. The hilltribes who live in such remote area have been known as under developed minor group people. They are low in education, poor health, hungers and easily encouraged to do things illegally includes producing opium poppy (Papaver somniferum). Indeed, in the opium producing villages, opium is kept in the households for their own consumption or to be used as wages for addicted labourers. The hilltribe people often use opium as a drug for treatment of illnesses and as a psychoactive drug for anxiety and depression. It is also used for recreation of individuals on their own and for social activity of groups. Moreover, the political fight of the minor group of people against the crown government and among the minor groups themselves around Thai border is apparently to be

related to an opium poppy. The produce of opium may be sold for cash to buying food and arm weapons, or use as a budget for arms group establishment. It may often use as a direct exchange between opium and kinds of weapon. It is also believed that the production of the opium poppy will never be wiped out from this part of the world as long as the political movement around the Thai border still be in action.

Most of the hilltribe growers may be considered as true' shifting cultivators' with the aim of just not only the production of rice and other crops which are their subsistence needs but rather of opium poppy production. They would cultivate the cleared fertile lands for some periods, then move to other places after the fertility of the old ones has been exhausted by repeated cultivation. They may shift a hundred or more square kilometre in one movement particularly, to highlands above 1,000 metre and as high as 1,600 metre above mean sea level. Such movement may start from individual local villages. The villagers may firstly shift the land and farm in approximity to their village site. If the population in which a group settled is large, they will later farm further away. Their secondary houses may be needed in the fields where they work, but the first ones still being maintained during slack period and at times of festivals. As the distance from village to cultivating area increases, the secondary houses will be built to a better standard and may often become the only houses. The original ones may leave behind for generations or others. After a full growth of houses over the village territory, the next step is that a group of villagers will be away from the village searching for a new land to settle. New congregations will then be gathered in new places, and the process of such movement will be repeated endlessly in hilltribe population. In consequence, the forest lands and/or watersheds would be ruined to the fast diminishing as so far experienced. The programme for individual watersheds development and others have had to end the process of the tribal movement before more problems on watershed destruction will never be controlled.

However, the uncultivated tracts of land that were once found so easily no longer exist. The problem of a land shortage is beginning to be recognized by the hilltribes, who are gradually evolving a rotational system of cultivation that enables them to stay in one place.

It is also believed that the production of the opium poppy among hilltribe people would be the main cause of serious deforestration and watershed destruction. The major components of the programme for individual watersheds development based agriculture would include a programme for crop replacement and community development ; new introduced crops research, cultivation of promising cash crops, extension activities, pasture and livestock improvement, etc.

Elimination of opium poppy cultivation and introduction of modern agricultural technology and alternative crops into the remote northern highland would be extremely beneficial not only to the northern hilltribes and of remainder of Thailand, but also to the international community, Europe and to the United States of America.

Since a firm basis of agro-technical knowledge and experience about the highland is a prerequisite of the successful implementation of a programme designed to achieve those objectives, concerning agencies under the Royal Northern Programme have included the setting-up of several research projects. There have been established with the assistance of national and international agencies and are directed by the Highland Agricultural Research Coordinating Committee (HARCC). A wide range of crops were tried out at varying altitudes in order to establish which crops were most suited to each altitude.

The amount of agro-technical knowledge that has been accumulated from these researches is now sufficient to permit the implementation of farming methods in a systematic manner. The detailed information about the types of crops and methods of cultivations which would be appropriate in the Royal Ang Khang Research Station and elsewhere would be used as the basis for the programme on crop replacement and community development.

3.1 The Highland Agricultural Development Programme to Replace Opium Based Agriculture.

A so-called 'The Highland Agricultural Development Programme to Replace Opium Based Agriculture' is one of the most effective programmes in extending the results of the highland agricultural researches and other improved agricultural practices into individual watersheds to eliminate opium poppy ~~production~~ production and to improve the standard of living in hilltribe population.

The detailed statement of work in the programme may include :

3.1.1 Establish extension project headquarters in the individual key village area, employ personel and collect necessary materials and supplies as needs to accomplish project objectives.

3.1.2 Make a socio-economic and soil survey of the extension project area as a base for effective planning and evaluation.

3.1.3 Help tribal people to define their problems and needs and then jointly determine goals for the extension project.

3.1.4 Provide in-service training for village extension agents on extension methods, soil, crop and animal technology and farm management skills as needed.

3.1.5 Establish demonstration areas on tribal farmers fields consisting of the following :

3.1.5.1 improved cultural practices of basic food crops (cereals, legumes and vegetables)

3.1.5.2 establish cash crops and demonstrate their culture with emphasis on high return cash crops such as coffee, deciduous fruits, pyrethrum, chrysanthemum

tea, flower seeds, vegetable seeds and strawberries.

3.1.5.3 provide systematic farm planning, farm layout and cropping systems (conservation, rotation, multiple and inter-cropping systems).

3.1.6 Provide for various kinds of effective training programmes for tribal farmers to complement the farm demonstration plot training.

3.1.7 Multiply new and/or improved crops not available locally on tribal growers fields as needed.

3.1.8 Develop a marketing system, involving tribal people, to handle agricultural commodities to be sold from the cluster village area.

3.1.9 Promote the following activities:

3.1.9.1 adult leadership.
3.1.9.2 adult literacy.
3.1.9.3 Youth group.
3.1.9.4 Cooperatives.
3.1.9.5 home handicraft industries.
3.1.9.6 Community healths and farmity planning
3.1.9.7 treatment and rehabilitation of narcotic addiction.

3.1.10 Evaluate with tribal people and project staff progress toward established joint goals.

In regard to the Maejo Institude of Agricultural Technology, the Highland Agricultural Development Project to Replace Opium Based Agriculture has been conducted at two different locations ; Ban Thung Luang in Chiangmai and Ban Mae Pun Luang of Chiangrai.

The project has formerly designed as a follow up subproject to the Royal Northern Development Programme, which is aimed to improve agricultural production, socio-economic and finally to promote the well-being in the inhabitants of the northern hilltribes.

Until June, 1979, the project has been continued with major financial assistance from the USDA. It would be convenient to take activities done only at Ban Mae Pun Luang for example to describe the project pattern.

The project site of Ban Mae Pun Luang lies approximately 135 kilometers northeast of Chiangmai among the mountain range at an altitude of 3,000 ft. to 4,600 ft. having slopes of up to 40 degrees or more. The project area comprises 3 villages with 3 different tribemen. The Lahu is in Ban Mae Pun Luang with its population of 350 in 50 households. Chinese Hau and Lisu are the local inhabitants of

Ban Khun Chae and Ban San Khula with their population of 250 in 40 households and 90 in 15 households respectively. The walking distances from one village to another are approximately 5-7 kms. with earth track along the hillsides. The cultivating are in each village being 800 rai at Ban Mae Pun Luang, 400 rai at Ban Khun Chae and 200 rai at Ban San Khula.

The site of the project headquater however was selected at Ban Mae Pun Luang which was once considered as the largest area for a swidden opium cultivation among those villages. Of which the majority of the land is considered as steep slope and the soil is derived mostly from granite parent material having light texture and porous. Climatic conditions is normally subtropical with temperature during some period goes down to 4°C or less and often maintains at 7°C in cool season. Prevailing of frost may occur during winter but rather in short period, in places without wind as the areas at the deep bottom of the valleys. The area is often prevailed with high rainfall during wet season.

The deforestration and watershed destruction caused by the hill-tribe population, plus a high degree of slopes, a porous of the soil and high rainfall could be the main causes of soil erosion, reduction in soil fertility and ruination of watershed ecosystems. The project is thus, set for elimination of such serious problems and help the local people to reach a better standard of living ; earning high income,having good health, attending courses for literacy, etc. The project activities however, may be summarized as follows :

At the start of the project, a land of about 12 rais at Ban Mae Pun Luang was offered by the villagers for establishment of the project headquarter and demonstration plots. Five units of cottage have already been built in the given area. Of which three of those have been used as staff accommodation with capacity of 15 persons, one store house of 5 x 8 metre and one 6 x 6 metre temporary office. A reddish brown lateritic is a soil characteristic typical to the area. Observation made on growing plants also indicated a severe deficiency symtom of phosphorus and other trace elements. Water condition is not really problem in the area. The three inches diameter of PVC pipes have been laid from a small constructed weir, a few hundred metres in distance from the land. The water supply would be used for both, village consumption and irrigation purposes.

It was decided to use this area as for introduced crops trial and demonstration purposes. Modern technology on soil and water conservation for example, has firstly been put into the area. Method of intensive cropping being conducted on bench terracing and hillside ditch constructed land using some basic food crops (rice, corn and vegetables) and/or some promising cash crops (coffee, deciduous fruits, vegetable seeds and strawberries). It is not only because of an increased problem on land shortage as recognized in the hilltribes, but intensive cropping also gives high return and makes more income to the growers. This would lead to the change in tribal attitudes from their typical shifting cultivation practice and turn into a modern farming method demonstrated.

The successful crops developed at the site also include peaches, pears, persimon, apricot, kidney bean and vegetables (carrot, chinese raddish, etc.) could be used as replacement crops in the programme. A programme on demonstration of cropping systems and modern soil conservation practices has also been initiated in the farmers fields. The tribal people were always encouraged to believe that all activities were a part of the village activity. . The individual growers were also encouraged to try out new introduced crops and livestocks in their own farms, of which any losses being borne by the project but any benefits going to the farmers. In addition, the project also provided some specific amount of necessary agricultural facilities; plant seedlings, fertilizers, etc. to the villagers who keep follow the project activities and make themselves busy in their own lands. The villagers were once told that such people would be put in prior lists for help. Consequently, more and more requests for the project demonstration activities being put in other tribal lands as so far experienced.

As ones know however, most of the hilltribes are less in education and always stick themselves to the old fashion of living which is not easy to make change in their attitudes and turn into a new surrounding. The project therefore has set up plan for 4-5 years period to complete the programme.

The development of viable agricultural economy that is not dependent on opium has been practiced on the basis of improvement of communication, transportation, and marketing system. On the other hand, the marketing section under the Royal Northern Programme will play a role on selling most agricultural items produced from the site.

In providing a more stable income to the villagers has been made on the manner of improvement of village roads and marketing system in town.

Development of village socio-economic status and promotion of tribal education are considered as prior step to approach improved standard of living in hilltribe population. A two-roomed school for children was established at Pan Mae Pun Luang in which all facilities and expenditures had been supported from the Royal Northern Project and other agencies. It is fortunate that in cooperation with the project, the school is now transfered to be undertaken by the Chiangrai Provincial Authority.

In addition to complement a programme for treatment and rehabilitation of narcotic addiction, a number of opium addicts were sent from the site for detoxification to the hospital in Chiangmai. The accomplishment achieved from such treatment is evident from a marked decrease in number of addictions in hilltribe population in the project area. Perhaps the use of opium for illness treatment among hilltribes may be one of the reasons for addiction problem. Two young villagers from Pan Mae Pun Luang were selected as participants for basic nurse training in Chiangmai. The trained participants are

supposed to learn the general know-how of some basic illnesses and their medical treatments after the course is over. Also, the trained boys could benefit from their newly acquired medical knowledge when they return home. It is also believed that any serious problems on opium addiction will certainly be recovered in the near future.

Section VI

CASE STUDY COUNTRY REPORT

VI-1 CASE STUDY REPORT - SRI LANKA. THE UPPER MAHAWELI CATCHMENT.

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May 25 - June 8, 1981.

In Sri Lanka, like in most South East Nations, the socioeconomic demands of an expanding population are generating basic needs for additional employment and increased agricultural production. The present agricultural activities have continued to be insufficient to meet the food requirements of the growing population. Recognizing these problems the Government has in recent years sponsored a series of studies for planning and promotion of socioeconomic development in the country.

To increase agricultural output it is concluded that the chief limiting factor was a reliable water supply. Further, the fact that there is comparatively small amounts of land suitable for further agricultural development in the wet zone of the country made it necessary to focus attention to the Northern and Eastern dry zone areas where considerable land resources are still available for agricultural extensification. However, neither rainfall nor ground water supplies are believed to be adequate to support a substantial programme of additional cropping in the dry zone.

Consequently, in order to accomplish agricultural expansion in the dry zone, new irrigation schemes have to be developed. Thus logically because of its size, the Mahaweli Ganga has become in recent times the focus for the planning effort that had been directed towards increasing agricultural production.

The Mahaweli diversion programme includes a scheme to provide irrigation from the Mahaweli Ganga which will enable the development of 360,000 hectares of new and existing agricultural lands in the dry zone, the construction of about a dozen large reservoirs to generate 460 megawatts hydropower and the settlement of over a million persons. The entire scheme encompasses about 39 percent of the island and 55 percent of the dry zone and was started in 1972.

The Mahaweli Ganga drainage basin has a total area of over 4,000 square miles and is the largest basin in Sri Lanka covering about one sixth of the area of the island. Almost all the important tributaries and the headwaters of the Mahaweli Ganga rise in the core of the central highlands, the latter rising in the vicinity of Nuwara Eliya with elevations ranging from 1,200 m. to over 2,000 m. The river itself rises in the Hatton Plateau, a formation to the south west with elevations ranging around 1,400 m. The river then flows north from this plateau until it curves around the town of Kandy in the Kandian Plateau at an elevation of 500 m., it turns and flows in

an easterly direction before crossing the wet zone boundary at elevation of approximately 100 m. and then flows northwards for the remainder of its course.

The Highland Catchment which lies in the southern and central part of the basin contributes a large proportion of the total run-off from the basin in relation to its size. As such, it remains the principal source of water for the numerous hydropower and irrigation schemes in the Mahaweli Programme. It therefore is vital that these multi-million dollar investments must be safeguarded by a regulated supply of acceptable sediment free water.

The area of the Upper Catchment is approximately 316,000 hectares with a topography that is both steep and mountainous. 7.2 percent of the Upper Catchment lies above 1,800 m. 26 percent between 1,200 and 1,800 m. and the balance above 600 m. The higher elevations have a very high rainfall (over 5,000 mm. in places), rugged topography and the land use is dominated by tea plantations and areas of natural vegetation. The lower parts of the hill country have high rainfall in the west around Kandy, with dense agricultural settlement of long standing, but the rainfall decreases in an easterly direction as the range of crops becomes more limited.

Although the Upper Mahaweli Catchment has a large variety of land forms and covers a number of agro-ecological zones the dominant feature affecting run-off and erosion is the very steep, often mountainous terrain. However, the extent of soil erosion overall in the Upper Catchment can be described as moderate, but becoming severe in some parts. It does seem, however, that in the absence of a considerable improvement in the standard of land management the situation is likely to deteriorate rapidly.

About 70 percent of the Upper Catchment is under some form of agricultural usage, the remainder being natural forests, grasslands and forest plantations. Perennial crops, in this case almost entirely tea, occupy by far the largest proportion of the area accounting for 35 percent of the total. There has been no significant changes in the area under tea in the past 20 years although a deterioration in the crop over fairly large areas is evident.

Well managed tea provides an almost complete soil cover, and under these circumstances is the best erosion control measure known. Unfortunately in the Upper Catchment much of the acreage under tea is in a degraded state and often provides no more than 30 percent soil cover. Here moderate to severe erosion has taken place over the past few years and considerable soil loss is evident from exposed roots and other signs. This situation in the mid country is much more serious than in the up-country tea areas, due to the unfavourable growing conditions in the former.

Tea managed to a high standard can be regarded as a very sound Upper Catchment protection measure as well as producing a crop of major economic importance. However effective the mature tea is in controlling erosion there is always a very high hazard when new tea is planted out.

Figure 1 Generalized topography on the Mahaweli Ganga basin

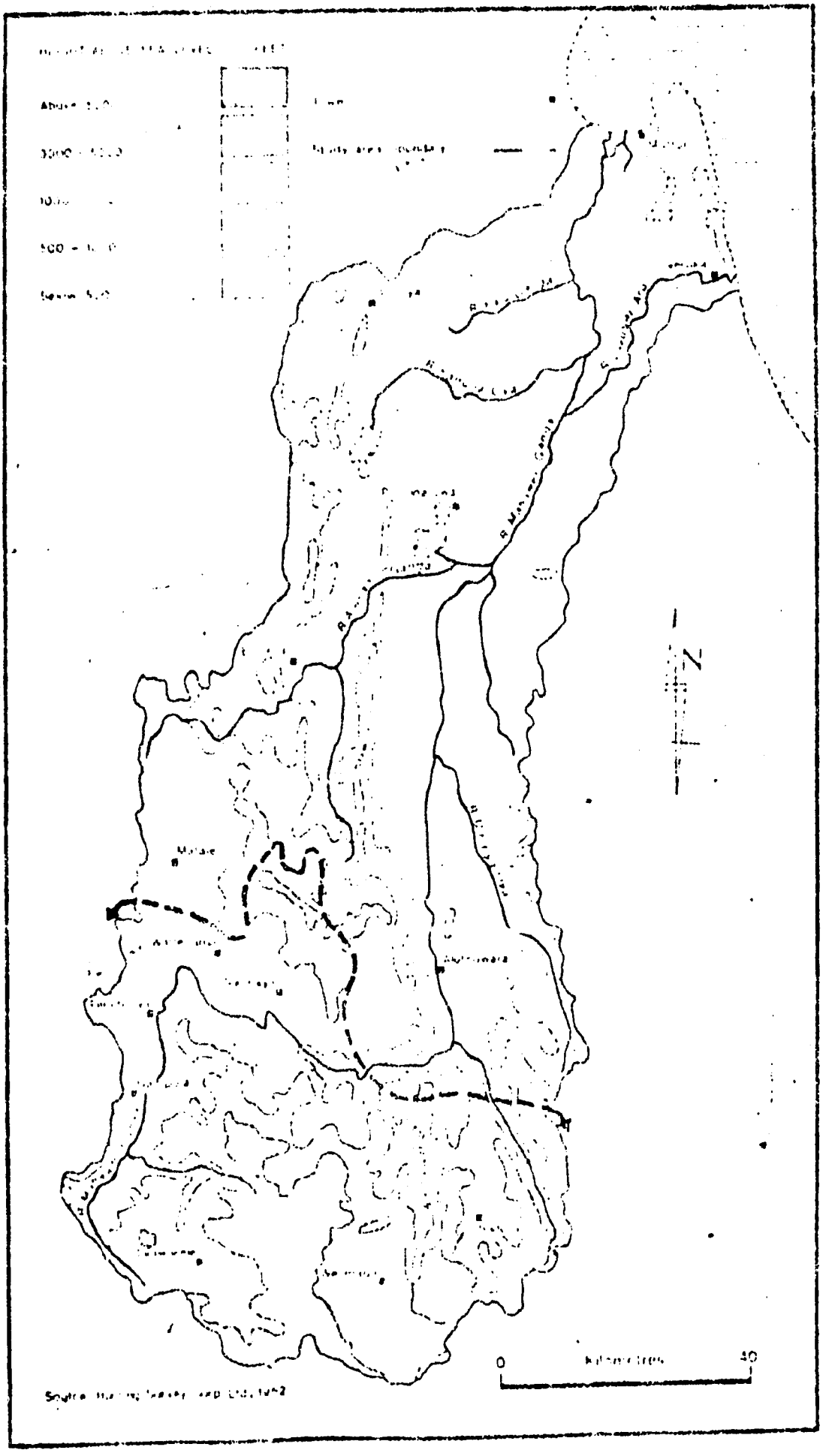

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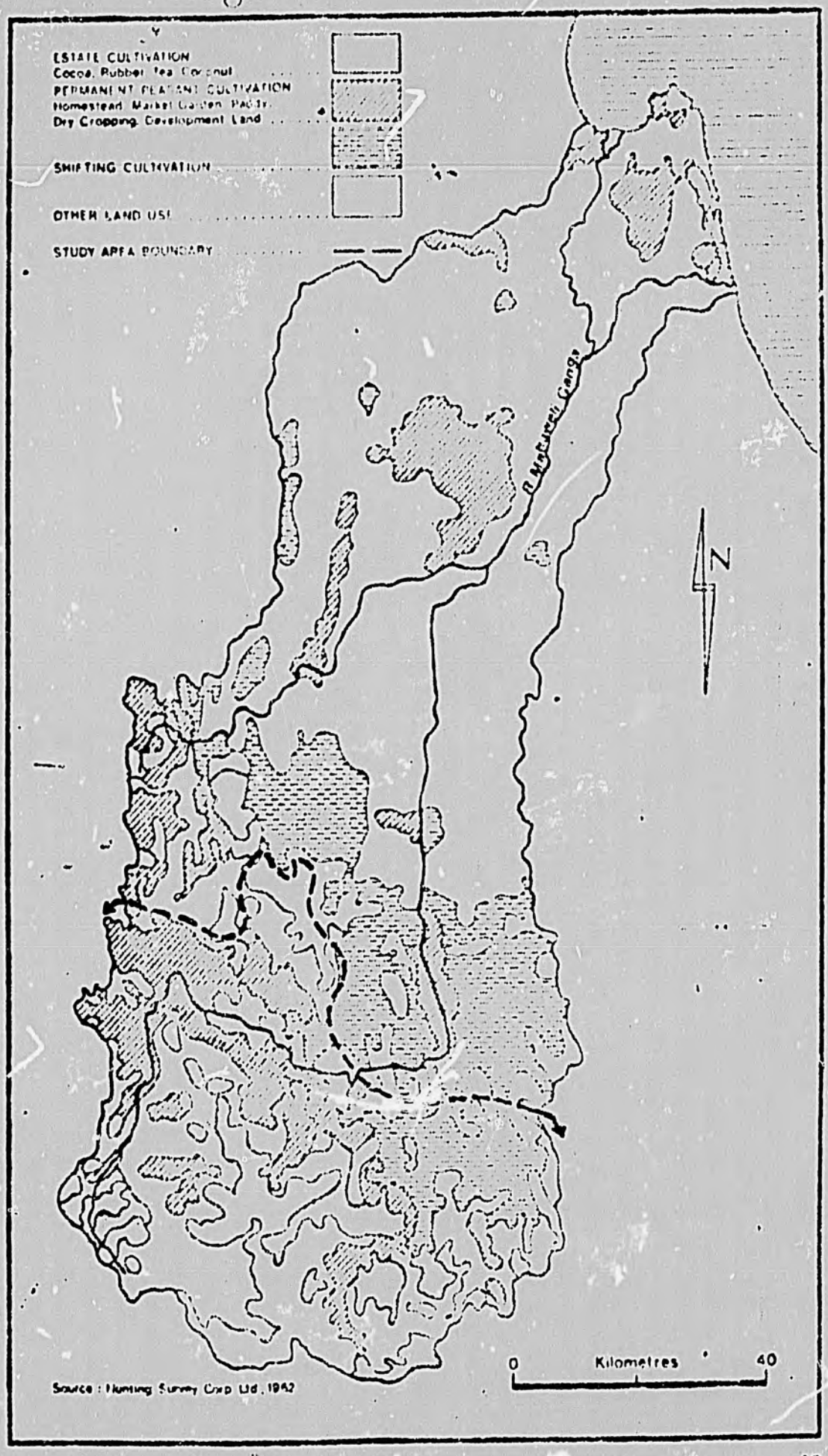
Figure 2 · Generalised land use in the Mahaweli Ganga basin



The Tea Research Institute has obtained good results with Guatemala grass during the planting periods, which are cut and the cuttings left on the ground as a cover.

In the drier areas at the lower elevations particularly in the eastern sector much of the land is being used for the production of seasonal crops under the system of shifting cultivation. Approximately 7 percent of the area is under this wasteful land use practise and in recent times settlement and cultivation of mountainous terrain is increasing at an alarming rate. This is due to such projects as village expansion schemes, food production drives and illegal occupation where, even forest areas, stream reservations and land over 30° have been alienated.

The Upper Catchment area contains about 10 - 15 percent of permanent dry land cropping, in which grain crops, tobacco, chillies and vegetables are grown. These areas usually occupy the slopes and hills and hence have high erosion hazard. The area under this type of land use has increased 2 to 3 fold within the past 20 years.

Tobacco growing in this region which is today an important economic activity makes use of about 5,000 hectares on the steep hillsides bordering the Mahaweli Ganga adjacent to the site of the proposed Victoria reservoir and in the vicinity of stream tributaries to the river. There has been much criticism of tobacco growing in relation to soil erosion, which also causes a depletion of the soil fertility.Tobacco is a short season crop giving a poor soil cover in which a moderately high degree of erosion has to be accepted as part of the economic package of tobacco production. It is believed that tobacco cultivation is one of the most serious problems in the watershed. The Ceylon Tobacco Company who buy the leaf have introduced a subsidy payment to growers as incentive to construct soil conservation measures.

A large area (10%) of the upper watershed is under horticulture which includes the familiar homestead gardens as well as market garden types. The homestead gardens occur at lower elevations in the north west and usually contains a rather dense growth of fruit and other trees. In the best gardens a good cover is provided and erosion is limited, but the position is often less satisfactory where the rainfall is less and areas of bare ground give rise to some soil loss.

The market garden category comprises those areas which are intensively cultivated for the production of vegetables throughout the year. Most of it is concentrated in the north central part of the Catchment and also at high altitudes around Nuwara Eliya. The conservation measures used are very poor, yet only slight erosion is evident probably due to the generally low intensity of the rainfall and the nature of the soils.

Coconut, Rubber and Cocoa plantations are also formed here. Some are on steep slopes with little ground cover under the trees and erosion is often evident, however in most cases grass or other crops provide adequate protection.

Paddy is cultivated in valley bottoms or on terraced slopes throughout the Catchment and includes both rainfed and irrigated types. This is of little erosion threat.

Two main types of grassland or as they are referred to Patanas are found; the dry and the wet Patana types, the latter found on the upland plains. The patanas have a natural growth of coarse grasses that are marginal for grazing and specially the dry patanas are burnt during the dry season.

Undisturbed grasslands provide complete protection against excessive run-off and soil erosion, but when grass is burnt on a regular basis this is not always the case. In some places the wet patanas have been developed for livestock production which however is fortunately of low livestock stocking. Overgrazing on steep slopes may result in erosion problems, which is showing up in certain areas. About 10 percent of the Catchment is in scrub with a scattered to dense growth of bushes, a feature that has shown up only in the recent decade. It is usually found after clearfelling in the forest or after shifting cultivation.

There are a number of different types of natural woodland in the upper Catchment, now mostly remanants of the former forest cover. The natural forest which was about 23 percent in 1961 has been badly fragmented over the years because of the requirement for fuelwood by the villagers, tea factories and tobacco kilns. Construction timber has also been taken out from the forest on the Reserves and other state lands. In the upper Catchment there are about 100 patches of timber of less than 100 hectares, eight from 100 to 1,000 hectares and only four larger than 1,000 hectares. The last mentioned are Forest Reserves which are found mostly in the wetter parts. Trees grown are mainly Pines and Eucalyptus species - both exotics. Most of the remaining timber in the Catchment is above an elevation of 1,525 metres (5,000 feet) and in many places the timber has been cut to above the 1,825 m. elevation level.

Where the natural forests are undisturbed and not subject to any burning they provide one of the best possible measures for regulation of the hydrological regime of the Catchment. Plantation forests however particularly Eucalyptus grown on steep slopes with poor ground cover offer very little resistance to erosion. In the very recent times, fortunately the thinking is more oriented towards soil conservation rather than solely timber and indigenous species as opposed to exotics. This argues well for forestry in Sri Lanka.

In summary it may be stated that the upper Catchment has four major land use groups, intensively managed land comprising 51 percent of the area, unmanaged agricultural land of 15%, nine percent is covered by forest or forest plantations which is well below the permissible limit for ensuring protection of the upper Catchment and 24 percent is unused or misused land, mostly scrub, shifting cultivation, grassland and abandoned tea. Hence 39 percent of the area of the Upper Catchment are suffering extreme erosion, all well above the tentative standard of acceptable loss.

The highest priority area for soil conservation measures are the unmanaged agricultural land comprising 15 percent of the Catchment. Fortunately the soil factor throughout the upper Catchment areas constitutes a low erosion hazard than other soils. They are deep well drained, well structured with good infiltration and permeability. Yet, controlled erosion can only be sustained under good management practices.

The Upper Catchment is one of the most productive and economically important areas in the Island and about 70 per cent of it is under some form of agriculture. Whatever may be considered desirable from the point of view of the hydrological regime the land use situation is unlikely to change and hence any proposals for improved catchment management have to recognize this.

Present management practices although able to control erosion to a limited extent, are inadequate to safeguard against the deterioration of the Watershed. This has been further aggravated in the past by the uncontrolled clearing of the forests for shifting cultivation and village expansions and the increasing detertoration of a great extent under tea.

The erosion control measures that have been employed in the Upper Watershed have been by far confined to the tea lands, elsewhere it is not truely the case. The traditional physical protection measure used on tea lands is the "lock and spill" drain designed to hold the maximum amount of run-off, but allowing the surplus to discharge into a protected waterway. Like the "lock and spill" drain many physical soil conservation measures are specifically designed to store water until it has time to infiltrate. On steep slopes the possibilities for natural surface storage are obviously limited, and therefore land management practices which artificially increase storage are more important.

Conservation measures employed are not universal throughout the estates in the Upper Catchment and unfortunately less common in the mid-country areas where the erosion hazard is greater since the rainfall is assumed to have a higher erosivity.

On slopes less than about 15 percent, mechanical protection measures often take the form of graded or contour bunds (channel terraces) usually in combination with contour cultivation. On land slopes in excess of 15 percent in some of the better managed estates, some form of bench terracing is evident. In these lands, stone terracing, grass hedge filters and stone paving for down drains are measures employed for erosion control. However, this is not always the case, much of the acreage under tea is ill managed and splash erosion has resulted in considerable soil losses. The maintenance of contour drains has been neglected and many have become ineffective through siltation. Gully formation is also not uncommon.

In the case of agricultural lands other than in tea, the situation is more alarming, especially in tobacco lands where special conservation measures are generally absent or rudimentary. This is even so, for the market gardens which are intensively cultivated throughout the year. The

standard of layout of the gardens is poor from the conservation angle and very little terracing can be observed. Growers seem mainly concerned with surface drainage and many drains between beds are put in at very steep gradients.

Various other agronomic and conservation measures are employed in a few situation. These include practices as cover crops or overhead shade, mulches, cultural practices such as weeding and intercropping. Additional measures encountered include stream bank erosion control and stabilization, road erosion control among others. But these measures are limited in application.

Under the Soil Conservation Act of 1951 regulations have been made to protect erodible areas which requires the prevention of mechanical damage to the soil, prevention of cultivation of erosion susceptible lands and the employment of soil conservation practices in cultivated lands, the prevention of fire and the afforestation of degraded lands. In addition the total banning of clearing of forests above 1525 m. applies to the entire Watershed. Tobacco cultivation has been restricted in erosion hazard areas which account for about 50 percent of the tobacco lands in the Upper Mahaweli Catchment.

The effect of erosion in the Upper Watershed of the Mahaweli is no more obvious than in the case of the Lake Gregory at Nuwara Eliya. The once clear Watershed lake is today subjected to extensive silting. This is mainly due to the cultivation of lands in its catchment without adopting proper soil conservation methods, the clearing of lands in steep valleys, the changing of crop patterns from permanent to seasonal crops and the cultivation of seasonal crops without proper soil conservation measures.

The lesson from Lake Gregory is to a certain extent a fortunate experience, for, it has resulted in an increased importance being placed on conservation measures for the three large upstream storage reservoirs being built on the Mahaweli. Extensive silting of these reservoirs will greatly affect the irrigation and hydropower potential of the Mahaweli scheme. The new measures that have been drawn up for the protection of the catchment of these reservoirs include the following

- Maintaining existing Forest Reserves and the creation of a buffer zone around them.

- The closing of erosion hazard areas to cultivation.

- Reafforestation of all steep and unstable lands and those lands with limitations.

- Changing land use to a more economic type of cultivation.

- The adoption of conservation measures in tobacco and seasonal crop lands.

- The creation of a reservoir perimeter of trees just above F.S.L. and upto 10 chains above it.

- The protection of reservoir shoreline with grasses,

- Stream reservations, silt traps etc.

Recent studies shows that 71,000 hectares of the Upper Mahaweli Watershed are in a degraded state and in need for rehabilitation. Various Projects have commenced or are proposed in order to maintain and improve watershed value.

For the large areas of abandoned and poorly managed tea, grassland and scrub, tree crop diversification is showing good results. A recent study (UNDP/FAO 1979) has resulted in the creation of the National Agricultural Diversification and Settlement Authority (NADSA), with funds negotiated through the World Bank. The purpose of this body is to broaden the agricultural base by increased diversified total value of agricultural production while simultaneously improving land use techniques, soil fertility and soil conservation. This scheme involves settling families on 1.0 hectares of degraded tea land for the purpose of growing mixed crops of jak and fruit trees and minor export crops of pepper, cardamons, nutmeg, cloves etc. An afforestation component with Pinus and Eucalyptus to the extent of 4,960 hectares over a three year period is also incorporated under this scheme. It appears that this type of redevelopment would be used on suitable lands requiring rehabilitation throughout the catchment.

The Forest Department in cooperation with the USAID are programmed to the creation of timber plantations that specifies that 1,215 hectares are to be planted every year for 5 years on degraded and poorly managed tea lands and a large area under scrub. The State Plantation Corporation has also a programme for reafforestation with exotics in small extents of degraded tea lands.

The Ministry of Lands and Land Development is to undertake a re-afforestation project with World Food Programme (WEP) assistance over a four year period for afforestation of 800 hectares in the Upper Mahaweli Catchment and 400 hectares of abandoned seasonal crop lands annually. The emphasis will be on the re-afforestation of all steep or eroded montane lands to protect water catchments and conserve water and soil. The planting of fast growing fuelwood species and the development of forestry plantations are envisaged. In addition the afforestation of about 800 hectares of grasslands annually is also visualized by providing additional incentives in the form of food aid to attract labour from the surrounding villages.

The Asian Development Bank loan will finance a major community forestry development project covering villages in certain parts of the Catchment and outside. 0.8 hectares of land will be provided to each family for forestry and food crops and fuelwood as well as to stabilize

the ecological conditions of the village. In addition to small village plots the project also includes the reforestation of 10,000 hectares of degraded lands with fuelwood species.

In addition other Governments are planning out projects in the Upper Catchment. The Netherlands have an integrated rural development project for Nuwara Eliya, and the Canadian International Development Agency for the Lower Uva region.

Various subsidies are provided as incentives for soil conservation measures. This includes the Tea Rehabilitation and the New Planting Scheme under the Tea Commission, the Tobacco Subsidy Scheme and a scheme for Minor Crop planting. Voluntary participation for community and social forestry may also become a reality in the future.

The numerous projects to maintain watershed value may seem adequate, however, in the next few years fairly large acreages of tea lands will be replanted, but many areas of degraded tea will not be replanted with this crop, since it would be uneconomic to replant the more marginal areas. This means that in the future the large areas of marginal tea lands will become available for other uses, the nature of these uses will have an important influence on run-off and erosion in the Upper Mahaweli Catchment. Allowing old tea lands to revert to natural vegetation would be the satisfactory solution.

VI-2 THE WATER-QUALITY MONITORING WORK AND THE WATER-QUALITY CONTROL IN PEARL-RIVER

GuangDong, China

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Abstract

The Pearl-River is the largest river in GuangDong province, and it is also the largest river in South-China. In the past thirty years, since the people's republic of China has been found, as a consequence of rapidly improvement of industry and agriculture, promotion of urbanization, the waste-water and sewage coming from different sources are increasing seriously in recent years. Accordingly, the pollution of Pearl-River is one of the problems which we are facing.

This report presents the hydrologic features and current pollution problems and some water-quality control measures in Pearl-River watershed.

Hydrologic Feature and Current Pollution Situation

The major branches of Pear-River in GuangDong are namely : West-River, East-River and North-River. The total basin area of Pearl-River covers about 4.7% of the area of China, and in GuangDong province, has a basin area of 104,838 Km^2 covering about 45.2% of the total area of this province. The mean annual stream flow is 3,412 x $10^9 m^3$. It is more than one third that of Yountze-River and seven times that of Yellow-River.

Some hydrologic parameters of the branches are :

1) West-River : It is the largest branch of Pearl-River, and has a basin area about 77,717 Km^2, annual mean stream-flow 2,540 x $10^9 m^3$, about 74% of the Pearl-River.

2) North-River : Basin area about 42,135 Km^2, and an annual mean stream-flow of 661 x $10^9 m^3$, about 17% of the Pearl-River.

3) East-River : It has a watershed area 29,017 Km^2, an annual mean stream-flow 346.5 x $10^9 m^3$, it is about 9% of the Pearl-River.

All of the three branches are joined in the vicinity of Guangchow (a city of 3 million people), at which location, it is named the Guangchow section of Pearl-River and empties into the South-China sea.

The monitoring data from 1971 to 1978 show that, as a whole, the Pearl-River hasn't been polluted except for it's sections in the vicinity of cities and industry plants, and the water-quality of East-River is the best among the three branches. No water-borne diseases have been reported throughout the whole Pearl-River basin for recent decades. In West-River, the amount of incoming wastewater is 570 thousand tons per day, the major pollutants are organic materials, sulfides, phenol heavy metals, etc. In the North-River the amount of incoming wastewater is 410 thousand tons per day. The principle pollutants are heavy metals, phenol, arsenic, etc. In the East-River, the incoming wastewater is only 70,000 tons each day. The pollutants are : organic material, phenol, and arsenic. In the Guangchow section, the wastewater discharged amounts to 2.25 million tons each day. The pollutants are : petroleum, phenol and organic material. 1

The Water-quality Monitoring Work in Pearl-River Basin

Since 1975, we began to proceed with this work step by step. It consists of the following :

1) The establishment of a water-quality analysis lab. and sampling stations :

The water-quality monitoring net-work is composed of 62 sampling stations. They are distributed along the major branches of Pearl-River, that is West-River 13, North-River 18, East-River 12, Guangchow section 19. Most of these sampling stations are located in :

A) Industry concentrated area and urbanized area.

B) The drinking water resource of the large cities and rivers harvest area.

C) The major scenic spots for Sight-seeing.

D) The area which shows the hydrologic features which begin to change such as the joint point of the major branch, the entrance of the major irrigation area, the river mouth from where the river empties into the sea, etc. Not all of these sampling stations could be situated in the

lentic area or the end-point of the discharge pipe line. Normally, they must be placed in the mixing-zone down-stream of the pollution sources. If the river-width is more than 50 m, three sampling stations are set up, one at the left, right and middle of the river cross-section. If the depth of the sampling area is greater than 10 m, samples are taken from different layers.

2) Parameters & frequency of sampling :

According to the National water-quality Monitoring Regulation the basic parameters for each water sample are : pH, TSP, total hardness, DO, BOD, NH_4, N, NO_x, phenol, Cn, As, Hg, Cr, and bacterial concentration, etc. Generally, sampling and analysing is done 6-8 times annually and at least 2 times during periods of low-water, high-water, and normal water of the river.

3) Monitoring of water-quality accidents :

In addition to the normal monitoring program, the monitoring net-work also includes water pollution accident supervision. It is demanded to find out the kind of pollutants coming from accidental discharges, the concentration of pollutants, and the border of the impact area. The assessment report must be worked out as soon as possible and sent to the environment protection agency of the local or central government (according to the harmfulness of the accident).

In recent years, we have finished several investigation projects in the field of water-quality control of Pearl-River : i.e. The back-ground imformation of water-quality in Pearl-River. The evaluation of the water-quality in the polluted section (for example, Guangchow section). The survey of water-quality in the off-shore area of Pearl-River mouth, and it's impact on marine organisms, All of the results of those studies are very helpful .

Some Measures of Control and Management

In China, the Environment protection agency implement the water-quality protection program in conjunction with the Department of water conservation. The Pearl-River water conservancy has established a water-resource protection office recently. In accordance with the Environment Protection Law of The People's Republic of China (Adopted on 13 Sept.1979) and also as a result of water-quality monitoring, we are now taking several measures to prevent and reduce the pollution of Pearl-River :e e

1) Promulgation of an Act for water-quality Management in East-River watershed :

Though the pollution of East-River is very slight and the water-quality still good. The drinking-water of Guangchow and Hongkong comes from the East-River. Therefore, it is urgent to protect the water-quality of these regions. The People's gov't of GuangDong Province promulgated

the Act of water-quality management in East-River watershed in Jan. 1981. The Act regulates to set up a special section at local gov't in charge of the management of water-quality in the East-River basin. It requires water-quality of this river to be kept in compliance with the sanitary criterial of surface water set down by the state. And from the date of publication of the act, all of the institutions and factories located along the East-River must submit an application to the Environment protection Agency for approval. It is strictly prohibited to discharge poisonous and harmful waste water by way of seepage pits, crevics, lava holes or dilution methods. All of the cities and towns of which population are over 10,000 must build a sewage treatment in a planned way. Destroying the forest in river resource and river bank of the East-River are strictly forbidden. These are the important and primary measures to manage the Pearl-River watershed.

2) The economical factors for water-quality control program in Pearl-River :

A penalty regulation was promulgated in Jan. 1981 by the People's gov't of GuangDong province, the major points are :

A) A fine shall be charged when wastewater discharged from enterprises and institutions goes beyond the limits of the standard laid down by the state. The rate is decided according to the volume and the concentration of wastewater effluent released.

B) The effluent released by factories and institutions are divided into four ranks according to harmfullness. 1) radioactive waste-water 2) Wastewater contains Hg, Pb, Cr, Cd. 3) Wastewater contains : sulphide, phenol, cyanide, phosphorous, organics, oil, Cu and its compounds, nitrobenzene, suspension matter COD,BOD. 4) The effluents of hospital.

The max. rate is for the 1) rank and min. rate is for the 4) rank. The rate also increases according to the concentration of the effluent.

And then, in order to improve the construction of wastewater treatment equipment, some additional regulations are specified.

A) Those factories discharge wastewater directly without operating the installed water treatment equipment, would be charged more than 30% additional fine.

B) All the factories and institutions which haven't set up their water-treatment in the target date regulated by the E.P.C. would be charged more than 30% additional fine.

C) If the new construction of factories and institutions haven't designed and installed their wastewater treatment plants, they would be charged more than 50% additional fine.

D) The fining rate increases 30% each year after the publication of the regulations for those units which show no improvement. All of the factories and institutions stop payment when their discharge meet the national standard.

90% of the income collected from this fining regulation is used for water-quality control and the another 10% is use for water-quality monitoring.

This penalty regulation is very effective as an economic way for watershed management.

3) To establish local standards for pollutant discharge :

The hydrologic features are very different in each section of river, and the self-purification and assimilation capacity of rivers are varied. So we have to work out different standard for each area based on the different conditions of different section of river. The local standards are based upon the general standards of the state and as a complement of the latter. This is the plan which we begin to study.

Future Project

1) In the coming years, we shall endeavour to carry out the decided measures of the water-quality control program, first of all, to keep the water-quality of East-River.

2) New water-quality sampling stations and analysis laboratories will be equipped and constructed in order to improve the net-work.

3) In order to make long-term progress and yearly plans for the water-quality control program in Pearl-River, we are going to organize an interdepartmental team to work with relevant departments, such as Agriculture, transportation, mining etc.

VI-3 COUNTRY REPORT ON WATERSHED CONDITION
by
Rajendra B. Shrestha, NEPAL

Nepal, as a mountainous kingdom stretching along the slopes of the Himalayas and lying between the Tibatian plateau of China on the north and Indian plain on the south, has an area of about 150,000 sq. kilometers. The country's topography ranges from about 100 meters above Mean Sea Level on the Tarai belt to over 8,000 meters on the High Himalayas within a breadth of 150 kilometers. Contrasting altitudinal levels of high mountains and peaks on the northern side with a fair share of low levels of valleys and plains on the middle and southern side present rugged relief with a wide variety of terrains.

FAO (Rome), is one of its recent publications on watershed condition of Nepal,[1/] reports that 51 percent of the kingdom which is represented by southern reliefless (Tarai belt, and "pristine" snowy northern Himalayas) is in excellent condition. Much of the less disturbed middle mountains and portions of transitional zone having smaller sedimentation problems, make up 35 percent land of good condition. Eastern Siwaliks, Central Middle Mountains and some portions of transitional zone which are the places of deforestation, frequent landslides and high population density, constitute the areas of fair condition and share 11% of the country. Sixteen 'Hot spots' and small areas of Mustang, Dang and Rapti Valleys which represent 3 percent (or more precisely 2%) of the country, is in poor or very poor condition.

Relatively small percentage of poor or very poor condition class need not mean that there is a minor watershed management problem in the Kingdom. 1% of Nepal is about 1,410 Sq. Kilometers or approximately 200,000 farms. So one should realize that the 3% figure for poor condition lands does constitute a large area of serious watershed problem. Development of badland topography in Dang valley (west Nepal); occurence of desertification in Mustang valley (Central west Nepal), several patches of wastelands or abandoned lands in lower velleys of Dolpo (near Seldang), and loss of vegetation cover in the Middle Mountain zone including much of Siwalik and part of Kathmandu catchment, exemplify the worst watershed condition existing in Nepal. Even Tarai belt and upper High Himalayas which are said to be in very good condition because of their Hydrological stability, low population pressure (in terms of people per hectare of land) and low relief (in Tarai) are afflicted with wind erosion, soil breakage, floodings and siltation.

1/ NEPAL : A RECONNAISSANCE INVENTORY OF THE MAJOR ECOLOGICAL LAND UNITS AND THERE WATERSHED CONDITION - SUMMARY REPORT, Technical Report, UNDP/FAO, Rome, 1980.

Reasons behind such bad watershed condition are obvious. Widespread deforestation for fuelwood, extreme grazing by domesticated animals s for fodder, extention of cultivation onto unsuitable marginal steep slopes (owing to the absence of cultivable lands on the plains and off-farm employment opportunities), large scale migration from hills to plains in quest for better living conditions, and traditional agriculture practices coupled with faulty irrigation are some of the major activities associated with the evidence of poor watershed condition in Nepal. The root causes of the mishappenings cited are : poverty, ignorance, greed, lack of appropriate technology and desperate need to pursue economic development at whatever cost. These causes, in turn, stem diversely from the problems of rapid population growth (rate : 2.52% per year) and scanty natural resources. Above all, the deteriorated condition of the country's watersheds is by and large, attributable to Nepal's location in the geologically sensitive Himalayan zone itself. The Hindukush Himalayan range of which Nepal is a part, is the world's youngest, tallest and steepest mountains with the most fragile and erodible sedimentary rocks and highest concentrated rainfall.

Based on the knowledge of growing population pressure, decreasing forest coverage at the rate of 25% per decade, and declining production rate (5.7%), it may be observed that watershed condition of Nepal is on negative trend and may reach a point of no return by 2,000 A.D., if the trend is not reversed. This bleak picture of the Nepalese watershed itself remained bleak until Mr. Erik Eckholm, an American scientist came out with a desperately alarming picture of Nepal's Environmental crisis in 1970s (ref : 'Loosing Ground'/ Refugees from Sangri la). It caught the attention of development experts of various levels at home and abroad and called for immediate actions through an integrated approach.

Realizing this serious situation, attempts have been made by HMG/Nepal through various national and international agencies to rehabilitate the exposed watersheds according to the size of the problems and degree of urgency. Some of the notable efforts are :

a. Extensive reafforestation on 10,000 sq. kilometers of deforested lands along the middle mountain zone,

b. Development of grasslands in northern hills with grasses palatable to grazing animals and other species adapted to disturbed conditions, to meet the fodder need of 14 million livestocks, and at the same time to prevent the loss of soil through sheet erosion,

c. Plantation of fruit trees and/or cash crops in the areas which are neither ecologically suited to cultivation nor population pressure allows them to return to forest (eg. apple farmings in Helambu, Jumla etc.), for the coupling of environmental protection with the economic return,

d. Extention of formal as well as non-formal education at various levels (schools, campuses etc.) to stimulate awareness over the nation's ecological problems among people, through publications, training, audio-visual programmes, etc.,

e. Integrated Watershed Management in Fewa lake, Tinau Khola, Bagmati and several other smaller catchments, to check the loss of precious top soils (loss rate : 20-60 tons/ha./yr) through the construction of check dams, retaining walls, terracing and diversion channels,

f. National parks and wild life development to preserve a native genepool (establishment of 4 National Parks : Rara - west , Langtang - midwest , Chitwan - middle and Sagarmatha - east),

g. Implementation of proper land-use policies and tourist regulations.

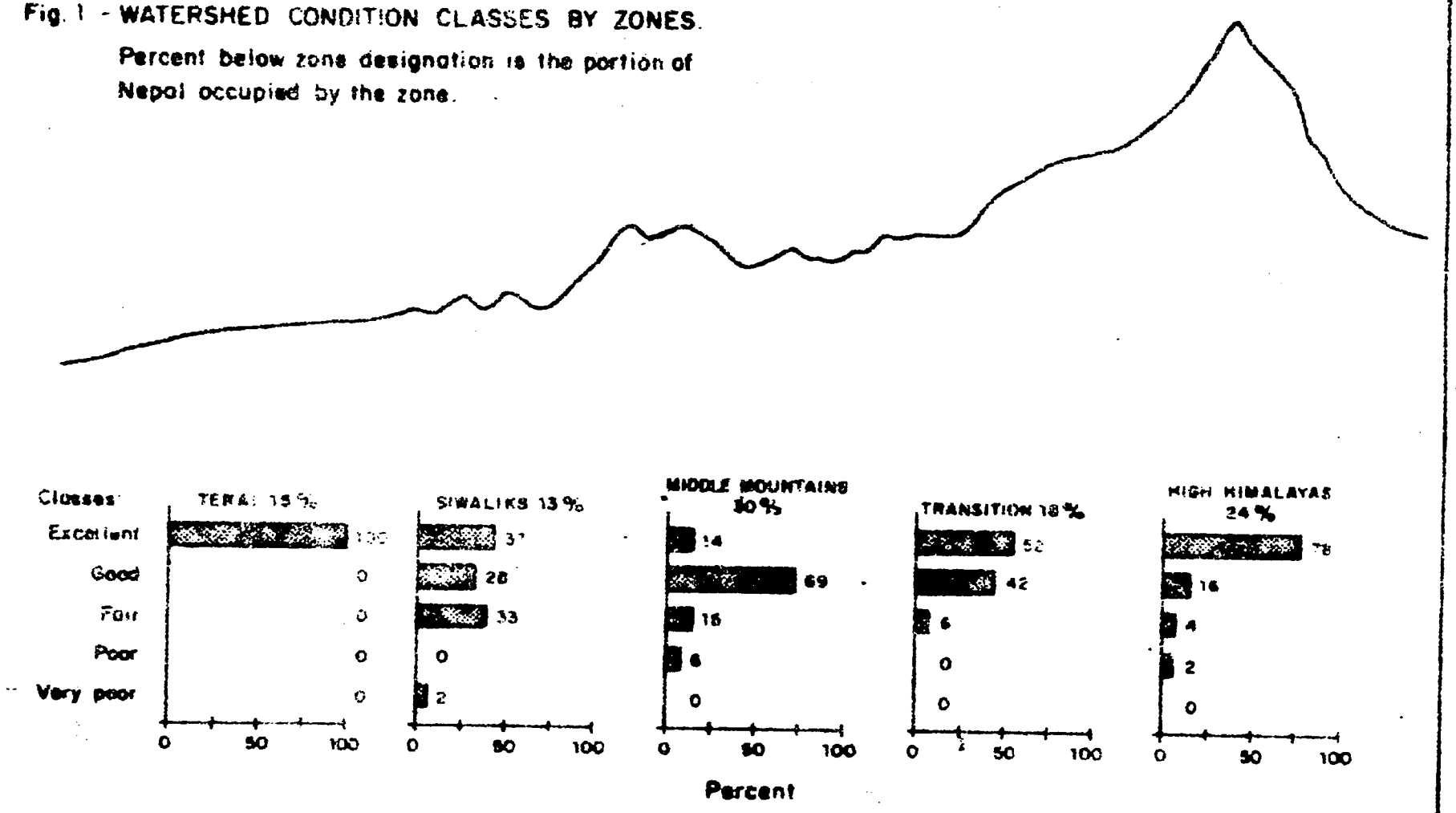
Seventeen governmental/non-governmental agencies and 700 affiliated foreign missions are, someway or other, involved in these conservation aspects of development.

Uplift of the socio-economic standard of the people through the mitigation of the environmental damages (that economy can cause) without slowing the pace of economic progress has been and will be the basic objective of Nepal's conservation efforts. And as it should be, the country's sixty Five Year Plan (1980 - 1985) has given much emphasis to such efforts as in previous plans. Nepal maintains much faith on the conservation of environment beforehand than on its restoration after degradation. After all, prevention of environmental problems is often much cheaper than cure.

thank you.

Fig. 1 - WATERSHED CONDITION CLASSES BY ZONES.

Percent below zone designation is the portion of Nepal occupied by the zone.



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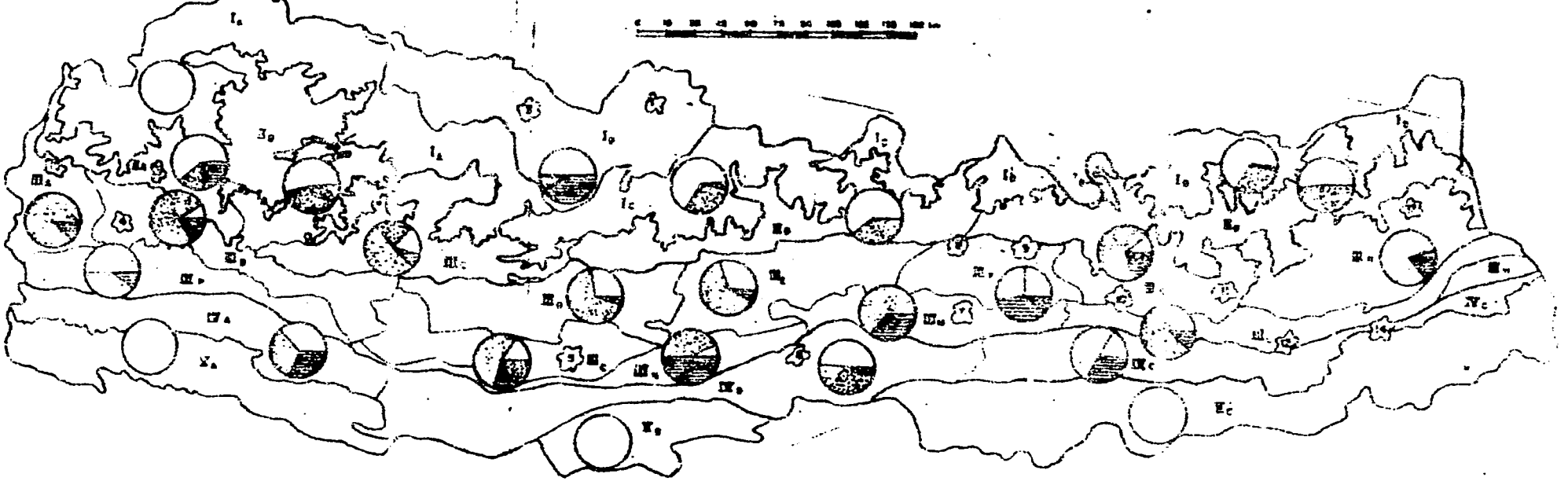
WATERSHED CONDITION CLASSES AND HOT SPOTS BY ECOLOGICAL REGION

Fig. 2



HOT SPOTS

1 - UPPER MUSTANG VALLEY
2 - GOLPO LOWER VALLEY
3 - [illegible] VALLEY SIDE SLOPES
4 - [illegible] SLOPES AND [illegible] VALLEY
5 - [illegible] LOWER [illegible]
6 - DANG VALLEY TOE SLOPES
7 - [illegible] SOUTH OF KATHMANDU
8 - TRISULI FAN AND VALLEY SLOPES
9 - UPPER [illegible]
10 - SOUTH FACING SUN [illegible] SLOPES
11 - [illegible]
12 - SOUTH SLOPE OF [illegible]
13 - [illegible]
14 - [illegible] OF SUN [illegible]
15 - CHARCHULA - UPPER CHAMKA
16 - THE AREAS IN THE [illegible] WHOLE MOUNTAIN AND TRANSITION ZONES CAN BE [illegible] AS "GENERALIZED" HOTSPOT

1 - EXCELLENT
2 - GOOD
3 - FAIR
4 - [illegible]
5 - POOR

N

VI- 4 CASE STUDY REPORT - MALAYSIA

FOREST HYDROLOGY STUDIES IN THE HILL FOREST

BY

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CASE STUDY REPORT - MALAYSIA

FOREST HYDROLOGY STUDIES IN THE HILL FORESTS

1. INTRODUCTION

1.1 Malaysia has a total land area of 329,750 km^2 of which Peninsular Malaysia accounts for 131,590 km^2. Malaysia is generally hilly to montainous with steep slopes even on low hills. Low lands usually occur as relatively narrow river valleys or coastal plains.

1.2 The natural vegetation of Malaysia is the Tropical Rain Forest. In 1979, tropical rain forest occupied 68 % of Malaysia's total land area, mainly in the hills and mountains. Most of the lowland forests have been converted to agricultural use.

1.3 At present, forestry activities in Peninsular Malaysia are mainly confined to the hilly regions, especially in the hill dipterocarp forests. Exploitative selective logging practices have created a number of hydrological problems such as increased slope erosion, increased river sedimentation and decreased water quality.

1.4 Due to these problems the Forest Research Institute, Kepong, Malaysia, has set up a Forest Hydrology section to study the effect of logging on the environment particularly in the hill forests in Peninsular Malaysia.

2. Purpose and objective

2.1 The purpose of this project is to highlight the hydrological consequences of selective logging utilizing different mechanized logging systems in the hill forest. The objective is to study the effect of different methods of logging, viz. cable logging and tractor/san-tai-wong logging methods on :-

(i) stream flow quantities (low flows, flood flows, monthly and annual yields),
(ii) physical, chemical and biological water quality,
(iii) soil erosion and sediment yields, and
(iv) soil water regimes.

3. Method of study

3.1 The study was established on two contrasting types of terrain derived from different parent rocks. (Fig. 1)

3.1.1 Jengka Basin

The Jengka experimental basin was established on forested hill country underlain by sedimentary rocks. It consists of three catchments that are adjacent to each other and cover a total area

of about 56.5 ha (catchment 1 - 28.4 ha, catchment 2 - 25.3 ha and catchment 3 - 2.8 ha). Slopes average about 25° and covered by primary forest. Catchment I will be logged by cable logging system while Catchment 2 by the traditional tractor/santai-wong method. Catchment 3 will not be logged and remain as control. (Reference Malaya 1: 63,360 sheet 70. Grid ref. 141513)

3.1.2 Bukit Berembun Basin

The Bukit Berembun experimental basin was established on granitic - derived terrain and also covered by primary forest. The basin consists of three catchments which cover a total area of about 46.1 ha (catchment 1 - 12.7 ha, catchment 2 - 4.2 ha and catchment 3 - 29.2 ha). Two catchments, i.e catchment 1 and 3 will be logged by the tractor/santai-wong method. One catchment will employ carefully designed roads, landing areas and protection zones under close supervision of harvesting operations. The other catchment will be logged without any restriction. Catchment 2 will not be logged and remain as a control. (Reference Malaya 1 : 63,360 sheet no.103. Grid ref. 997356).

4. Duration of study

4.1 The experiment involves four phases :-

(i) Phase 1 : Experimental catchment selection : Establishment of stream flow weirs, sediment traps, instrumentation and initial soil and vegetation survey (May 1978 - Dec.1979)

(ii) Phase 2 : Pre-logging calibration : Measurement of stream flow, water quality, rainfall, weather climate and sediment yield. (Jan. 1980 - Dec. 1981)

(iii) Phase 3 : Logging : At each experimental basin, two catchments are to be logged and the third will be left undisturbed and act as a control. (Jan. 1982 - Dec. 1982)

(iv) Phase 4 : Post logging : Measurement of hydrological parameters to be continued in all catchments. (Jan. 1983 - Dec. 1985)

5. Instrumentation

5.1 Each catchment is equipped with a 120 degree V.- notch weir, a sediment trap and a stilling well instrumented with an automatic water level recorder (Stevens Type F water level recorder). Input

from precipitation is measured by automatic and manual rain gauges. Three OTA tipping bucket rain gauges equipped with Ota Keiki recorders plus 8 manual gauges have been installed at both experimental basins.

5.2 A small climatological station equipped with maximum, minimum, wet and dry bulb thermometers, anemometer, evaporation pan, sunshine recorder, and soil thermometers was established at each experimental basin.

6. Data collection

6.1 The data collection programme for both experimental basins are as follows :

(i) weekly servicing of the water level recorder , checking that they are properly calibrated for stage height and changing of charts,

(ii) weekly servicing of automatic and manual rain gauges, checking, calibration and changing charts.

(iii) daily readings of temperature, windrun, thermometers (wet, dry, maximum, minimum, soil) and other climate recordings,

(iv) manual collection of 5 litre water samples at the weir outflows for water quality analyses. Sampling of lowflows and highflows is essential to characterise the physical, chemical and biological quality of stream flows,

(v) periodic sampling and measurement of sediment accumulated in the sediment traps, will be carried out once every 3 to 6 months. At each measurement time, the wet volume and wet weight of sediments and organic materials accumulated in the traps will be recorded and a 10-kg sample will be taken for particle-size analyses and organic/mineral ratio determination.

7. Preliminary result

7.1 At this time few conclusions may be made from the data so far collected. River flow and rainfall data are being processed by computer but have not reached the analyses phase yet.

7.2 Rainfall

Catchment rainfall totals were calculated using the Thiessen Polygon method based on the distribution of manually 20cm diameter gauges. Monthly catchment rainfall totals for 1979 and 1980 are presented in table 1. Fig 2 shows the monthly rainfall pattern in the experimental basins.

7.3 Climate data

Tables 2 and 3 summarise the climate data for the Jengka experimental basin and Bukit Berembun experimental basin studies respectively.

8. Conclusion

Due to the rapid land development and exploitative nature of logging in Peninsular Malaysia and the lack of data available on the hydrological effects of land development, priority should be given to basin type studies. These studies provide data and hence guidelines for the improvement of watershed management techniques.

FIG. 1 EXPERIMENTAL BASIN PROJECT.

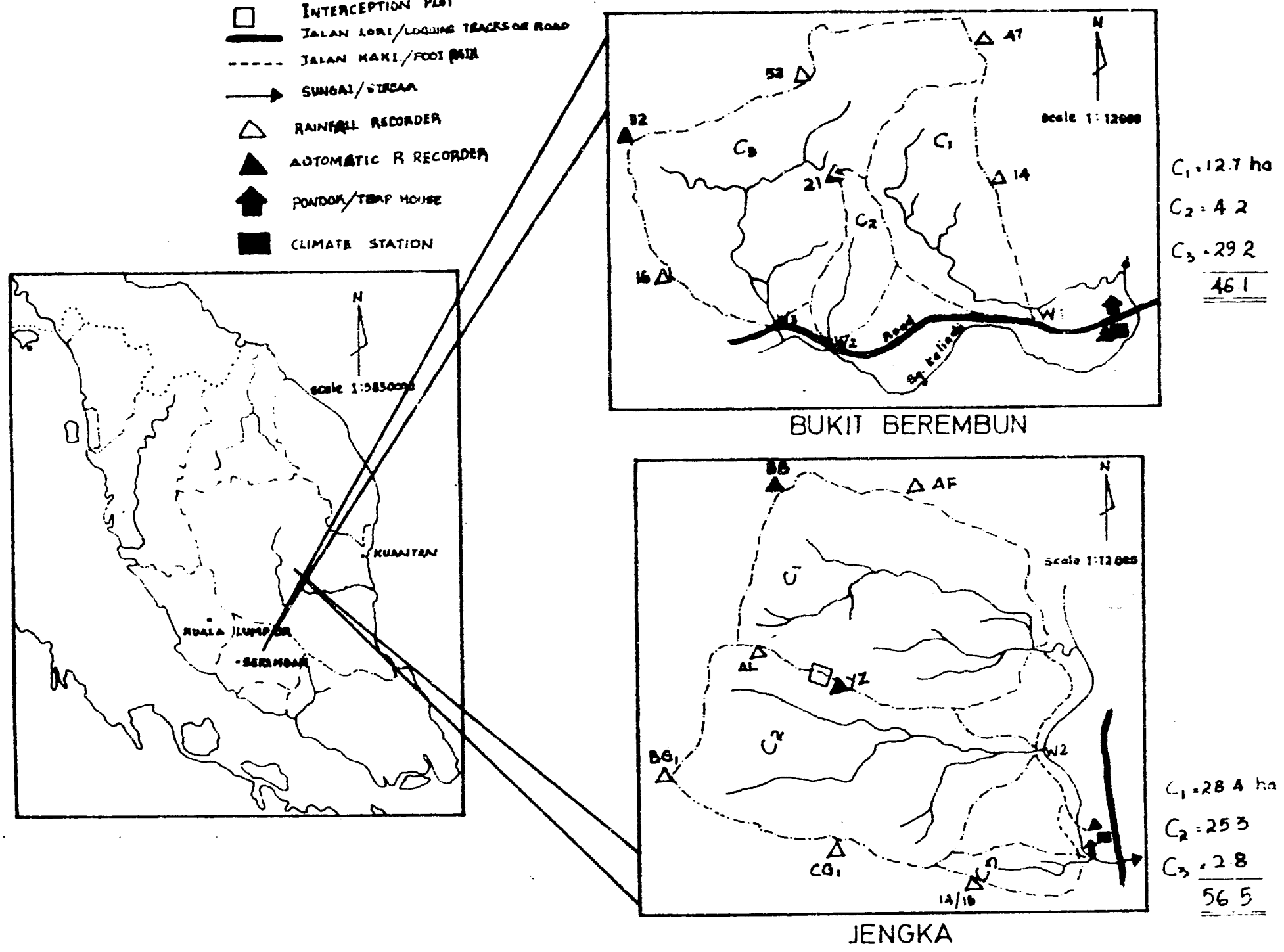


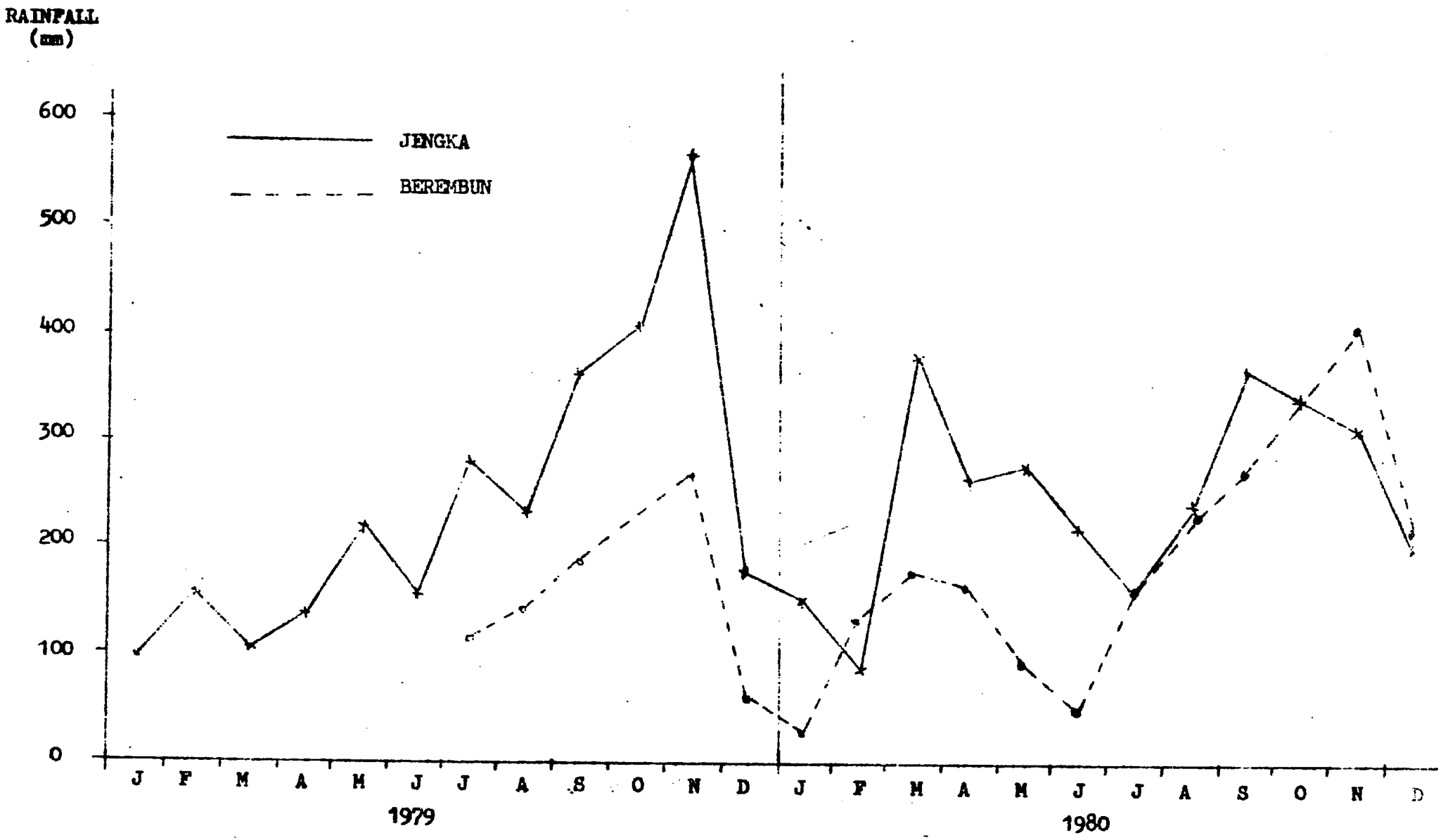
TABLE 1 . CATCHMENT RAINFALL TOTALS FOR JENGKA AND BUKIT BEREMBUN EXPERIMENTAL BASIN

(mm)

YEAR 1980

MONTH	JENGKA CATCHMENT			TOTAL	BUKIT BEREMBUN CATCHMENT			TOTAL
	C_1	C_2	C_3		C_1	C_2	C_3	
JAN	64.2	79.0	5.9	149.1	7.3	2.5	17.6	27.4
FEB	36.2	44.9	3.0	84.1	36.4	12.9	85.8	135.1
MAR	158.2	200.9	14.0	373.1	42.8	17.2	117.2	177.2
APR	104.2	147.4	11.5	263.1	42.4	14.5	103.4	160.3
MAY	122.6	145.6	10.0	278.2	23.8	9.0	60.3	93.1
JUN	100.4	106.9	8.7	216.0	12.0	4.3	33.4	49.7
JUL	71.9	83.5	6.0	161.4	44.2	17.2	101.2	162.6
AUG	72.9	153.7	11.9	238.5	48.0	27.0	149.8	225.4
SEP	172.4	187.4	12.2	371.8	63.9	29.1	176.4	269.4
OCT	154.7	171.1	13.7	339.5	54.4	21.2	144.4	220.0
NOV	151.8	149.0	11.1	311.9	84.0	34.4	293.5	411.9
DEC	88.0	104.9	7.4	200.3	43.6	19.9	153.5	217.0
TOTAL	1,297.3	1,574.3	115.4	2,987.0	503.4	209.2	1,436.5	2,149.1
1979	1,190.0	1,473.4	111.4	2,816.8				

FIG. 2. MONTHLY RAINFALL TOTALS



YEAR 1980

TABLE 2 : CLIMATIC DATA FOR JENGKA EXPERIMENTAL BASIN

MONTH	Temperature (°C) 0730 D	0730 W	1330 D	1330 W	1800 D	1800 W	Mean D	Mean W	Max	Min	Rain-fall (mm)*	Wind (km/day)	Sunshine (hrs) Month	Sunshine (hrs) Day	Evaporation (mm) Month	Evaporation (mm) Day
JAN	20.8	20.5	29.9	28.1	-	-	25.4	24.3	30.9	-	114.0	21.8	181.9	5.9	98.7	3.2
FEB	20.7	20.1	30.3	25.1	27.0	24.9	26.0	23.4	32.7	-	119.0	25.2	139.7	5.2	93.1	3.7
MAR	22.3	21.7	31.1	26.3	25.7	25.0	26.4	24.3	31.9	-	236.0	21.3	195.0	6.3	120.3	3.9
APR	23.3	22.6	31.4	25.9	27.5	25.7	27.6	25.1	32.8	-	194.5	18.4	136.0	4.6	99.4	3.3
MAY	24.0	22.8	31.9	27.1	28.1	26.4	28.0	25.4	33.2	-	156.5	19.6	185.3	6.0	106.8	3.4
JUN	23.3	22.8	31.5	29.4	27.4	27.0	27.6	26.4	32.0	-	128.0	16.0	144.1	4.8	84.0	3.0
JUL	23.4	23.0	31.1	28.2	27.3	26.1	27.2	25.8	32.5	-	102.0	17.6	143.6	4.6	91.2	3.2
AUG	22.9	22.6	30.2	26.2	27.0	25.4	26.6	24.7	31.1	-	187.5	19.0	121.6	3.9	95.7	3.2
SEP	23.3	22.5	30.4	26.5	27.2	26.2	27.0	25.2	31.4	21.4	271.6	17.9	141.7	4.7	74.6	2.5
OCT	23.7	23.0	30.8	26.6	26.8	25.4	27.1	25.0	31.1	22.2	208.3	18.6	156.0	5.0	80.4	3.2
NOV	23.5	23.0	29.7	26.6	25.9	24.8	26.4	24.8	30.8	22.0	159.0	15.7	118.7	6.3	74.6	2.5
DEC	22.7	22.1	28.3	25.4	25.2	24.1	25.4	23.8	29.0	21.1	191.0	13.0	69.4	2.2	49.9	1.7
TOTAL	275.1	267.0	360.6	322.6	295.1	281.0	320.7	298.2	380.3	-	1966.9	224.3	1733.0	-	1068.7	-
MEAN	22.9	22.5	28.0	26.9	26.8	25.0	26.7	24.9	31.7	-	163.9	18.7	144.4	5.0	89.0	3.0

* Rainfall recorded at climate station.

TABLE 3 : CLIMATIC DATA FOR BKT. BEREMBUN EXPERIMENTAL BASIN

YEAR 1980

MONTH	Temperature (°C) 0730 D	0730 W	1330 D	1330 W	1800 D	1800 W	Mean D	Mean W	Max	Min	Rain-fall (mm)*	Wind (km/day)	Sunshine (hrs) Month	Sunshine (hrs) Day	Evaporation Month	Evaporation Day
JAN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FEB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
APR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
JUN	22.8	22.6	31.0	28.0	26.9	26.2	26.9	25.0	32.7	-	-	17.8	-	-	93.0	3.1
JUL	22.0	21.8	30.7	26.0	27.1	25.9	26.9	24.5	32.8	20.3	155.0	16.8	-	-	89.9	2.9
AUG	21.5	21.1	29.0	25.8	26.7	25.2	26.1	23.8	31.9	-	-	15.4	137.4	4.4	99.2	3.2
SEP	22.4	21.8	30.9	26.2	26.5	25.3	26.6	24.4	32.3	21.3	223.0	13.0	163.1	5.4	93.0	3.1
OCT	22.8	22/2	29.6	26.6	27.0	25.7	27.2	24.8	31.9	20.1	202.5	15.8	128.3	4.6	102.3	3.3
NOV	22.7	21.7	28.9	26.5	26.2	24.8	25.9	24.3	31.3	20.3	256.9	10.5	115.6	3.8	84.0	2.8
DEC	22.2	21.9	28.7	25.1	26.1	24.5	25.7	23.8	30.6	21.8	126.5	21.0	114.8	3.7	108.5	3.5

* Rainfall recorded at climate station.

VI-5 SOME PROBLEMS OF WATERSHED LANDS IN INDONESIA

by : Sigit E. Pratignyo

National Biological Institute, Indonesia

Introduction

Indonesia has wide areas, from Sumatra in the west to Irian Jaya in the east, made up of thousands of Islands. There are several types of climates from humid to arid. The western areas such as Sumatra, West Java and a part of Kalimantan have humid climates while easter the climate becomes arid especially in Lesser Sunda islands. Beside this, Indonesia has many tribes with their different cultures.

Indonesia has more than 137 million people but 60% of them live in Java, inhabiting only 7% of Indonesia's areas so the big islands such as Sumatra, Kalimantan, Sulawesi and Irian Jaya could be mentioned as empty islands.

This situation makes the problems of watershed lands in Indonesia different at each place.

Some Problems of Watershed Lands in Indonesia

In Java where the greater part of Indonesian people live, activities of human beings are more developed. Hills and mountains are farmed with crops. Although the farmers practice terracing on their farm, erosion still happens. Furthermore, at some places in East Java where the farmers plant their crops only in the rainly season,terracing is not intensively practiced. The climate there is semi arid. Rivers are dry in the dry season and flooded in the rainy season with it's brown-red water showing the heaviness of erosion. Almost every river in Java always floods in the rainy season.

In Kalimantan, people practice primitive cultivation. They usually clear forest, then burn all parts of trees such as woods branches and leaves, and then they plant rice seed. They wait until harvest time and after they harvest their rice, they again plant rice seeds on that land. They do that twice or three times until the soil become unfertile ; then they leave the area and look for another forest to clear for another farm. And, as they leave, alang-alang (Imperata cylindrica) grows rapidly on those lands to make alang-alang field. Another problem in Kalimantan is caused by timber companies that clear forests for commercial purpose. Although government rules prohibit cutting of trees less than 45 centimeters in diameter and orders them to make plantations of industrial plants such as rubber, coffee and cocao, etc., controlling these activities is very difficult. So forest clearance in Kalimantan has been done very effectively. Unfortunately, the organic layer on the soil surfaces there is very thin and soil consistency generally low, so if the forest is cleared, the heavy rains there cause substantial erosion.

Problem-solving in Indonesia

Reforestation is a general program of government to solve the problems of watershed lands in Indonesia. But it takes a long period to see improvements. Short period programs are : more intensive terracing, building dams, and regulating stream flow in the rivers.

Conclusion

Due to the wideness of Indonesia's areas, variation of it's conditions, and developing of Indonesian's life, problems of watershed lands are very important and require attention.

VI-6 CASE STUDY COUNTRY REPORT

"Watershed Resources Management
and Environmental Monitoring in
Humid and Tropical Ecosystems"

29 May 1981

THAI PARTICIPANTS

1. Introduction

Thailand has extensive areas of mountainous wildlands that provide some of the Kingdom's most valuable natural resources. Water from these wildland watersheds is a major resource. Forests and other kinds of vegetation on these lands should be managed with the primary objective of protecting the soil, producing sufficient amount of water for beneficial uses with a minimum of sediment as well as forest products and other resources.

Realizing the importance of water yield and sediment control to meet increasing demands of water for domestic, agricultural and industrial purposes, there is an urgent need to focus our attention upon integrated watershed management planning. Emphasis should be given to some factors such as natural forest cover, shifting cultivation, and other uses of mountain lands that affect water yield and cause soil erosion. Erosion should be studied to develop measures for efficient practices of watershed management to meet the optimum level of natural resources utilization on a proper sustained yield basis.

Watershed management as a comprehensive nation-wide program has yet to be developed in Thailand. The present practice is that either operating agencies have more or less integrated watershed management projects in small areas or take part in inter-agency projects in other areas. In the latter, a leading agency will function as coordinator with other agencies participating in aspects of concern relative to the project.

This paper places emphasis on identifying agencies involved in one way or the other of various aspects in watershed management activities in northern Thailand. A case study will be provided to illustrate the common practice in inter-agency projects where problems in coordination and implementation will be analysed and identified as a basis for general discussion.

2. Organizations Involved

Various government agencies and institutes involved in implementation projects and researches. The major agencies and institutes are :

2.1 Land Development Department (LDD)

To resolve the problems of land development in Thailand, the Department of Land Development, Ministry of Agriculture and Cooperatives, has many functions to perform. One of its main tasks is to improve water quantity and quality through the best use of lands. Work in watershed resources management is still in the initial stage because of many constraints in administration, supporting authority, technical-know-how, departmental policy and political resistance. Most of the Department works are conducted through Watershed Conservation Section which belongs to the Division of Soil and Water Conservation and Management.

The Land Development Department has established five projects under the watershed resource management programs since 1968. Because of the lack of funds, the Watershed Conservation Section has emphasized only two main projects, i.e. (1) study and investigation of stream discharge, sediment transport and nutrient loss of watershed areas throughout the country (2) study and evaluation of hydrological characteristics on experimental basins.

The Soil and Water Conservation and Management Division of LDD has set up many Land Development Centres in the North. Their works in general include mobile unit for soil and water conservation, facilities construction, soil improvement, plant material, experimentation, demonstration and extension. Their working areas are mostly on gentle slopes or rolling lands. The Thai Australian World Bank Land Development Project (TAWLD) working in seven provinces of the upper north typifies its working area as "the low and middle terrace zone of northern Thailand". The work includes using heavy equipment for clearing the land, building narrow based terraces and ploughing, followed by land management advisory in cropping system. In addition, the Division has 10 Royal Land Development Projects in the north in coordination with the King's Project described under Section 3.

2.2 Royal Irrigation Department (RID)

The Royal Irrigation Department, Ministry of Agriculture and Cooperatives, has major responsibility for Thailand's water resource development including all of the major irrigation development. Water conservation, irrigation, drainage, land reclamation, flood control, and inland navigation are included in the Department's water resource development strategies for multiple purpose use of water resources in each watershed area.

2.3 Department of Public Welfare

The Department of Public Welfare, Ministry of Interior, estimates that at the present time there are about 500,000 hill-tribe people who live in the mountains of Northern Thailand. They practice a slash and burn type agriculture in the watershed areas for producing subsistence and cash crops. These practices result in losses of top soil, nutrients, and sustained yield of forest products as well as cause sedimentation and flooding in downstream areas. To redirect these activities, the government has developed special programs and subsidized for hill-tribes. Many new practices have been stipulated such as conservation farming, permanent agricultural land allocation, etc. to increase the income and improve the standard of living for these hill - tribes in Zonal Development Areas. Such projects will be in line with the National Economic and Social Development Plan and will be integrated through agricultural production, marketing, and supporting services such as fertilizer, seed, livestock, insecticides and agricultural credits. Also, the Department is setting up Hilltribe Farmer Groups to form the basis for later establishment of Agricultural Cooperative.

2.4 Electricity Generating Authority of Thailand (EGAT)

The Electricity Generating Authority of Thailand, Office of Prime Minister, has stated that consideration of environmental aspect for natural resource development projects are as important as engineering aspects. The Environmental Division of the Public Communications Department has the responsibility for all environmental and ecological studies of power generating expansion plans such as hydroelectric projects. The division has also been assigned to carry out environmental impact assessments and recommend mitigative measures for EGAT's projects. Some EGAT hydroelectric projects for multipurpose use of water resource are located in the highland watershed areas in the north.

2.5 Department of Mineral Resources (DMR)

DMR's responsibilities in watershed areas are to issue permits for mining operations and to control and regulate implementation of these operations. An environmental unit has recently been set up to promote environmental protection during and after mining.

2.6 Royal Forest Department (RFD)

RFD has the major responsibility among Thai agencies for planning, research, management, and reforestation on forested lands as well as enforcement of regulation that pertain to watershed activities. The Department activities are administered by the Watershed Management Division. Three sections are mainly involved in northern Thailand. The Royal Watershed Development Section maintains 35 watershed units in the 7 provinces in the North and deals mainly with hill tribes and highlands in watershed protection, reforestation, agricultural land use and settlement. The Section's head office is in Chiang Mai. The second section is the Pilot Watershed and Demonstration Section to which the Mae Sa Project is attached, (Figure 1). The third section is Watershed Rehabilitation which has 11 units in Chiang Mai with its head office in Bangkok. This last Section also deals with people other than the hill tribes and its main task is reforestation.

At present, the highland watersheds of northern Thailand are mostly under the care or management of the Royal Watershed Development Section. The Pilot Watershed and Demonstration Section, which at present consists of the Mae Sa Project, has the functions of demonstration, training and provision, technical information and expertise to the Royal Watershed Development Section.

2.7 National Environment Board and office of the National Environment Board

The National Environment Board (NEB) is responsible for implementation of the National Environmental Act of 1975 including policy direction, adoption of regulations and guidelines, approval of environmental management plans, and coordination of activities among government agencies, state enterprises and the private sector. NEB has entrusted the Office of the National Environment Board (ONEB) with day-to-day

operations and submission of recommendations to the Board for further proceedings. The section of Natural and Water Resources, Environmental Policy and Planning Division, is responsible for watershed management coordination. OEEP has authority to require environmental impact evaluation of certain types of projects that could degrade watersheds, such as water projects. OEEP follows through on such projects to ensure that the evaluation process is fulfilled and that environmental management plans are implemented by responsible entities.

2.3 Department of Agricultural Extension (DOAE)

The Department of Agricultural Extension, Ministry of Agriculture and Cooperatives, is responsible for rendering agricultural extension services throughout the country, including the highland watershed areas. On the highland areas, the Department intends to :

a. promote food crops primarily for sufficient home consumption,
b. introduce high - value crops such as coffee, flowers, peach, pear, apricot , strawberry and vegetable to substitute for illegal crops,
c. reduce shifting cultivation on the watershed areas, and
d. encourage agricultural production improvement through updated technology.

2.9 Universities

Major contribution is in research on various aspects pertaining to watershed resources management. The current Universities actively involved are Khon Kaen University, Chiangmai University and Maejo Agricultural Institute of Technology.

3. Inter - Agency Projects

3.1 Highland Agriculture Project

The Hihgland Agriculture Project is conducted by technicians from various universities and government agencies experienced in both technology and field practices. These technicians and agencies cooperate under Highland Agriculture Research Cooperation Committee. The problems growing of illegal crops. The overall project goals are to (i) apply modern agriculture techniques on suitable land, and (ii) replace illegal crops with cash crops that provide higher yeild and profits. Distribution of the results of research tasks and marketing-insurance to farmers is also to be provided by the project.

To meet these project goals, the following objectives have been established

1. Acceptance by farmers of appropriate cash crops that are suited to climatic and watershed conditions.

2. Adoption and implementation of agricultural practices that protect watershed values.

3. Development of guidelines for classifying watershed as to resource management and utilization.

4. Distribution of the results of demonstration and promotion activities to farmers and other land managers.

5. Provision of market places and marketing insurance for farm products.

The research station and promotion tasks of the Highland Agriculture Projects are subsidized by the Thai Government and drug suppression agencies.

The cooperating entities for the Highland Agriculture Project are :

1. Kasetsart University Highland Agriculture Project which includes exotic crop research stations at Doi Ang Kang and Doi Pui, Chiang Mai.

2. Chiangmai University Highland Agriculture Project which operates research stations at Pa Kia and Mae Muang Luang, Chiang Mai.

3. Maejo Agricultural Technology Highland Project which maintains a research station at Tung Luang, Chiang Mai.

3.2 Committee of Watershed Quality Classification

This committees, objective is to establish categories that classify watershed areas throughout the country. The final results of the work will establish guidelines for natural resource management in the watershed areas including a watershed quality classification. This committee is a sub-committee under the National Environment Board.

3.3 Mountainous Land Development Project under His majesty The King's Advice

According to His Majesty's advice,he has suggested that the hill tribe people and the Thai farmers who live in upland slopes and highlands need permanent cultivation areas for better living. Therefore, he wants these people to use and manage their own cultivated land appropriately in order to raise their incomes and prevent shifting cultivation. The main purpose is to protect and preserve the watershed forests which are the important headwaters in the upper-most part of northern Thailand.

His Majesty transferred this policy to the representatives of government agencies such as the Land Development Department, Royal Forest Department and Royal Irrigation Department. His Majesty has personally visited the people annually in several areas which have been selected for the development projects.

3.4 Other Institutions or Projects

Many other institutions and multi-lateral and bi-lateral projects in Northern Thailand undertake agricultural assistance, land management, crop replacement, irrigation, rural development, extension, and hill tribe settlement work. The Mae Sa Project integrates these institutions especially with the King's Project, United Nations Programme for Drug Abuse Control, Northern Region Agricultural Development Centre, United States Department of Agriculture , Department of Agricultural Extension and two universities; Kasetsart and Chiang Mai. However, the responsibility for watershed development and conservation farming rests mainly on the Royal Forest Department and partly on the Land Development Department.

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4. Demonstration Case Study

THE MAE SA INTEGRATED WATERSHED AND FOREST LAND USE PROJECT

Introduction

The forests Northern Thailand are disappearing at an alarming rate, probably over 10,000 ha (310,000 rai) of forest are being destroyed each year. This is not only destroying a valuable natural resource but probably even more important is the effect that is likely to have on the water supplies on which the prosperity of Thailand so largely depends. Destruction of forests increases the run-off ; less water is absorbed by the soil, so during heavy rains much of the rainfall runs directly into the rivers, causing flooding. Soil is eroded by the rivers, causing siltation of reservoirs, so that a reservoir with a planned life of two hundred years may become unusable after half this period or less. The catchment areas -- the watersheds -- of the rivers of Thailand need careful management if this is to be prevented.

The main cause of forest destruction is clearing land for shifting cultivation which destroys the forest completely and replaces it with something else. The land will be cultivated until it becomes so infertile that it is no longer economic to grow crops, and then the cultivators move to a completely new area. Often it results in the permanent replacement of forest by Imperata grass (ya kha). It is this type of cultivation which is most prevalent in the Mae Sa area.

Therefore the preservation of the forests in Northern Thailand depends on reducing, and eventually eliminating, shifting cultivation. How is this to be done ? It is not possible simply to drive the cultivators out of the forest area. They are shifting cultivators because they have to earn a living, and so an alternative form of life must be found for them, in which they will become permanently settled, prosperous farmers, using the land according to its capability. This is the basic reason for the Mae Sa Project.

Organization of the Project

The Project originated from a request by the Government of Thailand to the United Nations Development Programme (UNDP) for assistance in dealing with the problems of the watersheds. It was agreed to set up a joint project, in which the Food and Agriculture Organization would be the Executing Agency, and the Royal Forest Department as the implementing agency. The Project began with a preliminary phase in 1973, in which the problems were assessed. Mae Sa is chosen as the project area. Field work on Phase I of the Project began in March 1974, over an area of 140 sq km. (87,500 rai). A second phase began in 1978, in which the area was increased to 390 sq km. United Nations participation in the project is planned to end in 1981, when it will be taken over completely by the Thai Government.

Within the Royal Forest Department, the project comes under the Pilot and Demonstration Watersheds Section of the Watershed Management Division. The Thai Project Director is head of this section. Thus it is essentially a pilot project, with the aim of acquiring knowledge which can be applied on a wider scale in other development units of the Watershed Management Division, which at present are 32 in number.

The objectives of the project are

(i) To promote economic growth and improve living conditions of farmers in the highland zones in Northern Thailand.

(ii) To foster social integration within the Thai nation between the various peoples of the area.

(iii) To improve the environment through the replacement of the present slash and burn economy with settled, market-oriented agriculture, compatible with rational land-use and through improved forest conservation and reforestation measures.

The project activities are carried out by the following sectors:

(i) Conservation farming and watershed management

(ii) Forest grazing and range management

(iii) Horticulture

(iv) Forest management

(v) Forest fire control

(vi) Road construction

(vii) Extension

The Project Area

The original project area consisted of the Mae Sa watershed-the valley of the Mae Sa river-which lies mainly within Mae Rim district of Chiang Mai Province, but also includes a small part of Muang district. The extended area also includes parts of Samoeng and San Pa Tong districts. The topography is rugged, and ranges in altitude from 300 m in the plains to 1,68[illegible] m at the summit of Doi Pui.

Project Activities

The activities of the project are aimed at introducing integrated land use to the project area, in which each type of land will be used for the purpose to which it is best suited, and developed for the long-term economic benefits of the inhabitants of the area, and of the country as a whole. The gentler land will be used for agriculture, care

being taken to reduce soil erosion by building terraces or other structures where this is necessary. More steeply sloping land can be used for tree crops, such as tea, coffee, and fruit trees, in which soil cover is maintained permanently, and which will provide a cash income to the farmers. Other areas of steep land will be kept under natural forest, or , where the forest has been destroyed, replanted to provide cover for the soil, and also to produce firewood and timber. Provision has also to be made for pasture for villager's animals.

As a general guide land under 35 per cent slope can be use for annual agricultural crops, with soil conservation measures where necessary. Slopes between 35 per cent and 50 per cent can be used for tree cash crops or pasture ; those over 50 per cent should be used for forest plantations. Very steep slopes, over 55 per cent, should be kept permanently under protection forest.

Activities of Conservation Farming and Watershed Management Sector

In conservative farming, this sector's activities include land-use planning, helping farmers to construct soil-conservation measures, establishment of small-scale irrigation schemes, managing the agricultural side of the demonstration area, and in general introducing improved agricultural practices. Watershed management activities include keeping records of climate and stream flow, establishment of run-off plots, and stabilization of road banks and other erodible areas.

As described previously land-use plans have been completed or are under preparation for three villages. These plans include preparation of topographic, slope, soil, present land use, land capability, and occupancy plans. On the basis of these plans decisions can be made on the suitability of land for agriculture or tree crop plantations, what soil conservation measures will be needed, and what land should be put under permanent forest. Implementation of these plans will follow ; it is partially complete at Pong Khrai, and some structural work has begun at Kong Khan village.

Forest Grazing and Range Management

There are about 4,000 cattle and buffaloes in the project area. Most of these are work animals, and essential to the farmers in their agricultural activities, so provision must be made for their needs in fodder. Previously this has been obtained from forest grazing, grazing on fallow rice fields in the dry season, and grazing on abandoned shifting cultivation areas. As these abandoned areas are being developed for other purposes, difficulties have arisen, and, particularly in forest plantation, grazing is often a problem. So other solutions need to be looked for.

Possible solutions include combining grazing with forestry plantations,by planting fodder crops between the trees, though grazing would have to be excluded for at least the first two years after planting ; establishment of village pastures, with improved grasses and legumes, enabling a larger number of cattle to be grazed on a

smaller area ; and growing fodder crops in combination or rotation with agricultural crops or orchards, in which case the fodder would need to be cut and carried to feed the animals. If such fodder crops could also yield a marked production, such as peanuts and lablab, they would be more acceptable to farmers.

Horticulture

The Horticulture sector of the project has made trials of a wide variety of fruit and nut trees, which can be planted on steeper slopes than are suited for agricultural crops, and which will eventually provide a cash income for farmers. Nut trees are attractive for remote mountain areas, as the nuts can be easily handled and stored, and transported on mule back without being damaged.

Nut trees which so far are promising are Macadamia, (Araucaria angustifolia (from Brazil), and Malabar chestnut (Pachira sq.). Chinese chestnut also shows promise, but as yet is young.

Forest Management

The main emphasis in forest management has been in the creation of plantations. Although proposals have been made for managing parts of the natural forest for provision of local needs of forest produce on a conservative basis removals from the forest would not exceed growth-these are at present held up by legal difficulties.

Plantations are established with a dual purpose, firstly to restore forest cover on areas from which it has been removed, and secondly to obtain a useful product, timber or firewood, from land which is unsuitable for agricultural crops.

In the past the species planted have been those which would eventually be used for commercial purposes, either for timber or for wood - pulp, which would benefit the country as a whole, but are not particularly interesting to the local inhabitants, apart from providing them with employment in establishing the plantations, and later in thinning them and harvesting the timber. A large range of species have been tried, but the most promising and the most widely planted has been Pinus Kesiya (son sam bai). This is relatively easy to establish, grows quite quickly and has the great advantage that after it is about three years old it is resistant to forest fire . It can eventually be used either for paper pulp if a paper mill is established near Chiang Mai, or allowed to grow larger and be used for sawn timber. Although pine timber up to the present has been little used in Thailand, Owing to the availability of higher quality species such as teak, exhaustion of supplies of these other species will make pine more attractive. Timber of pine and similar species provides by far the larger part of timber used in building and construction in Europe and the United States.

Teak has been planted on a smaller scale, at lower elevations. It is not suitable for planting in pure plantations on steeply sloping ground, as the ground cover tends to be very sparse , and there are dangers of erosion.

Other species planted have included Eischoffia (mai teum), Gmelina (mai saw), and Melia (mai liyan), among a dozen or more others. Originally Cedrelatoona (yom haum) was planted on a fairly large scale, but has had to be abandoned because of the damage caused by a moth larva which bores into the stems (Hypsipyla sp.).

Forest Fire Control

Forest fire is an annual occurrence in mountains of Northern Thailand, and from February on wards visibility is obscured by smoke haze. Apart from obvious cases such as when forest plantations are burnt, superficially forest fire may appear to cause little damage. Over centuries many species of trees have developed a resistance to fire by growing thick bark, or developing other protective devices, and thus are rarely killed by fire . However this apparent relative harmlessness of forest fire is deceptive ; they do kill young trees, and so slow down the regeneration of the forest, and even more important, they destroy the accumulation of decaying leaves, the litter, under the forest. It is this litter layer which absorbs the rainfall, and cause the water to soak into the soil from where it eventually emerges to replenish springs and rivers. If the litter layer is destroyed, the rain run off the surface of the soil almost as fast as it falls, causing flooding and soil erosion. Several experiments in Thailand have shown that run-off is greatly increased after forest fire .

Road Construction

Motorable roads are a very important requisite to development. If roads exits, farmers can send a wide variety of crops to market in local towns and further field. If there is no road the only crops which can be marketed are those which can be carried on horse or mule back, without suffering damage and capable of supporting the high cost of this form of transport. Opium is the prime example of such a crop.

So the Mae Sa Project includes a Road Construction Sector. Up to February 1979 the sector had constructed 28 km of new roads, and had partially realigned or other wise improved 30 km. of existing roads.

Apart from making roads, the Road Construction Sector is responsible for making earth dams for irrigation works, and levelling land for buildings. Minor activities have included levelling of a playing field for the school at Pong Waang Nai, and clearing ground for a new Wat at Pang Lung.

Extension and Training

Extension is a very important part of the project's activities, as success depends almost entirely on the willing co-operation of the villagers. Extension work is carried out through personal contact, meetings with villagers, film and slide shows and so on.

Another important aspect of the project 's work is training. In addition to the course for farmers mentioned previously, training has

been given to students from the Phrae Forestry School, officials from various Government departments, including of course the Royal Forest Department, and project staff at all levels. It is intended to expand this training programme even further, and money has been allotted for the construction of a permanent training centre at the Demonstration area in 1979.

Comments

The Mae Sa integrated watershed and forest land use Project is not yet reach the anticipated goals. There are few factors decelerated the project that should be interpreted as follows :

1. Lacking of integrated implementation of the plan among various concerning agencies. Every institution considered its own work as more important than that of others.

2. The annual budget allocated to the project is arranged to Royal Forest Department in each programs. It should be rationally distributed to each responsible agencies.

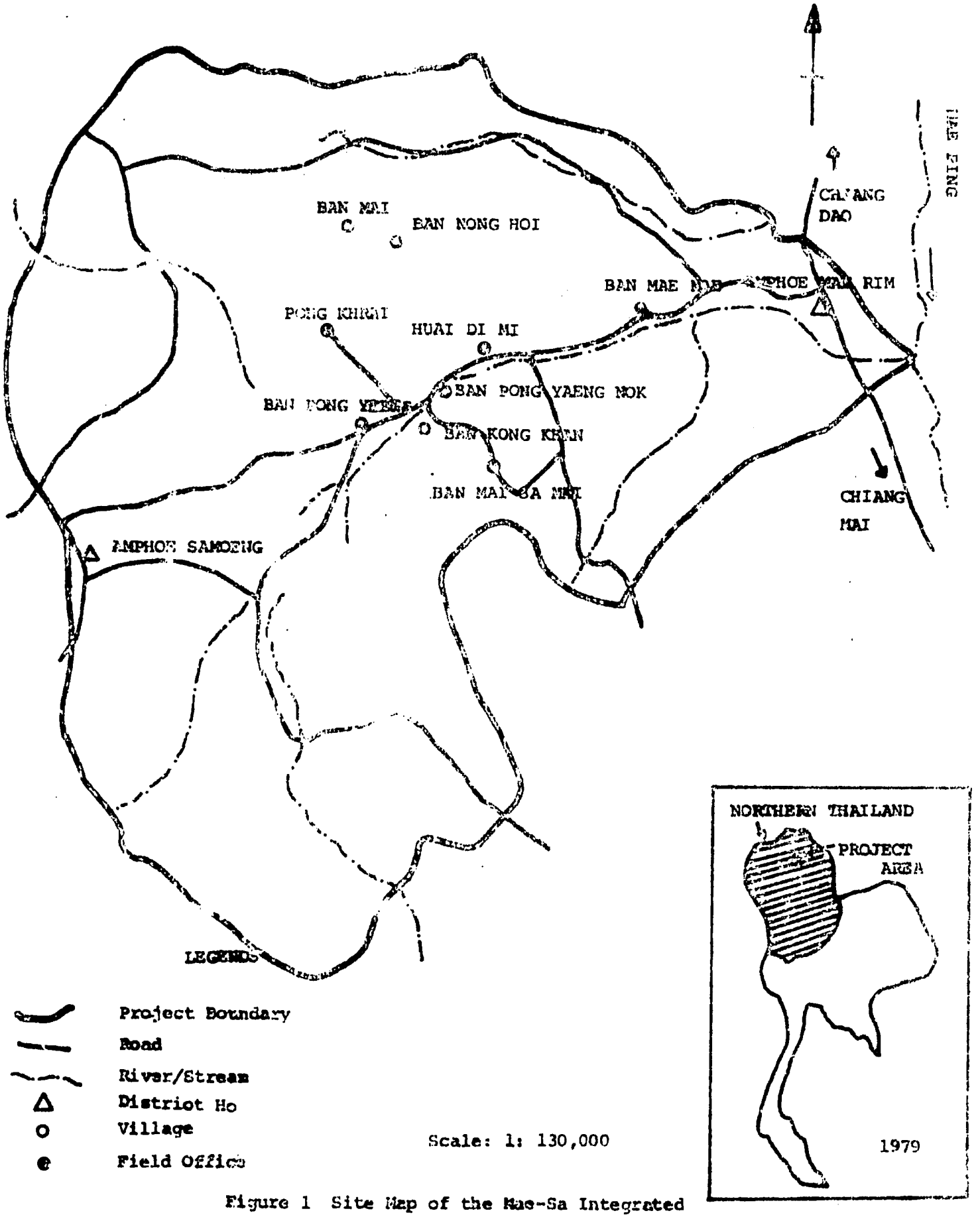

Figure 1 Site Map of the Mae-Sa Integrated Watershed and Forest Land Use Project Area

Section VII

CLOSING REMARKS

VII CLOSING REMARKS

by

Mr. Kasem Snidvongs

Secretary-General, National Environment Board

Participants, observers, lecturers and others.I consider it a special privelege to be able to make the concluding remarks for this training course. From all reports it has been most successful and well-received. I am only sorry that I was unable to spend more time with you during the past two weeks.

My staff tells me that the course purpose and objectives have been met and that great interest and enthusiasm has been shown by all involved - those to be trained and those providing the training. A high degree of communication and rapport was set early and this expanded as the course progressed. A particularly valuable part of the course was the contribution by the participants, both the case study country reports and the field sampling-lab analyses activities.

All of us will remembers certain highlights of the information exchange that has taken place during the course. From what I've heard, my highlights would be :

- Of all our resources, watershed resources are and will continue to be among our most valuable in terms of socio-economic, environmental, and recreational benefits. At the same time, there is an alarming loss of these resources without adequate steps being taken for proper management and renovation.

- Common problems exist in watershed resources management among the countries represented here, namely poor planning and land-use decisions, forest harvest without enough reforestation, over-grazing, and shifting cultivation.

- Although practical physical techniques and practices have been demonstrated for watershed management in tropical ecosystems, difficult challenges remain in implementing these practices because of the customs and low income of the people using the watersheds and the difficulty of law enforcement. These difficulties drive home the realization that watershed management must be a joint effort involving soil, water, forestry, agriculture, fishery and other scientists along with social assistance agencies, drug suppression agencies, and other agencies who work directly with and influence the lives and incomes of people. Also, a part of this joint effort are the officials who make and enforce laws. The training course has proven , I believe, that watershed management can be effective only if these responsible people cooperate and pull in the same direction.

- My understanding is that the field trips to the Mae Sa, Khun Khong and Inthanon Watershed Projects were a valuable addition to the lectures and other course material. In applying what you're learned throughout Thailand and the other regional countries, I believe the field trip areas show a full range of watershed management-what can happen with no management along with poor resource and land-use practices as well as the benefits that can result from watershed restoration and appropriate land-use practices.

- One concern related to watershed management and deforestation that was not highlighted during the course is the impact on the carbon dioxide balance from a global perspectives. International organizations such as UNEP have warned that widespread deforestation may promote a global "greenhouse" effect thus raising temperatures and triggering vast hydrologic changes. This may be a theorum we cannot afford to test because of its staggering implications.

- The last highlight I want to mention is the resourcefulness of you participants in taking advantage of the weather to apply principles presented during the course. When caught in the rain during the Mae-Sa field trip, participants used that opportunity to study rainfall interception. Study findings were that Dr. Ffolliott's Crown intercepted only 10 percent of the rainfall whereas interception by the rest of the group ranged from 60 to 70 percent.

I want to conclude my remarks with the hope that each of you have benefitted from your involvement in the training course. Your jobs in the coming years will not become easier but it is my hope that the insights and incentive you have received here will help you tackle and solve the watershed problems that are waiting for us out there.

Speaking for the National Environment Board and the Department of Technical and Economic Cooperation as the host agencies for the training course, I want to express my sincere thanks to the University of Arizona team and the guest lecturers for their contributions, to Chiang Mai University, Maejo Institute of Agricultural Technology, the Royal Forest Department, and the Northern Region Agricultural Development Center for their unreserved hospitality and assistance, to the planning committee that arranged for the course, and to the assisting agencies that made the course possible, namely the U.S. Agency for International Development, Man and the Biosphere, and the United Nations Educational, Scientific and Cultural Organization.

Thank you.

Section VIII

ANNEXES

Annex VIII - 1

WATER SAMPLING / LAB ANALYSIS REPORT

VIII-1 WATER QUALITY MONITORING AND LAB ANALYSIS

Introduction

The workshop on water quality monitoring and lab analysis is one of the most important session in this training course. In general, the successful of watershed management can be evaluated by means of quality, quantity and timing of water from the watershed. Among those indicators, water quality is the most vitality in watershed resources management. However, water quality is easily affected by land use practices in the area and other development activities of the watershed. Determination of water quality is an intensive task which needs a skilled and experienced personel to deal with. Therefore, the purpose of this workshop is to render participants more capable and to gain some experiences in water quality analysis including field work performance such as selection of sampling station, water sampling and preservation of water samples.

Objective

Objectives of the workshop are to :

1. Instill participants to gain experience in site selection, water sampling techniques and preservation of the samples.

2. Render participants experiences in analysis of water quality both in the field and laboratory and also using of instruments.

3. Provide a forum of knowledge in relating land use practices on the watershed to the water quality.

Description of the study area

The Mae-Sa watershed, under the Mae-Sa Integrated Watershed and Forest Land Use Project, had been chosen as the study area. The main objectives of the project are to introduce integrated land use to the project area for development of the watershed. Indeed, land use activity is a key factor affecting water quality of the watershed, and, it is a controlled factor at the same time. Informations concerning land use practices in the Mae-Sa watershed area are also available for the interpreting of the hydrological test results.

The Mae-Sa watershed area lies mainly within Mae Rim district and a small part of Muang district of Chiang Mai Province. The extended area also includes parts of Samoeng and Hang Dong districts. The topography is rugged, and ranges in altitude from 300 meters in the plains to 1,685 meters at the summit of Doi Pui. In the original area, over 50 percent of the land had a slope of over 35 percent (19°). Average annual rainfall ranges from about 1,300 mm. in the plains to over 2,000 mm.

near the summit of Doi Pui. The maximum temperature recorded is over 40°C and the minimum is 2°c.

The sampling of water was made at 3 stations in the Mae-Sa Watershed Project for quality monitoring and analysis. The sampling stations are identified as follow :

.Station I at Ban Mae-Mae represents the downstream with catchment area of water from the Mae-Sa watershed area. Land use is mainly undisturbed and plantation forests and parts of shifting cultivation, paddy, upland crops, and human settlement.

.Station II at Ban Mae-Sa Noi is the sub-watershed of a tributary of the Mae-Sa river with catchment area of 3 km^2. A large portion of land (about 50 percent) is under shifting cultivation and the remaining is parts of upland crops, natural and plantation forests. This sub-watershed is mostly influenced by activities of Mae village.

. Station III at Ban Pong Yang Nok with catchment area of 30 km^2. Land use is a combination of shifting cultivation, forest reserve, paddy and upland crops.

Procedures

According to the objectives mentioned, participants are assigned to (1) measure various chemical and physical properties of water from pre-selected sites on the Mae-Sa watershed, and (2) interprete the lab results by making general conclusion in relation to the land uses of the sub-watersheds.

A. Preparation prior to the workshop

- Three sampling stations had been selected for water quality analysis in Mae-Sa watershed
- "Workshop Manual for the Analysis of water Samples" had been prepared by the Organizing Sub-Committee.
- The Land Use Maps, scale 1:50,000, of Mae-Sa Watershed Project had been prepared for each group. Land use patterns , drainage patterns and sampling stations were identified, using topographic maps.
- Participants are arranged into 5 groups according to their background so that each group will perform with various background members.

B. Water sampling and preservation of the samples.

At each of the three sampling stations, each group was assigned to (1) measure some parameters in the field by instrumental methods, and (2) collect samples for measuring some properties the following day, one sample was preserved and fixed by chemicals and the other was preserved in 4°C temperature.

C. Water quality analysis

1. Field analysis : After water samples are collected, They are ready to be determined for some properties on the site. These properties and instrumental methods are as follows :

temperature	by	thermometer
pH value	by	pH meter
dissolved oxygen	by	DO meter

2. Laboratory analysis : The analysis of chemical and physical parameters, following the procedures prescribed in the Workshop Manual, was carried out at the Environmental Engineering Laboratory and the Chemical Laboratory, Chiang Mai University. The parameters and methods applied are as follows :

turbidity	by	turbidimeter
light transmittance	by	colorimeter
conductivity	by	conductivity meter
alkalinity	by	indicator method
total hardness	by	EDTA titrimetric method
dissolved oxygen	by	azide modification of the Winkler method
orthophosphate	by	colorimetric method
nitrate	by	nitrate electrod method
pesticide (chlorinated)	by	gas-liquid chromatographic analysis
settleable solid	by	using Imhoff cone
filterable solid	by	total filterable residue dried at 103-105 °C
total solid	by	total residue dried at 103-105 °C

Result and Discussion (extract from participant reports)

The results and discussion of water quality analysis of each group are presented as follows :

Group 1

1. Result of water quality analysis.

Parameters	Station I	Station II	Station III	Standards for drinking water
Physical Properties				
Temperature, °C	27.0	24.5	25.5	
Turbidity, FTU	45	51	17	5
% Transmittance	70	56	81	
Conductivity, micromhos/cm	210	138	210	
Settleable solid, ml/l	0.35	0.45	0.55	
Filterable solid, mg/l	80	183	74.9	
Total dissolved solid, mg/l	301	317	293	500
Chemical Properties				
pH	8.05	7.74	7.35	7.0-8.5
Alkalinity, mg/l as $CaCO_3$	114	44	55	
Total hardness, mg/l as $CaCO_3$	136	80	152	100-200
Dissolved oxygen, mg/l	7.5	7.3	6.8	8.4
Orthophosphate, mg/l PO_4^{3-}	5	4	5	
Nitrate, mg/l NO_3-N	trace 1/	trace 1/	trace 1/	45
DDT, mg/l	trace 2/	none	trace 2/	none

Note : 1/ trace refers to amount less than 0.02 mg/l
2/ trace refers to amount less than 0.001 mg/l

2. Discussion

1) Temperature The temperature at station I is somewhat high because the measurement was made in the sample container not on the stream.

2) pH The pH value of the stream is normal and meets the U.S. Public Health Service Drinking Water Standards.

3) Total hardness Since the total hardness standard of surface water in Thailand is about 100-200 mg/l. So it shows that the total hardness value of the water in Mae-Sa river is also good.

4) Dissolved oxygen value As indicated in the manual, the oxygen solubility in fresh water at temperature 24°C is 8.4 mg/l. The dissolved oxygen at Mae-Sa river as tested here is very approach to this value. Therefore, we can say that the water quality is good.

In China, DO value of 4.5 mg/l will meet the standard of fresh water for fishing. The water quality of Mae-Sa river can thus be used for fishing as well.

5) Total dissolved solid It meets the U.S. Public Health Service Drinking Water Standards.

6) Alkalinity The tested value is about 3-10 times higher than the U.S. Public Health Service Drinking Water Standards. Water treatment is recommended before supplying it as drinking water.

7) Insecticide DDT is trace at Station I and III. While none of DDT was found at station II. It meets the National Standards of Thailand.

According to these parameters examined, the water quality in the Mae-Sa river is still good and can be used as public water supply, irrigation and fishing.

3. Conclusion

The data obtained for solid matter in these three stations can be related to the land use and slope. The dissolved solid values at three stations, 301.5, 317.0 and 293.5 mg/l respectively, are considerably high and highest at station II. This is because shifting cultivation in the station II area is greater than that of the others and, as we know sampling time is about 16 hours after a storm.

As seen in the map, the watershed area are mountainous with altitude from 300 to 1,685 meters. Fifty percents of the land has slope of over 35 percents so the transport capability is high for eroded material thus impacted the solid matter in all three stations.

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Group 2

1. Result of water quality analysis

Parameters	Station I	Station II	Station III	Standards for drinking water
Physical Properties				
Temperature, °C	24.8	24.2	24.2	
Turbidity, FTU	28.0	44.0	19.0	5
% Transmittance	68.5	55.8	79.0	
Conductivity, micromhos/cm.	194	131	192	
Settleable solid, ml/l	0.3	0.5	0.1	
Filterable solid, mg/l	107.2	162.1	57.8	
Total dissolved solid, mg/l	298.0	211.4	202.2	500
Chemical Properties				
pH	8.14	7.70	7.35	7.0-8.5
Alkalinity, mg/l as $CaCO_3$	130	92	146.5	
Total hardness, mg/l as $CaCO_3$	137	85	148	100-200
DO-using DO meter	5.50	6.7	6.1	8.4
-chemical method	7.50	7.15	6.70	
Orthophosphate, mg/l PO_4^{-3}	4.25	3.75	3.50	
Nitrate, mg/l NO_3-N	trace 1/	6.2	6.2	45
DDT, mg/l	trace 2/	none	trace 2/	none

Note : 1/ trace refers to amount less than 0.02 mg/l
2/ trace refers to amount less than 0.001 mg/l

2. Discussion

1) Temperature Measured results obtained in the stream were about the same for all three stations. The measured temperatures are a little higher than the average of 20-21 C perhaps due to the time of day (early and mid morning) and to shallowness of the streams. The machine measurements are a little higher than the first set perhaps due to the samples being hand held and the differences in calibration between the hand thermometer and the HACH machine.

2) pH and Alkalinity Our data for these two properties did not turn out to be congruent our experimental method or instrumentation may be to blame. Given the procedure, we may want to trust the alkalinity measurement, which shows station II to be lower. Perhaps this is due to sub-watershed II having the lowest percentage of forest reserve and the highest percentage of shifting cultivation and treated agriculture.

The pH is highest at station I, then followed by station II and III. The same pattern shows for DO (see DO explanation next page). With a higher CO_2 release, pH increases.

Appears that the alkalinity reading at station II could be caused by low amounts of carbonate and hydroxide at the site. Station II has the lowest alkalinity reading.

3) Dissolved oxygen (DO). DO is highest at station I. One contributing factor might be the steeper slope at the site as evidence by the waterfall. This would cause CO_2 to be released from the water.

4) Turbidity Turbidity is distinctly highest at station II. We attribute this to soil erosion and surface runoff. That is associated with clear cutting and shifting cultivation, which makes up 50 percents of land use in the sub-watershed.

5) Transmittance The transmittance reading have an inverse correspondence to the turbidity and filterable solids readings as expected. Station II has the least transmittance, as it has the most solids and turbidity, that would hinder transmittance.

6) Conductivity Again, the reading for station II is the smallest for this variable. With increased turbidity and solids and the lesser amount of water molecular surface, conductivity is reduced.

7) Orthophosphate Orthophosphates were measured at all three station. The differences in concentration were low, we are not certain of the implementations of our measurements.

8) Nitrate Only a trace amount of nitrate were found from the station I sample, and equal amount of 6.2 mg/l at station II and III. This corresponds to the estimated percentages of land donated to treated agriculture. In sub-watershed II and III, 15 to 20% of the land in each is donated to treated agriculture, winder fertilizers could be a part of the technical package, while only about 8% of the land is uncer treated agriculture in sub-watershed I. The relative amounts of nitrates could be found in the receiving streams.

9) Total hardness Station II had a lower reading of 85 mg/l while station I and III had 137 and 140 mg/l respectively. These measurements correspond to the alkalinity readings.

10) Solids, settleable, filterable and total dissolved Station II had the highest measurement of settleable and filterable solids, which we describe to the greater capacity for erosion and runoff on this sub-watershed which a percentage of shifting cultivation, the measurement for total dissolved solid was higher from station I than II and III, reasons for which we are not certain.

11) DDT Trace amounts of DDT were found from station I and III and nothing were detected from station II. These measurements could reflect the various treatments of DDT in paddy rice, treated agriculture, forest plantations, orchards or in miang-tea plantation, since we do not know exactly what technical packages are being employed in the different land uses, we will only note that caution should be taken to protect the health of the inhabitants and to ecosystems stability.
(DDT measurement were made by technician experienced with gas chromatography)

3. Conclusion

Only very general conclusions about the hydrological test results and appropriate land use practices can be drawn from the team 2 data set. We had two primary limitations. The information base about the watershed is incomplete. For example, we have only little information about percentage of land donated to various land uses, the technical practices employed, soil types, vegetation composition, etc. Secondly, our sampling pool were limitted in both spatial and temporal terms. We were not able to carry out statistical analysis of the data nor determine standards of error.

More monitoring and study would be necessary in order to make conclusive statements and confident recommendations for the watershed, at which time the standards for drinking water could also be employed to assist in the decision making process.

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Group 3

1. Result of water quality analysis

Parameters	Station I	Station II	Station III	Standards for drinking water
Physical Properties				
Temperature, °C				
- using thermocouple	24.1	24.1	25.0	
- using thermometer	27.0	24.5	25.3	
Turbidity, FTU	19	76	35	5
% Transmittance	70	52	83	
Conductivity, micromhos/cm	198	132	213	
Settleable solid, ml/l	0.3	0.5	0.1	
Filterable solid, mg/l	107.2	162.1	57.8	
Total dissolved solid, mg/l	298.0	211.4	202.2	500
Chemical Properties				
pH	7.80	7.71	7.15	7.0-8.5
Alkalinity, mg/l as $CaCO_3$	133	84	146	
Total hardness, mg/l as $CaCO_3$	138	88.5	145	100-200
DO, mg/l				
- using DO meter	5.75	6.70	6.25	8.4
- Chemical method	7.50	7.50	6.10	
Orthophosphate, mg/l PO_4^{-3}	5.5	4.0	5.25	
Nitrate, mg/l NO_3-N	trace 1/	trace 1/	trace 1/	45
DDT, mg/l	trace 2/	none	trace 2/	none

Note : 1/ trace refers to amount less than 0.62 mg/l

2/ trace refers to amount less than 0.001 mg/l

2. Discussion

The data shows that turbidity level at the station II is higher than the other stations. This is perhaps because watershed area above station II is steeper than the others. Furthermore, a great extent of land use above station II is shifting cultivation and parts of treated agriculture and plantation forests. These factors induce a higher rate of erosion at station II

3. Conclusion

It can be concluded from the data obtained that erosion rate at station II is greater than station I and station III. So watershed area at station II needs more treatments.

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Group 4

1. Result of water quality analysis

Parameters	Station I	Station II	Station III	Standards for drinking water
Physical Properties				
Temperature, °C	25.0	24.5	25.5	
Turbidity, FTU	35	62	23	5
% Transmittance	70	58	8.4	
Conductivity, micromhos/cm	192	123	210	
Settleable solid, ml/l	0.35	0.55	0.30	
Filterable solid, mg/l	23.7	96.8	68.6	
Total dissolved solid, mg/l	186.8	205.7	176.4	500
Chemical Properties				
pH	7.95	7.52	7.32	7.0-8.5
Alkalinity, mg/l as $CaCO_3$	62	86	150	
Total hardness, mg/l as $CaCO_3$	152	94	180	100-200
DO, mg/l				
- using DO meter	5.3 at 28 °C	6.4 at 24 °C	6.1 at 25.9 °C	
- Chemical method	7.5	7.7	6.6	8.4
Orthophosphate, mg/l PO_4^{-3}	4.8	3.6	3.6	45
Nitrate, mg/l NO_3-N	248	trace 1/	124	none
DDT, mg/l	trace 2/	none	trace 2/	none

Note : 1/ trace refers to amount less than 0.62 mg/l
2/ trace refers to amount less than 0.001 mg/l

2. Discussion

1) Solid matter The table shows that by large all data pertaining to solid material (both suspended and dissolved) is greater at station II. This, of course, is attributable to the greater extent of shifting cultivation on its steep slopes. Shifting cultivation courses a load of sediment to be washed into the drainage waters. Road construction at Mae-Sa Mai village can also contribute towards the solid load. In station III, since paddy is cultivated in the valley, it can be postulated that it acts as a retardant to erosion. At station II the steep lands used for shifting cultivation extend right down to the base of the valley itself, but at station III the cultivation of paddy in the valleys requires the land to be either terraced or flattened, hence the latter station could check further erosion.

2) pH No significant difference

3) DO This does not give us any define conclusion, but it can be said that the oxygen levels are good since the values obtained fall only slightly less than that for saturation oxygen levels. Another factor that the DO content could be influenced greatly by the location of the sampling point, if collected just after the rapids it would give a higher value. DO content measured by the indirect method shows discrepancies as example of station III. The lower DO value at station III by using DO meter could possibility be due to the decreased solubility of oxygen at the mid noon temperature at which the sample was read.

4) Turbidity and transmittance Indicative of the amount of dissolved substances shows that station II by far has the greater amount of solutes possibly due to the land use practices.

5) Conductivity and alkalinity Shows variation from one station to the others, most probably due to the differences in the soil characteristics and parent material.

6) Total hardness A measure of the $CaCO_3$ content, another variable character is also influenced by parent material.

7) Orthophosphate and nitrate Orthophosphate values although low show the expected cumulative value at station I. Surprisingly nitrate levels seem too high too draw any conclusions, it could possibly due to some experimental error. A lower value of nitrate level at station 3, however could be the result of the fact the paddy is extensive there. Paddy is a crop that requires nitrogenous fertilizer.

3. Conclusion

The water of the Mae-Sa river from the above parameters show that the quality of the water is good by chemical standards and feel well within the value stipulated the U.S. Bureau for drinking water. The only factor that contributes to its disadvantage is the turbidity which of course should be attributed to bad land use practices. This water should have to undergo

a purification treatment before use as drinking water. However, the waters seem extremely good for irrigation purpose.

However, although conclusion have been drawn it would seem rather inadequate to make the above conclusion from just a single sampling at each site. What would necessarily be required before definite references are drawn is that sampling should be continued through a greater period of time and that will include both dry and wet season sampling.

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Group 5

1. Result of water quality analysis

Parameters	Station I	Station II	Station III	Standard for drinking water
Physical Properties				
Temperature, °C	24.8	24.8	25.4	
Turbidity, FTU	39.0	83.0	29.0	5
% transmittance	59.5	58.0	72.0	
Conductivity, micromhos/cm	187	137	210	
Settleable solid, ml/l	0.35	0.55	0.33	
Filterable solid, mg/l	24.8	95.8	67.5	
Total dissolved solid, mg/l	189.8	108.7	176.9	500
Chemical Properties				
pH	7.9	7.7	7.4	7.0-8.5
Alkalinity, mg/l as $CaCO_3$	37.5	41.0	39.0	
Total hardness, mg/l as $CaCO_3$	138	92	152	100-200
DO, mg/l				
- using DO meter	5.3	6.5	6.1	
- chemical method	7.6	7.4	6.7	8.4
Orthophosphate, mg/l PO_4^{-3}	4.5	4.0	4.2	
Nitrate, mg/l NO_3-N	0.0064	0.0064	0.0071	45
DDT, mg/l	trace 1/	none	trace 1/	none

Note : 1/ trace refers to amount less than 0.001 mg/l

2. Conclusion

The experimental results reveals that most of the parameters tested for the water quality of Mae-Sa watershed average at the acceptable level. This means the water can still be used for the domestic and agricultural purposed. However the presence of DDT and the relatively high level of turbidity (83 FTU) in the water samples indicate that the water needs proper treatments before it can be used for drinking. Shifting cultivation practice in major portions of watershed area (50%) contribute the main problem of Mae-Sa watershed and should therefore be contained, if not controlled effectively to the tolerable level.

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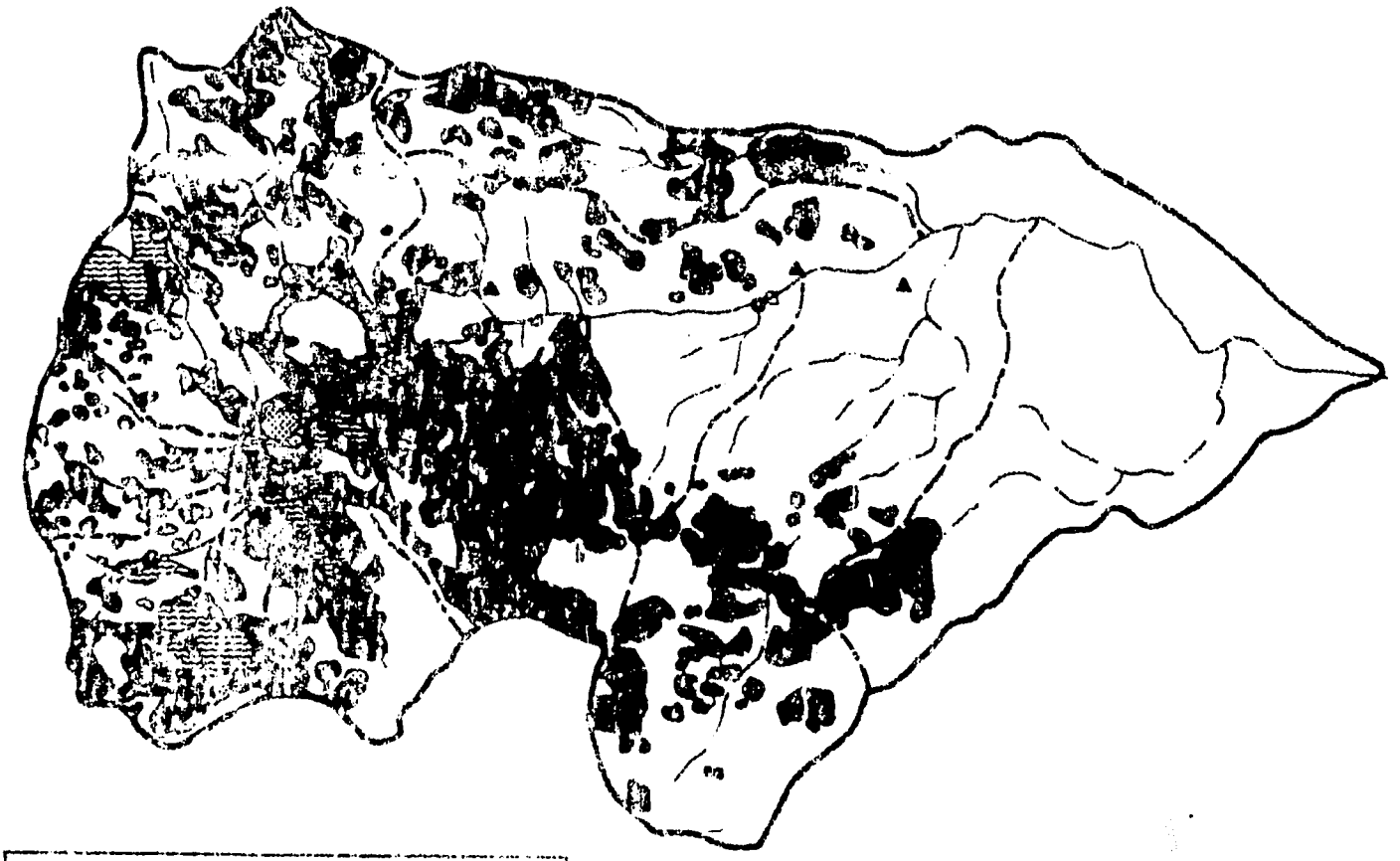
Summary

It should be mentioned that interpretation of the results in relation with land use practices is based on a single sampling at each site. It would seems rather inadequate to make a definite conclusion. In fact, data collection should be conducted through a longer period of time including both dry and wet seasons. Although variation of the data from each group may be significant, participants are nevertheless eligible for water quality analysis including site selection and sampling techniques. Since the accuracy of the results is beyond the objectives and not the most concerns, it is not recommended for making any reference of the data presented. However, it would be taken as a guidelines for implementing agencies for watershed resources management. The laboratory workshop also provides participants the techniques of sampling site selection, water quality analysis for initiating and further practicing in their own agencies. Conclusion will thus be drawn to some extent due to limitations of information base and time provided. Sampling pool was also limited and participants were not able to carry out statistical analysis of the data.

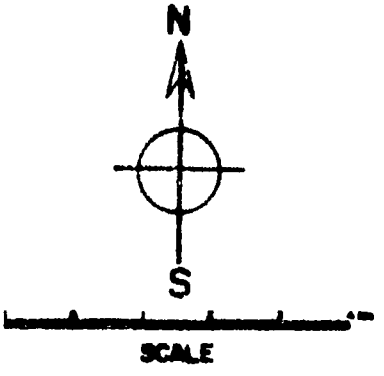
However, from the overall evaluation by participants, the laboratory workshop is considered very useful. And, it would be said that this experience is of advantages in various aspects of watershed resources management.

MAE SA WATERSHED AND LAND USE MAP



LEGEND

- Watershed Boundary
- Sub-Watershed Boundary
- Stream
- Weather Station
- Gaging Station
- Water Quality Sampling Point
- Paddy
- Forest Plantation
- Traditional Agriculture (Rain Fed)
- Swidden (Shifting Cultivation)
- Village
- Orchard
- Mixed (Tea)
- Pasture



Annex VIII - 2

COURSE PROBLEMS

PROBLEM

Calculate the potential annual soil loss for the watershed given in the runoff problem.

Assume:

R = 350

Average slope lenght and gradient

Area A = 80 ft, 40%
Area B = 100 ft, 20%
Area C = 150 ft, 8%

Soils

Area A

60 percent silt and fine sand with fine structure and moderate to rapid permeability with 3 percent organic matter (silt loams).

Area B

40 percent silt and fine sand with very fine granular structure, moderate to rapid permeability and 2 percent organic matter (clay loams).

Area C

30 percent silt, clay and fine sand with massive structures and 4 percent organic matter (heavy clay loams), slow permeability

Cover

Area A

Heavily grazed and burned, tree canopy approximately 20%. Litter cover 45% of area.

Area B

Grass ground cover, 60% density

Area C

Small grains, row cropped, 80% cover

Table 15.5 Erosion-control practice factor (P) for the Universal Soil-Loss Equation (From U.S.Soil Conservation Service 1975)

LAND SLOPE (%)	P VALUES			
	CONTOURING	CONTOUR STRIP CROPPING *	CONTOUR IRRIGATED FURROWS	TERRACING +
2.0-7	0.50	0.25	0.25	0.10
8.0-12	0.60	0.30	0.30	0.12
13.0-18	0.80	0.40	0.40	0.16
19.0-24	0.90	0.45	0.45	0.18

* Using a 4-year rotation of maize, small grain meadow, and meadow.
+ For prediction of contribution to off-field sediment load.

Table 15-3 Cropping-management factors. C in the Universal Soil-Loss Equation for woodland. (From U.S. Soil Conservation Service 1975b).

TREE CANOPY (% OF AREA)	% OF AREA COVERED BY > 2 INCHES OF FOREST LITTER	UNDERGROWTH	C
100-75	100-90	Grazing and burning controlled	0.001
		Heavily grazed and burned	0.003-0.011
70-40	80-75	Grazing and burning controlled	0.002-0.004
		Heavily grazed and burned	0.01 -0.04
35-20	70-40	Grazing and burning controlled	0.003-0.009
		Heavily grazed and burned	0.020-0.09
< 20	Treated as grassland or cropland		

Table 15-4 Cropping-management factors. C in Universal Soil-Loss Equation, for pasture, rangeland, and idle land.(From U.S.Soil Conservation Service 1975b.)

TYPE OF CANOPY AND AVERAGE FALL HEIGHT OF WATER DROPS	CANOPY COVER (%)	GROUND COVER*	PERCENT GROUND COVER					
			0	20	40	60	80	95-100
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush(0.5 m fall ht)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
Appreciable brushes or trees (2 m fall ht)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.83	.041	.011

*G = Cover at surface is grass, grasslike plants decaying compacted duff,or litter at least 2 inches deep.
W = Cover at surface is mostly broadleaf herbaceous plants(as weeds with little lateral-root network near the surface, undecayed residue or both).

BEST AVAILABLE DOCUMENT

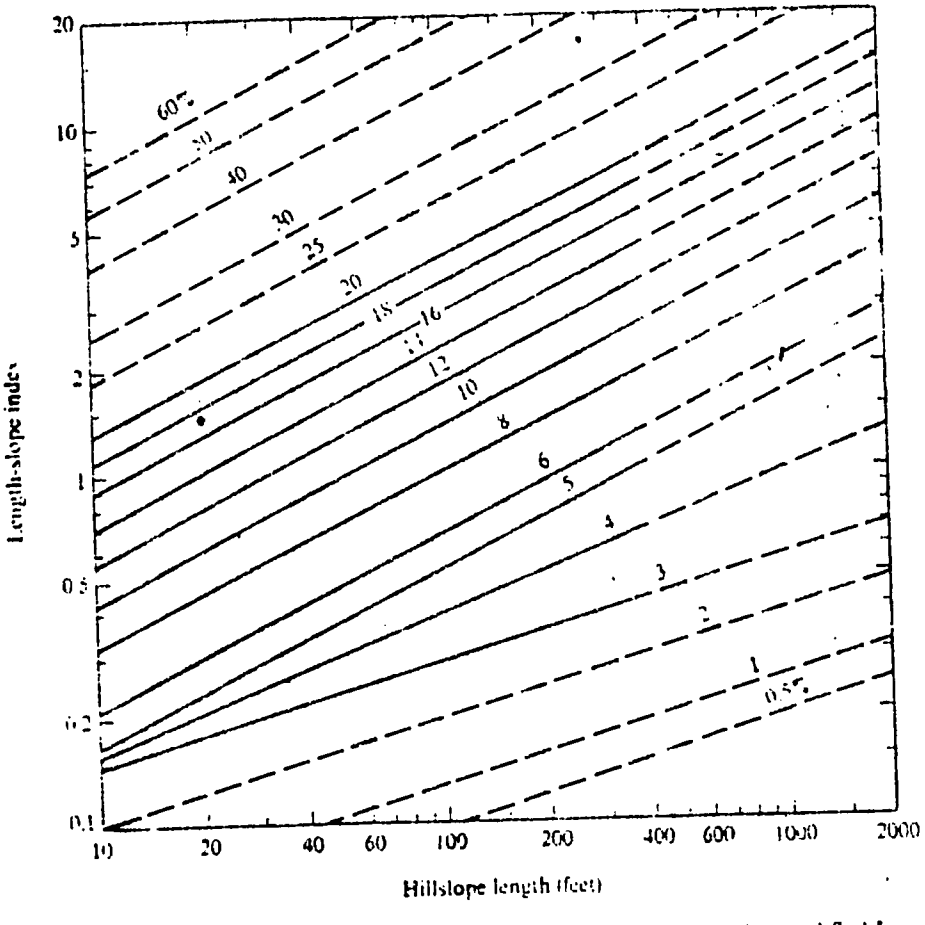
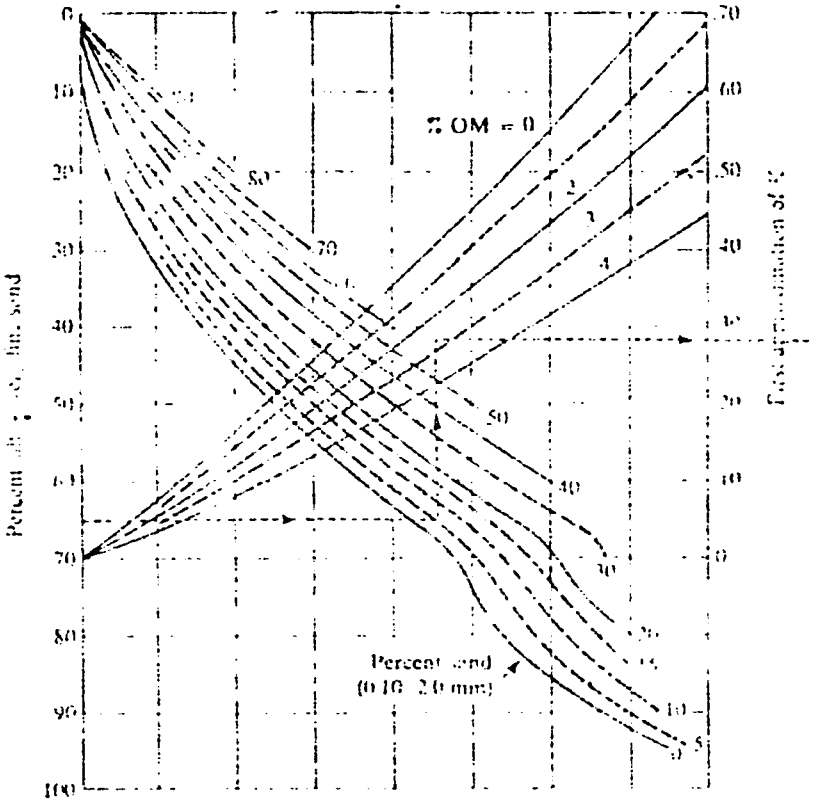


Figure 15-19 Chart for evaluating the length-slope factor, *LS*, in the Universal Soil-Loss Equation. The solid lines represent conditions within the range of data from which the curves were derived. The dashed lines are based on extrapolations and should be used with care. (From U.S. Soil Conservation Service 1975b.)

Table 15-2 Examples of cropping-management factors *C* in the Universal Soil-Loss Equation, for agricultural land. Many other crop combinations are listed in the original reference as well as in technical releases for particular regions. The crop stages are also defined in the original source. (From Wischmeier and Smith 1965.)

	CROP STAGE				
CROP	FALLOW	SEEDLING	ESTABLISHMENT	MAJOR GROWTH	RESIDUE
Corn with conventional tillage in rotation with small grains and grass	0.36	0.63	0.50	0.26	0.30
Alfalfa					0.02



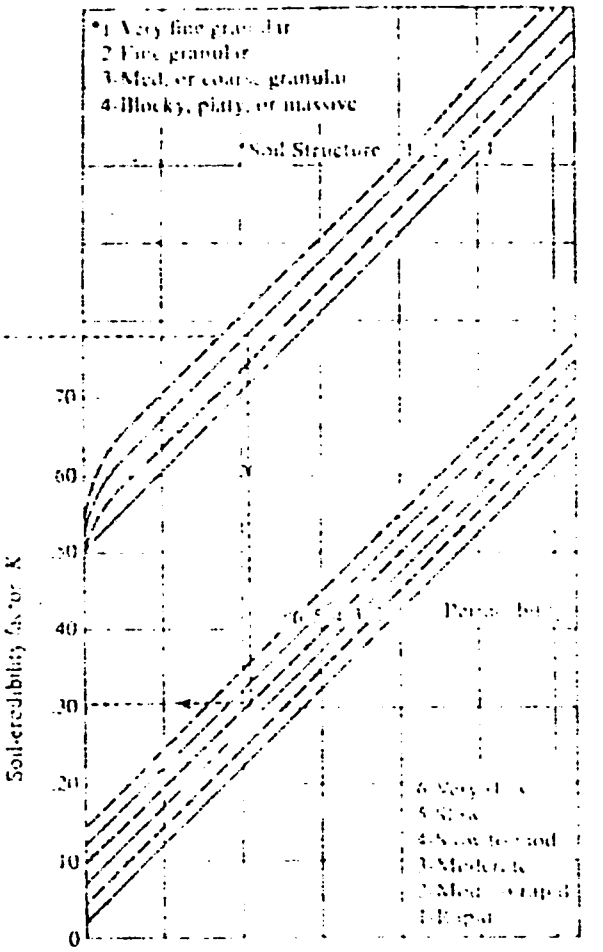


Figure 15-18. Nomograph for estimating erodibility indexes for the Universal Soil Loss Equation. The soil properties needed for use of the nomograph are available in County Soil Survey Reports or detailed profile descriptions and are defined in the U.S. Soil Conservation Service (USDA) Soil Survey Manual. *Procedure.* With appropriate data, enter scale at left and proceed to points representing the soil's percentage of sand (0.10–2.0 mm), percentage of organic matter (OM), structure, and permeability, *in that order.* Interpolate between plotted curves. The dotted line illustrates procedure for a soil having silt and very fine sand 65%, sand 5%, OM 2.5%, structure 3, permeability 4. Solution: K = 0.31. (From Wischmeier et al. 1971.)

BCI_WAMTAR DOCUMENT

PROBLEM ON DECISION MAKING

Dr. F. F. Ffolliott

Objective : Maximize Benefits

Constraints :

1. Maintain timber production at (as a minimum) 3.0 cubic meters per hectare.

2. Provide enough forage to achieve a livestock gain (as a minimum) of 0.0040 kilograms per animal.

3. Improve wildlife habitat over existing conditions.

4. Increase water yield by (as a minimum) at least 10 percent.

Problems :

Given the above, and assuming that you are responsible for the management of a 70,000 Hectare watershed, answer the following questions :

1. What additional biophysical and socio-economic information is required to select the "best alternative" in order to satisfy the objective ?

2. Assuming that you had all of the required information, which alternative would you select, and why? (To answer this question, you may assume hypothetical,biophysical and socio-economic information).

WATER QUALITY

PROBLEM

Assume the Function $w = A * q^2 + B$ gives the concentration (w) in parts per million (milligrams per liter) of suspended sediment as a function of discharge (q). If A = 20.0 and B = 10.0, find the average suspended sediment concentration and the total weight of the suspended sediment when the discharge varies in a linear fashion from 1.0 to 5.0 cubic meters per second in 1 hour.

REMOTE SENSING

PROBLEM

Design a remote sensing project to determine the change in acreage of forest covered land to agriculture in an area 30 km. by 30 km. Give specific details. The change is over a five year period between now and 5 years in the future.

RESERVOIR MANAGEMENT PROBLEM

(Brooks)

1. Using the information below and the situation presented in the hand-out, determine a demand curve for the estimated storage requirements.

	Volumes in $m^3 \times 10^6$											
Demands	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Water supply	0.2	0.3	0.4	0.5	0.8	0.9	0.8	0.7	0.3	0.2	0.2	0.2
Irrigation	0	0	0	0	0	22.3	48.4	74.5	56.9	18.6	0	0
Hydroelectric Power	290	290	290	300	300	300	300	300	300	290	290	290
Minimum flow downstream	37.2	37.2	74.5	74.5	148.9	223.4	223.4	223.4	156.4	74.5	37.2	37.2

2. Develop a matrix to compare the complementary or conflicting potentials for storage use. Include with the above information, a flood storage requirement of 450, 900, 900, and 450 $m^3 \times 10^6$ for the months FEB through MAY.

Purpose	Water Supply	Irrigation...
Water Supply	-	CF
Irrigation	CF	
.		
.		
.		

CF = conflicting
CO = complementary

3. Given the following information, determine the volume of dead storage needed for the reservoir if it is to last for 40 years. Sediment delivery from the 200 ha watershed is presently 0.9 tons/ha/year. Assume the bulk density of sediments is 1.6 g cm^{-3}.

If poor cultivation and overgrazing on the watershed above the reservoir are allowed, and result in sediment deliveries of 35 tons ha^{-1} $year^{-1}$, how many years will the dead storage space (previously determined) last ?

WATER BUDGET EXERCISE

One hundred ninety hectares of mixed hardwoods are to be clearcut on a watershed which drains into a water supply reservoir. The city which receives water from this reservoir is interested in determining how much of an increase in water yield might be expected as a result of this cut. In order to provide a conservative estimate of possible increases, a dry 21-month period was selected for analysis with a water budget. A water budget has been calculated for this dry period under pre-cut conditions (Table 1).

1. Using the following information and the same rainfall and potential ET data in Table 1, estimate the change in water yield in cubic meters for the 21-month period.

   a. Soils are clay-loam with an average depth of about 1.7 m; plant available water (field capacity minus permanent wilting point) averages 164 mm per meter of soil depth.

   b. The root systems of the mature hardwood stand fully occupy the soil, therefore, the total soil water which can be depleted by ET is 279 mm (1.7 m X 164 mm/m) as indicated in Table 8.

   C. Studies have shown that under light herbaceous plant cover, a condition similar to a clearcut area, soil water is depleted by ET only to a depth of about 0.6 m.

2. Discussion questions

   a. What assumptions were made in applying the water budget in this study ?

   b. What factors would be important in determining the quantities of increased water yield which would be available at the reservoir site ?

BEST AVAILABLE DOCUMENT

Table 1 - WATER BUDGET EXERCISE FOR A HARDWOOD-COVERED WATERSHED - BEFORE CLEARCUTTING

	Year 1												Year 2								
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
	mm																				
1. 1/ Average rainfall	58	103	133	98	100	48	27	4	31	42	36	12	50	120	140	105	90	95	65	20	46
2. 2/ Initial soil moisture	56	57	140	273	279	279	279	248	163	67	0	0	0	0	100	240	279	279	279	279	210
3. Total soil. moisture	114	160	273	371	379	328	306	252	194	109	36	12	50	120	240	345	369	374	344	299	256
4. 3/ Potential ET	57	20	0	0	3	13	58	89	127	173	157	107	57	20	0	0	3	13	58	89	127
5. 4/ Actual ET	57	20	0	0	3	13	58	89	127	109	36	12	50	20	0	0	3	13	58	89	127
6. Remaining available moisture	57	140	273	371	376	314	248	163	67	0	0	0	0	100	240	345	366	361	286	210	129
7. 5/ Final soil moisture	57	140	273	279	279	279	248	163	67	0	0	0	0	100	240	279	279	279	279	210	129
8. 6/ Runoff	0	0	0	92	97	35	0	0	0	0	0	0	0	0	0	66	87	82	7	0	0

1/ Average over the watershed for each month of record.

2/ At start of each month. Same as "final soil moisture" of previous month.

3/ Average annual values for the month, as estimated by Thornthwaite's method.

4/ Total available moisture, or potential ET, whichever is smaller.

5/ At end of month. Same as "initial soil moisture" for next month. This value cannot be larger than the soil-water holding capacity determined for the watershed, for this watershed 279 mm.

6/ Runoff occurs when the remaining available moisture exceeds the water holding capacity for the watershed (279 mm).

Annex VIII - 3

COURSE FINAL EXAMINATION

VIII-3 EXAMINATION

1. Define watershed resources management, and explain how your definition applies in your professional assignment.

2. Outline the procedures involved in establishing (a) a precipitation, (b) a streamgaging, and (c) a water quality monitoring network on a 70,000 hectare watershed.

3. If a weir or flume is not available to you, how can streamflow amount be estimated ?

4. What factors should be considered in evaluating the erosion potential of a watershed ?

5. Discuss three natural resources problems that can be solved by remote sensing techniques.

6. To achieve watershed management objectives, reservoirs are often needed. Discuss how watershed resources management activities relate to multi-purpose reservoir management.

7. Discuss two major problems affecting watershed resources management in the humid tropics.

8. How can simulation and modeling techniques be used in watershed resources management ?

9. What information and data are needed to perform an economic evaluation of watershed management activities aimed at sustaining the life of a reservoir ?

10. Briefly, outline an environmental monitoring program, discussing the primary topics to be mentioned.

Annex VIII - 4

COURSE EVALUATION SUMMARY

VIII 4 TRAINING COURSE EVALUATION SUMMARY

(24 Participant Evaluators)

I. Participant Data

1. Participants were sponsored by USAID, UNESCO, or DTEC.
2. Two of the evaluators were female.
3. Four participants indicated they are participating in other watershed resources training.
4. Professional fields included Forestry Management, Horticulture, Civil and Chemical Engineering, Chemistry, Forest Biology, Watershed Management, Ecology, Planning, Agricultural Development, Geography, Agronomy, and Soil Conservation.
5. Work experience ranged from 6 months to 36 years with a majority having less than 10 years.
6. The majority hold M.S. degrees.

II. Course Enrollment and Orientation

1. 42 percent felt they did not have sufficient information to decide whether to enroll in the course.
2. 75 percent felt the pre-announced training course objectives were clear.
3. 46 percent felt that before arrival the course financial arrangements were not made clear.
4. Comments were that participants should be picked based on holding jobs where training can be applied, should have been provided with hand-out information prior to the course, the time period between application and acceptance was to long, and participation should be limited to those who need it, not higher ranking officials.
5. 92% of the participants felt orientation was adequate; two felt that more orientation was needed prior to arrival and that more details on course conduct and financial aspects were needed.

III. Training Environment and Support Arrangements

1. Percentage response was as follows :

	Not Adequate	Adequate	Very Good
Training Facilities	8	75	17
Housing	21	63	16
Meals	4	79	17
Transportation	8	67	25
Field trip arrangements	0	79	21
Social activities	8	75	17

Comments were that tables were needed in rooms, food was unusual to foreigners, too far removed from town with inadequate transportation, course should have been held in town or at Chiang Mai Univ., field trips other than Mae Sa were not instructive, and should know in advance which field trip locations are to be visited.

2. The daily schedule was considered too short by 0 % about right by 75 % and too long by 25 %.

3. The rest and break time was considered too short by 4 %, about right by 96%, and too long by 0%.

IV. Course Activities

Percentage response was as follows :

	Not Useful 1	2	Moderately Useful 3	4	Very Useful 5
a. Lectures	0	0	33	38	29
b. Work Sessions	0	8	29	38	25
c. Work Session Reviews	4	8	33	42	13
d. Case Studies	0	12	42	38	8
e. Field Trips	0	12	17	33	38
f. Equipment Use	0	21	25	17	38
g. Data Analysis	0	17	17	42	25

Comments were that the lectures needed more examples of problems,more audio-visual, and more review; work sessions should have been more structured, more time allowed, and items covered more slowly; explanation of use of equipment should be more detailed and not enough equipment; field trips should be more than a sight-seeing tour and followed with discussion of major points observed; case study reports should have concentrated on actions taken and results; a major problem with the lectures was not enough general basics for some participants, too elementary for others.

V. Field Experience (s)

A. Regarding logistical arrangements and best learning experience the Mae Sa trip was judged by for the best. Most felt that, overall , prepatory information was inadequate. A number felt that explanation of management techniques at projects was inadequate and there should have been opportunity for discussion/critics. The great majority felt that except for prepatory information the other factors rated from adequate to very good.

B. 79 % felt the time allocated to field trips was just right; 21 % felt the time allocated was too little.

C. Factors attributed to success of the field trips were : well prepared and organized, allowed participants to see specific problems and management methods, previous lecture exposure for background,availability of advance written information on visited sites,and the opportunity to sample and analyse stream water quality flow.

D. Factors that detracted from overall success of field trips were : objectives for the trip not spelled out,no chance for discussion or critic of management techniques, no "post-mortem" after the field trips, all field trips should have included data collection and

participant involvement, limited time at the sites, varying expertise made water sampling activity difficult, and inactive role of lecturers.

E. 4 % of the participants found the field experience to be less than moderately useful, 25 % found it to be moderately useful, 46 % found it to be more than moderately useful, and 21 % found it to be very useful.

VI. Instructors

All U.S. instructors were rated from moderately effective to very effective. Comments were that some lecturers should speak louder and more slowly, there should have been more and better organized visual aids, and more on application of basic hydrology.

Regional lecturers were rated similarly. Comments were that too short a time period was assigned for the topics, lecturers should confine themselves to the topic, more general rather than regional information should be presented, and that lecturer's English was hard to understand.

VII. Participant Involvement

1. 67 % of the participants felt the degree to which they shared ideas and experienced with the group was moderate, 21 % felt it was more than moderate, and 12 % felt they shared a great deal.

2. 91 % of the participants felt they participated to the extent wanted; 9 % felt they did not.

   Comments on what would have helped to increase participation were that more group involvement was needed, better grouping arrangements during working sessions,and better skill in English was needed.

VIII. Organization and Conduct of Program

1. Participant percentage responses were as follows regarding the amount of time devoted to the listed activity :

	About Right	Too Much	Too Little
Lectures	92	8	0
Group Discussion	46	0	54
Small Work Group	46	8	46
Participant presentations	67	4	29
Field trips	83	13	4
Individual consultation with instructors	48	0	52

Comments were that as there was little time for group discussion, participants should have seperated into smaller groups, that more time should have gone to intragroup work, that instructors should have sat with the work groups, that work groups carrying through the course should have been established early, and that two field trips would have been enough.

2. 17 % felt that in general the level of presentation was too simple, 75 % felt it was about right, and 8 % felt it was too complex.

3. 4 % felt the written materials used in the course were less than moderately helpful, 25 % felt they were moderately helpful, 38 % felt they were more than moderately helpful, and 33 % felt they were very helpful.

   Suggestions for improving course materials were : More problem examples, more developed bibliography, duplicate problem papers and distribute to all participants, all materials given to participants prior to the course, charts should be more clear and easy to understand, and additional references, etc. would have been helpful for the case studies.

4. 4 % of the participants felt the issues and problems discussed during the course were less than moderately relevant to their work, 42% felt they were moderately relevant, 33 % felt they were more than moderately relevant, and 21 % felt they were very relevant.

   Comments were that issues and problems were useful, but limited time prevented more details; all issues had some relevance to present jobs; and issues/problems were useful as teaching examples.

5. 18 % felt the English language did not limit understanding or participation at all, 14 % felt English limited them less than moderately, 64 % felt English limited them moderately, and 4 % felt English limited them more than moderately.

6. 91 % were satisfied with the order in which topics and activities were presented. 9 % were not satisfied.

   A comment was that the environmental monitoring topic should have been more related to watershed management.

7. 22 % felt the length of the course was to short, 70 % felt it was about right, and 8 % felt it was too long. A comment was that it should last exactly two weeks.

8. One participant felt that the modelling/simulation techniques and erosion processes/control sessions should be expanded, one felt case study sessions and field trips should be expanded, two felt the multiple use and integrated watershed management sessions should be expanded; three felt group discussion/problem solving should be expanded; three felt sampling/analysis should be expanded; one felt hydrological study methods should be expanded; two felt vegetation management/erosion should be expanded, one felt water quality topics should be expanded.

9. Two participants felt the hydrologic methods session should be shortened; one felt the guest lecturer lectures should be reduced; one felt there was too much emphasis on mathmatical calculations.

10. The following topics were recommended as additions to the course :
    a. Multi-disciplinary integrated approach in planning watershed development (five participants)
    b. Man in the watershed (one participant)
    c. Data analysis for each hydrological parameter (one participant)
    d. Pedology with relation to erosion (one participant)
    e. Agro-forestry (one participant)
    f. Application of course material to humid, tropical ecosystems (two participants)
    g. land and land-use classification/mgt. (one participant)
    h. Economic aspects (two participants)
    i. Agricultural extension techniques (one participant)
    j. Cultural/socio-economic aspects (one participant)
    k. Remote sensing interpretation (one participant)
    l. Computer programming (one participant)
    m. Environmental monitoring (one participant)
    n. Regulation of watershed areas (one participant)
    o. Geographics and methodology (one participant)
    p. Energy development from watersheds (one participant)

11. The only topic that was felt should be omitted was interactive modelling and simulation (two participants).

IX. Overall Satisfaction

1. 52 % of the participants expressed moderate overall satisfaction, 44 % expressed more than moderate overall satisfaction; and 4 % were very satisfied.

   A comment was that new things were learned.

2. 17 % felt that the course subject matter was moderately important to their job, 48 % felt it was more than moderately important, and 35 % felt it was very important to their job.

   One comment was that some topics were important while other were not. Another comment was that a small group of participants should choose the topics.

3. 43 % felt that overall the course was moderately valuable in terms of professional needs and responsibilities, 26 % felt it was more than moderately valuable, and 31 % felt it was very valuable.

4. The following as learned or experienced during the course was believed to be most useful professionally in the participant's home country :
    a. Exposure to tested methodology (one participant)
    b. Hydrologic cycle/erosion process and control (three participants)
    c. Working with other government officials and learning problem priorities (two participants)

d. Learning the importance and fundamentals of watershed management (five participants)
e. Sharing of ideas/knowledge and planning work in the home country (two participants)
f. Sampling and analysis (four participants)
g. Confirmation of management concepts relative to small catchment inventory and development (one participant)
h. Modelling/simulation techniques (one participant)
i. Vegetative management and environmental monitoring (one participant)

5. All participants indicated that they would recommend the course to other participants with similar backgrounds.

X. Other Comments

Comments to improve the training course were :

1. Inter-disciplinary team work should be expanded.
2. More time for preparation of country reports.
3. Movies should be added to slides as visual aids.
4. Observers should have received certificate thereby increasing their participation.
5. Group reports too time-consuming to present in class; distribute written reports.
6. More group discussions needed.
7. Limited time for numerous topics.
8. Too many unintended observers spoiled the course.
9. Course is useful and should be given again in Thailand to allow other officials to attend.

Annex VIII - 5

PRELIMINARY INVENTORY OF

WATERSHED MANAGEMENT PROJECTS IN THAILAND

VIII-5 PRELIMINARY INVENTORY OF WATERSHED MANAGEMENT PROJECTS IN THAILAND

Project Title	Lead agency	Funding source	Date	Location;area;elevation	Objectives
1. Kog Ma Watershed Management Research	Kasetsart University	USOM	1964	Doi Pui, Chiang Mai; 0.65 km^2 ; 1300-1600 mMSL	a. Compare effects of water yield and soil erosion of (i) natural forest, (ii) burned forest, (iii) mountain slope swidden agriculture, (iv) other uses or mgmt, practices on mountain lands. b. Use data and information collected to (i) recommend use and management of mountain lands (ii) determine sediment sources affecting downstream rivers, water diversion structures and reservoirs.
2. Huai Thung Cho	Royal Forest Dept. (Watershed Mgmt. Div.)	RTG	1975	90 Km NW Chiang Mai; 220 Km^2 ; 1000-1300 mMSL	a. Stop deforestation by (i) reforestation, (ii) provide permanent residence and alternative lifestyle for dwellers. b. Improve quality of life of dwellers.
3. Mae Sa Integrated Watershed and Forest Landuse	Royal Forest Dept. (Watershed Mgmt. Div.)	UNDP-FAO	1973 (revised in 1978)	Mae Rim district of Chiang Mai Province; 390 Km^2 ; 300-1685 mMSL	a. Promote economic growth and improve living conditions of farmers in the highland zones of Northern Thailand. b. Foster social integration within Thai nation of various people of the area. c. Improve environment through replacement of swidden agriculture compatible with rational landuse and through improved forest conservation and reforestation measures.

4. Royal Watershed Development Project Unit No.26 Khun Khong	Royal Forest Dept.	RTG	1966	Chiang Dao district of Chiang Mai Province; 120 Km^2 ; 1200-1700 mMSL	a. Develop degraded area of Mae Ping River headwaters employing reforestation to stabilize flow regimes and water yield. b. Socio-economic rehabilitation of hilltribes-education, health, feeder road, new farming techniques and small irrigation development. c. Replace opium cultivation with cash crops.
5. Doi Inthanon Development Project	King Project	Under Royal Patronage and RTG	1979	Doi Inthanon, Chiang Mai Province, 0.65 Km^2	a. Provide permanent stable agricultural system for hill tribe settlements. b. Promote replacement crops for opium c. Provide technical and economic inputs to increase standard of living. d. Preserve natural resources and provide facilities for tourism.
6. Watershed Rehabilitation project No.2 (Mae Khlong) Lower Mae Ping Basin	Royal Forest Dept.	RTG	1971	Doi Inthanon National Park, Chiang Mai Province; 100 Km^2 ; 1000-1700 mMSL	a. Reforestation to control streamflow.
7. Mae Sa Mai Village Development	Ministry of Agr.and Coop, Narcotics control Board	UNPDAC	1969	Headwater of Mae Sa tributary to Ping River, Mae Rim district, Chiang Mai province; 0.4 Km^2; 1100 mMSL.	a. Education b. Public health, village sanitation c. Road improvement. d. Water resource development (3 small reservoirs). e. Agricultural development-demonstration and training for proper landuse and conservation farming and new replacement crops for opium replacement.
8. Highland Agricultural Development Program to replace Opium Based Agriculture	King Project	RTG and UN and National drug enforcement agencies	?	Five hill tribe resettlement areas in Chiang Mai Province	a. Develop cash cropping systems appropriate for watershed conditions b. Adoption and implementation of agricultural practices that protect watershed values.

					c. Develop guidelines for classifying watersheds terms of resource management and utilization. d. Distributions of results of demonstration and promotion activities to farmers and other land managers. e. Develop marketing. f. Replace opium cropping.
9. Northern Agricultural Land Development Project	Land Development Dept.	Australia and World Bank and RTG	1968	Areas in seven northern provinces.	a. Stop swidden agricultural practices. b. Land allocation. c. Introduction of new technology to farmers. d. Soil and water conservation. e. Improve nonarable land for agriculture.
10. Mae Chaem Watershed Development Project	Ministry of Agr.and Coop.	USAID and RTG	1981 (1 yr. project)	Mae Chaem District, Chiang Mai Province	a. Use of integrated rural and agricultural development to raise agricultural production to subsistence level.
11. Rural development through watershed management in Nam Pong Basin (Mekong)	Royal Forest Dept.	requested from UNDP/FAO	pro-posal	Catchment of Ubolratana Dam, Khon Kaon Province; 150 Km^2	a. Prepare comprehensive watershed management plan. b. Training.
12. Upper watershed hydrology and data analysis	Royal Forest Dept.	Requested from UNDP/FAO	Pro-posal	Upper Chao Phya watersheds	a. Provide RTG with a report which will lead to management and development of natural resources of soil, water, and vegetation on major stream source areas for maximum economic production consistent with long term hydrostability and protection of downstream investments in agriculture, power and urban infrastructure. b. Training

13. Thailand-Conservation of Watersheds	NEP through National Watershed Committee	requested from IUCN	pro-posal	Northern Thailand	a. Develop methodology for classification of watersheds for management. b. Recommend procedures for application of methods. c. Test methods. d. Training.

Annex VIII - 6

LIST OF LECTURERS, PARTICIPANTS, AND OBSERVERS

VIII-6 LIST OF LECTURERS, PARTICIPANTS AND OBSERVERS

Lecturers

U.S.A.

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Annex VIII - 7

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