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9. ABSTRACT

(Engineering--Hyraulics R&D)

Volumes I & II; Supplements to Volumes I & II

A PROJECT: Intended to guide the officers of the Agency for International Developme in evaluating and determining the technical and economic feasibility of desalination projects for which U.S. Government assistance may be sought. The original two-volume Manual -- one volume on technology and one on economics -- was prepared by Kaiser Engineers of Oakland, California in April, 1967. In October, 1972, Burns and Roe Inc., of Oradell, New Jersey produced a supplement to each volume.
Duration: 1967: 1972

DEVELOPMENTS: Technical improvements and cost reductions of desalination have added a new dimension to water supply planning: This method of supplementing freshwater supplies demands prominent consideration as a means of meeting future water needs. The Manual reviews various desalination processes and presents economic and technical guidelines for gathering and analyzing data on energy and water resources and requirements -- data that must be considered in deciding whether water desalination is a viable solution to an area's water shortage problem. Volume I discusses eight desalination methods and describes a typical plant for each: Distillation processes - 1. vertical falling and rising film, 2. multistage flash, 3. multieffect multistage flash, 4. vapor compressions, and 5. solar stills; Non-distillation processes - 6. vacuum-freezing vapor-compressions, 7. electrodialysis, and 8. reverse osmosis. It includes a feasibility study on combining desalination

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plants with electric power generating plants, and a discussion on combining desalination with production of chemical by-products. Volume II gives guidelines for studies to determine if desalination is the optimum solution to an area's water shortage problem. An Appendix lists existing plants, technical data on properties of seawater and brackish water, and sample survey questionnaires. The Supplements to Volumes I & II do not present new technologies but rather refinement and commercialization of the material in the two volumes. They update technical and economic guides - often pointing to the increased viability of desalination solutions. The Supplements describe typical plants built since 1967 and provide sections on conceptual designs, water development planning, and updated budget water plant pricing. They add as well some environmental considerations, and feed treatment and brine disposal methods. Whereas the Manual provides information for evaluation and determination of the feasibility of desalination programs, it does not provide the detailed technical data required by a desalination plant designer. Volumes I & II can be used independently of each other; the Supplements, however, do require reference to Volumes I & II.

# A MANUAL ON WATER DESALINATION

## VOLUME TWO—ECONOMICS:

CHAPTERS 8 - 11

APRIL 1967

PREPARED FOR

Department of State
AGENCY FOR INTERNATIONAL DEVELOPMENT
OFFICE OF ENGINEERING
Washington, D.C. 20523

KAISER ENGINEERS . OAKLAND . CALIFORNIA

# A MANUAL ON WATER DESALINATION

## VOLUME TWO

Prepared For

U.S. DEPARTMENT OF STATE

AGENCY FOR INTERNATIONAL DEVELOPMENT

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## Notice

"This manual was prepared for the Agency for International Development (AID), to guide its officers in evaluating and determining the technical and economic feasibilities of desalination programs and projects, for which United States Government assistance maybe furnished or sought. The information contained herein is not sufficient for and is not intended to be the sole basis for design or construction of a project at any particular location, or as a substitute for professional judgment, advice, and design work by competent engineers in connection with such a project."

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## APPENDIX

# LIST OF FIGURES

# VIII. SOLUTION OF WATER SHORTAGE PROBLEMS

VOLUME TWO of this manual provides guidelines for the initiation of a program for defining and solving the water shortage problems of a particular nation or region. The orderly solution of national or regional water shortage problems within a definite period of time demands the preparation of a logical and feasible plan of action.

The administration of a water development project from its initial study phase to satisfactory completion may be the responsibility of either an existing government agency or a special Water Development Board established by the government to solve the national or regional water shortage problems. In the subsequent text of this manual it is assumed that a special agency such as a Water Development Board has been created to administer the project.

The Water Development Board should organize or employ a Study Organization, which would be responsible for performing a comprehensive analysis of the scope and magnitude of the water shortage problems; for defining all possible solutions to these problems; and for determining which solution is technically and economically optimum. The following subsections summarize the structure and qualifications of the Study Organization and its objectives, and outlines the plan of action to be followed.

## A. Study Organization

### 1. Structure of Study Organization

The type of Study Organization selected will depend on the size and complexity of the water shortage problems, on the degree of national development and on the availability of personnel from government agencies and independent consulting organizations.

The organization may consist of qualified personnel assigned from other government bodies or public agencies related to the project, with outside consultants utilized for specialized tasks; alternatively, an independent consulting firm qualified to make preliminary surveys and preliminary feasibility studies may be engaged to perform the major portions of the study work.

2. Qualifications of Study Organization

The factors that should be considered in the selection of personnel and firms for the Study Organization are the technical and administrative capability of the organization's management and personnel and the previous technical achievements of members of the organization. The surveys and studies require qualified personnel, representing many disciplines; thus, the scope of the study is an important consideration in the selection of personnel and/or firm.

## B. Study Objectives

The responsibilities of the Study Organization would be to compile and evaluate available information, to develop any additional information required by the project, to perform preliminary design and cost estimates, and to present recommendations for Board action.

The primary objectives of the study would be:

1. To compile all available background information and water data, and perform sufficient additional surveys to define the water shortage problem in terms of present and future requirements and resources.

2. To evaluate background information and water data, and identify alternative solutions which may be economically and technically feasible.

3. To compare the alternative solutions by performing a preliminary feasibility study on each.

4. To prepare a report describing the results of the work performed and containing recommendations for future action. This report would be used by the Board in making plans for specific solutions to to the water shortage problems.

## C. Outline of Plan of Action

The solution ot the water shortage problems of a country or region should be sought in a series of logical steps, progressing from the point where a present or future water shortage is recognized to the point where a commitment is made for a specific facility. As shown in Figure VIII-1, the necessary steps are: background surveys which

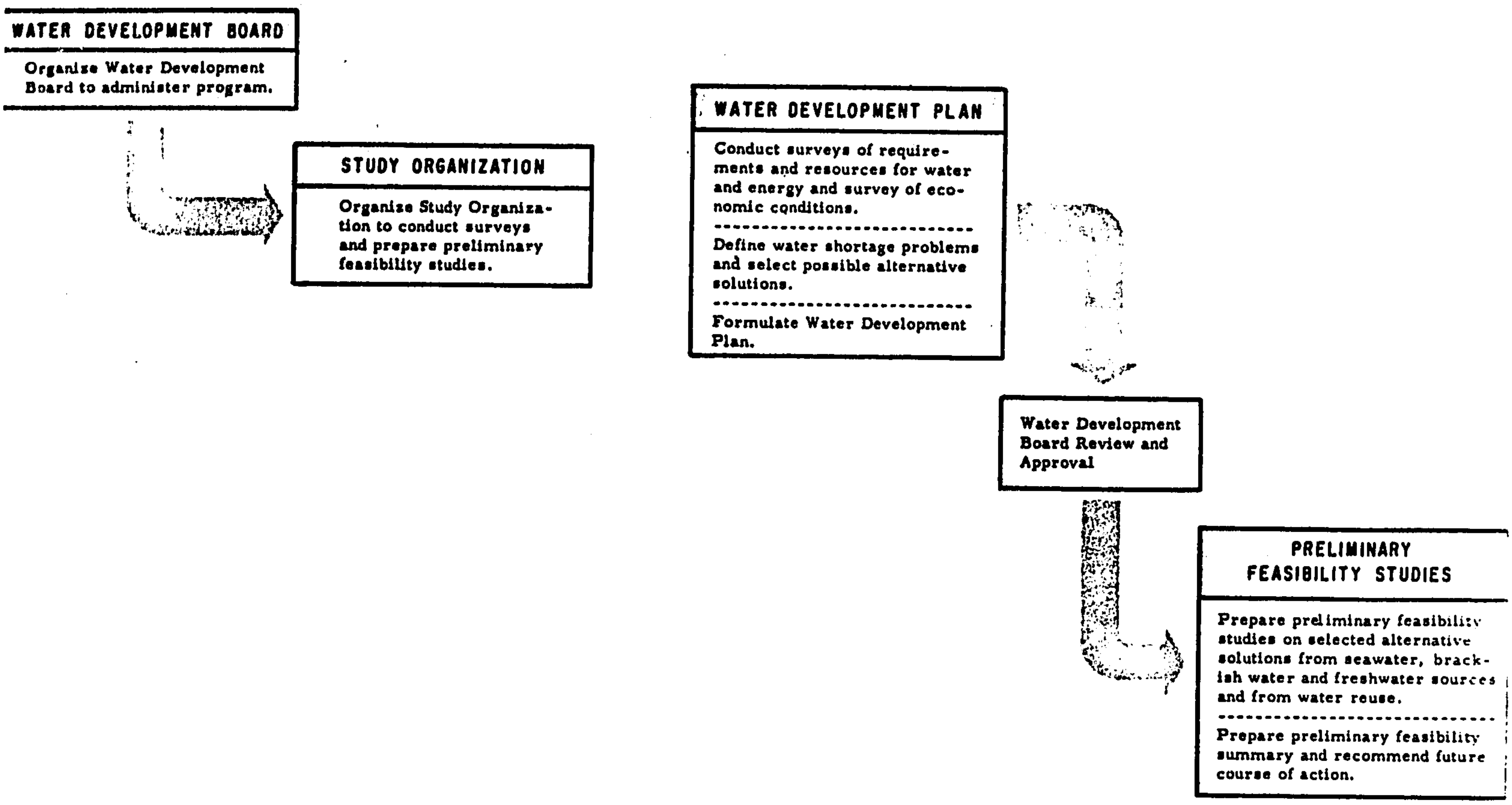
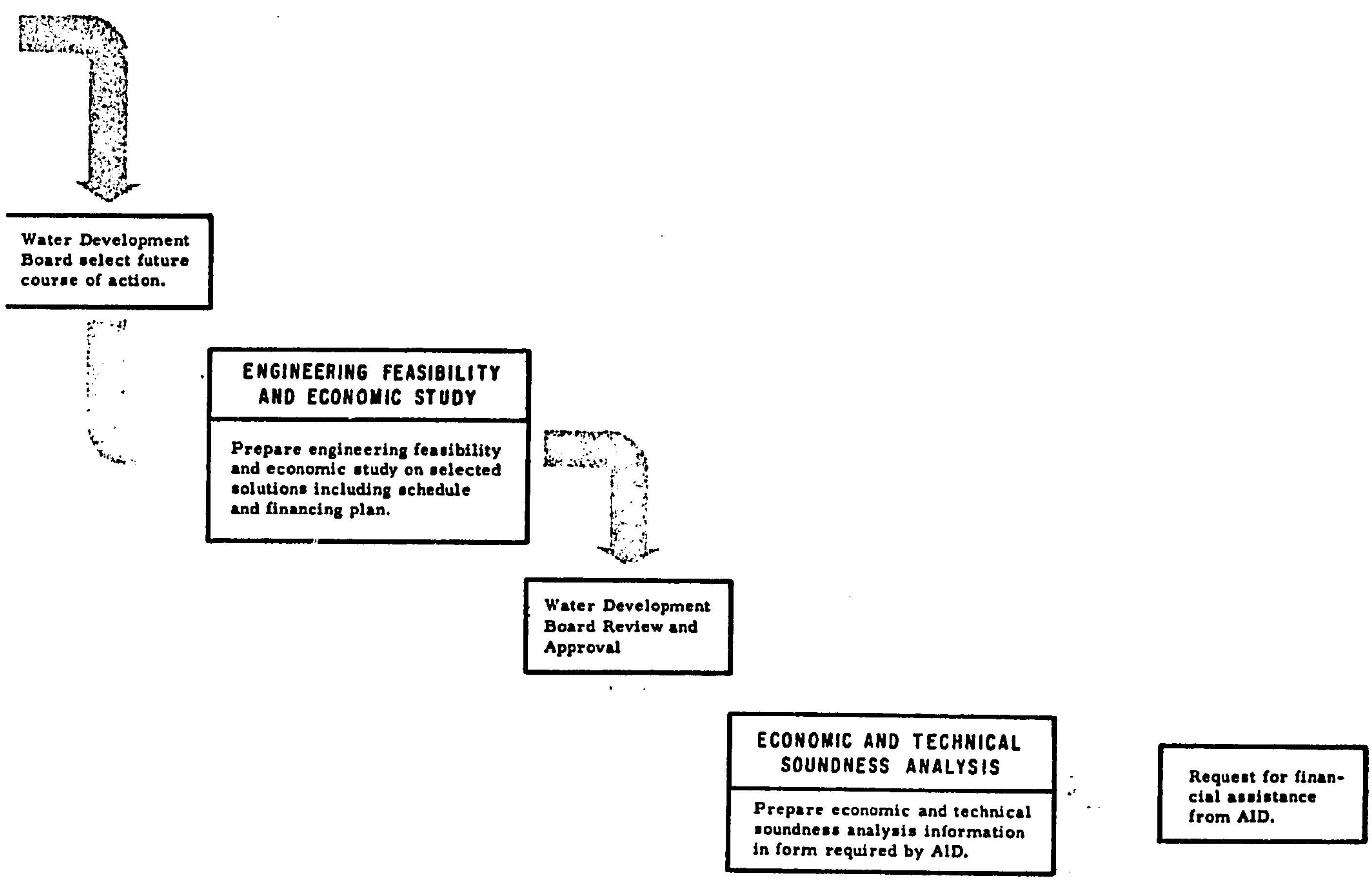

WATER DEVELOPMENT BOARD
Organize Water Development Board to administer program.
STUDY ORGANIZATION
Organize Study Organization to conduct surveys and prepare preliminary feasibility studies.
WATER DEVELOPMENT PLAN
Conduct surveys of requirements and resources for water and energy and survey of economic conditions.
Define water shortage problems and select possible alternative solutions.
Formulate Water Development Plan.
Water Development Board Review and Approval
PRELIMINARY FEASIBILITY STUDIES
Prepare preliminary feasibility studies on selected alternative solutions from seawater, brackish water and freshwater sources and from water reuse.
Prepare preliminary feasibility summary and recommend future course of action.

FIGURE VIII-1

# TYPICAL
# WATER DEVELOPMENT PROGRAM



provide all necessary background information; preliminary feasibility studies of possible solutions; and a detailed engineering feasibility and economic study.

In seeking the solution to the water shortage problems, consideration is given both to the development of present freshwater resources and to the production of potable water by desalination of seawater or brackish water, to determine which solution would provide the least expensive water. Volume One has provided comprehensive background information on desalination process technology; this information includes detailed descriptions of the many available processes, descriptions of typical desalination plant designs using these processes, and summaries of single- and dual-purpose plant design studies for specific applications. If a desalination facility is selected as part of the solution which fulfills the water requirements of a particular nation or region, the information contained in Volume One can be utilized in considering particular plants or process types.

In the logical sequence of steps leading to the solution of the water shortage problems, the following documents should be produced:

1. Water Development Plan

   The Water Development Plan should provide a definition of the water shortage problems of the region or country; it should report and summarize all of the background information on the resources and requirements for water and energy; and it should define and summarize all of the possible alternative solutions. Section IX of this Manual describes the procedure recommended for formulating the Water Development Plan.

2. Preliminary Feasibility Studies

   After the Water Development Plan has been formulated, preliminary feasibility studies should be carried out on the various alternative solutions defined in the Water Development Plan; these feasibility studies are described in Section X. The results of the preliminary feasibility studies should be evaluated, and the most promising solution (or solutions) should be selected for further, more detailed study.

3. Detailed Engineering Feasibility Study of Selected Solution

The solution (or solutions) selected in Section X should be subjected to a detailed engineering feasibility and economic study; the procedure recommended for this detailed study is described in Section XI. The results of this study would serve as the basis for a commitment for the design and construction of a specific facility; they would also be used in preparing the Economic and Technical Soundness Analysis which must accompany each request to AID for assistance on a proposed project.

# IX. THE WATER DEVELOPMENT PLAN

## A. Introduction

The first step in the search for the solution to the water shortage problems of a country or region is the assembly and evaluation of background information on the water and energy resources of the area. The Study Organization should carry out a number of concurrent surveys to obtain this information as well as information on possible solutions to the pro<sup></sup>lems; it should then summarize all the information in a document called the Water Development Plan. The suggested sequence for the surveys, definitions and evaluations which culminate in the formulation of the Water Development Plan is shown in Figure IX-1. Since the Water Development Plan is to be the basis for subsequent work it should include all the descriptions, maps, tables, graphs, evaluation materials and references necessary to present a clear and detailed picture of the water shortage problems and of their possible solutions.

Evaluations of energy requirements and resources should be an integral part of the Water Development Plan since the solution of water shortage problems is, in general, related to the production or use of energy. The development of rivers or the use of dual-purpose power-desalination plants (refer to Section VI) can result in the production of considerable quantities of electrical power; this can reduce substantially the cost of water at the point of use. Moreover, most desalination processes require large amounts of mechanical or electrical power for their operation (e.g., for pumping, for feedwater or brine heating, for vapor compressors, for freezing apparatus, etc).

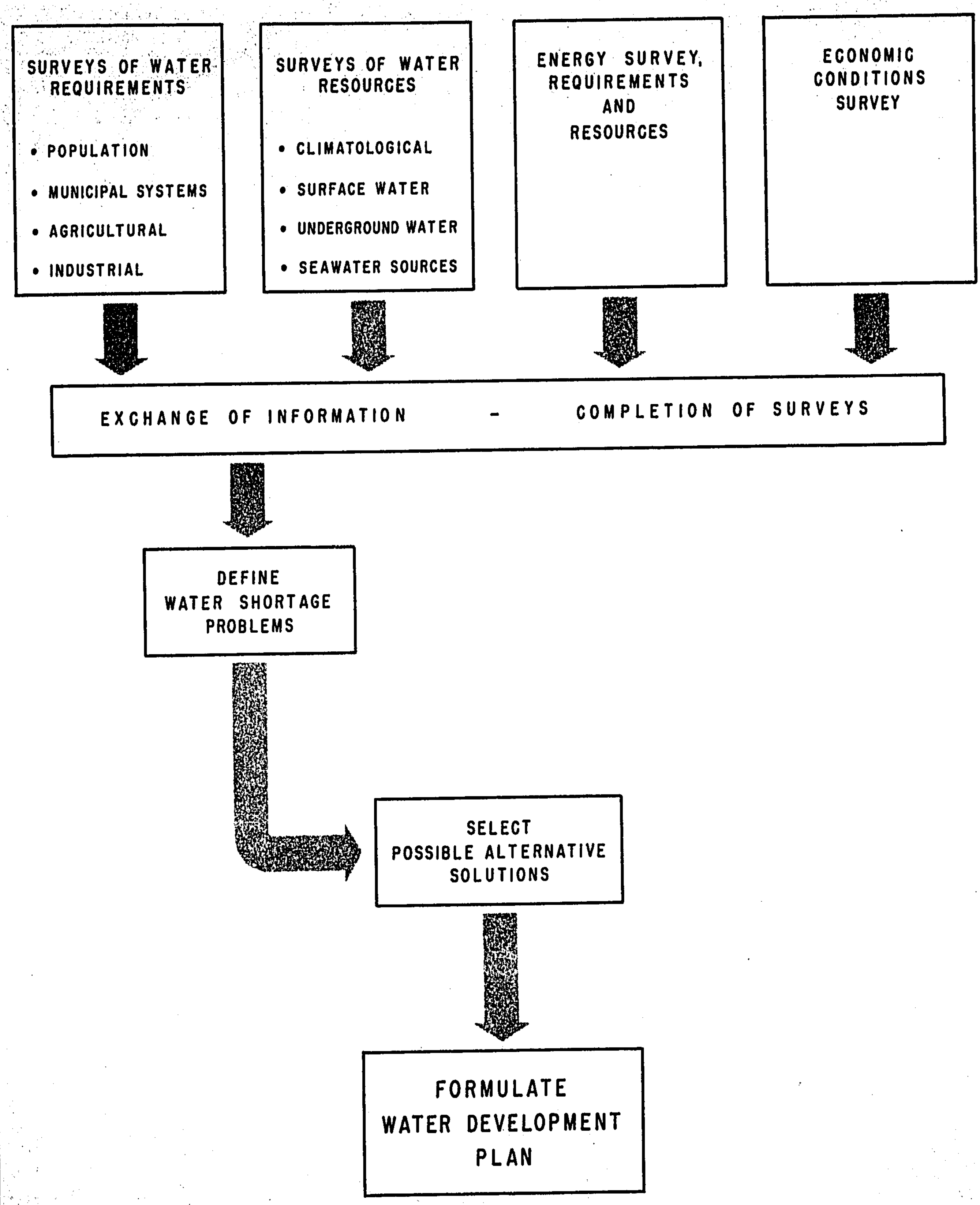
## B. Surveys of Requirements and Resources

### 1. General

The definition and solution of water shortage problems require a considerable amount of background information concerning present and future water requirements and sources, as well as comprehensive information concerning the methods by which additional water supplies can be made available.

FIGURE IX-1

## FORMULATION OF THE WATER DEVELOPMENT PLAN



Solutions of water shortage problems either by desalination methods or by development and utilization of natural water resources usually involve the use or production of energy; therefore, the background information should also include comprehensive data on present and expected power requirements.

To provide the background information necessary in determining the water and energy needs of an area and in determining the resources that are available to meet these needs, the following surveys must be made:

- A Population Survey to determine the locations, timing and amounts of water required to support the population projections
- A Municipal Water Systems Survey to determine the present capabilities and projected requirements of the systems used to convey and distribute water for municipal needs
- Agricultural Surveys to determine the influence of food production on the entire economic and population structure of the region or nation
- An Industrial Survey to determine the water needs resulting from industrial development
- A Climatological Conditions Survey of the nation or region
- A Surface Water Resources Survey, which should include both the fresh and brackish water surface flows
- An Underground Water Resources Survey (or a survey of aquifers) which also should include both fresh and brackish water aquifers
- A Seawater Sources Survey and a study of the problems associated with possible sites for desalination plants
- An Energy Survey of present and projected energy needs and availability
- An Economic Conditions Survey to investigate the economic climate of the nation or region

For optimum results, these surveys should be concurrent, and information collected by one survey group should be made available to other groups as quickly as possible in the form of preliminary interim reports. Using these reports, the parallel survey groups may revise their own projections.

The contents and factors that should be considered in each of these surveys of water requirements, water resources, energy requirements and resources and economic conditions are given below.

## 2. Surveys of Water Requirements

### a. Population Survey

A nation's or region's water needs are intimately related to its population count and character, whether urban or rural, and to its stage of development. Water needs are usually expressed on a per capita basis, with the per capita value being a function of the degree of development and industrialization in the area. A population survey is therefore necessary to determine the quantities, distribution and timing of the water supply required to support the population projections. The population survey should include the following elements:

(1) Historical background of the nation or region

(2) Compilation of available census information

(3) Analysis of census information (by age groups, birth and mortality rates and regional distribution)

(4) Analysis of population distribution and determination of distribution factors

(5) Evaluation and determination of "water requirements modifying factors" attributable to population changes and migrations. These factors would attempt to establish the secondary effects that an increased water supply would have on the population trends in a region.

### b. Municipal Water Systems Survey

Depending on the stage of development of a region or nation, the nonindustrial and nonagricultural water needs of urban areas are met by municipal water systems; to some extent these systems also serve industrial concerns.

The municipal water systems survey consolidates all information concerning the location and capabilities of the existing and projected municipal water systems. This survey should take into into consideration the following items:

(1) A description of present municipal water sources, storage, conveyance and distribution systems, stating design capacities and ultimate capabilities. The survey should also include a description of and data related to sewage handling and treatment facilities.

(2) A survey of the present condition of the municipal systems and their operating costs.

(3) A description of projected municipal systems, stating design capacities and ultimate capabilities and predicted construction and operating costs.

(4) An evaluation of possible water reclamation schemes.

(5) A determination of the present and projected per capita consumption, based on projected water availability and socio-economic development.

(6) A determination of municipal water requirements modifying factors which are attributable to availability and cost of water; to regional or national development; to population, agricultural, industrial and commercial changes; to availability of energy sources and production; and to general economic conditions.

c. Agricultural Surveys

In general, food production is related to the stage of development of a nation. This rule does not apply to highly industrialized nations (e.g., Britain, Japan) that have to import a considerable proportion of their food requirements because of limitations on the amount of land available for agricultural production.

Generally, in regions that sustain or can sustain considerable agricultural development, additional water supplies from desalting sources are not economically feasible, unless the agricultural effort is concentrated around extremely high value crops (e.g., dates, citrus, olives). Conditions might occur, however, where one region of a country could sustain considerable agricultural or food production while other potentially productive regions (e.g., regions rich in mineral or fuel resources, strategic ports or processing locations) could be developed only if water were made available for the population required to exploit these natural resources.

An agricultural survey of present and expected food production capabilities is, therefore, very important in determining the influence of food production on the overall economic and social conditions of the region or nation, since these conditions, in turn, affect the water needs.

The agricultural survey should:

(1) Determine the geographical distribution of crops, of livestock production and yields, and of prices received for agricultural products.

(2) Determine the projected geographical distribution of crops, of livestock yields, and of value of agricultural products.

(3) Determine the land available for agricultural production, for changes in farm sizes, for tenure methods of land allocation, for new crops, for rotation of crops, and the water requirement for various crops (acre-feet/year).

(4) Determine the available and projected water for agricultural purposes

(5) Determine the locations and sizes of markets and transportation facilities

(6) Analyze and make projections of population food requirements

(7) Evaluate the importance of the agricultural development, and determine the water requirements modifying factors due to:

   (a) Agricultural development of the region or nation, change and rotation of crops, yields, improvement of livestock, marketability and prices obtained for agricultural products and livestock.

   (b) Development of lands and changes in land tenure methods

d. Industrial Survey

The industrial development of a nation or region can be closely related to the availability of water; therefore, in determining the water needs of a nation or region the present and projected industrial development should be surveyed and evaluated. Examples of average water usages in industrial processes are:

| | Water Usage (Gal. per ton) |
|---|---|
| Steel | 32,000 |
| Aluminum | 30,000 |
| Synthetic Rubber | 660,000 |
| Newsprint | 240,000 |
| Rayon Fiber | 200,000 |

The industrial survey should:

(1) Make a compilation of raw material sources for the basic industries and an estimate of potential sources for development

(2) Make a compilation of the types, sizes and location of present and projected basic industrial activities and concerns contemplated

(3) Determine present and projected needs of the basic industries with regard to:

(a) Raw materials

(b) Markets

(c) Work force

(d) Financing

(e) Water availability and needs

(f) Energy requirements

(4) Make a compilation of the types, sizes and locations of present and projected secondary industry or manufacturing concerns.

(5) Determine present and projected water needs due to secondary manufacturing concerns

(6) Make a study of water reclamation or reuse facilities for industrial purposes

(7) Evaluate the impact of industrial development on the amount of water requirements, and determine the factors that interrelate water requirements and industrial development.

3. Surveys of Water Resources

a. Climatological Conditions Survey

The origin of all water resources can be traced to the natural atmospheric evaporation and condensation or precipitation processes.

Some of the precipitation returns to the oceans by the surface of the earth, part returns in underground rivers or aquifers and part returns to the atmosphere by evapo-transpiration.

The understanding of the climatological characteristics of a region or country is necessary, therefore, in determining the availability and extent of the available natural water resources. The climatological survey should:

(1) Make a compilation and an analysis of precipitation (rain and snow), wind, relative humidity, temperatures and solar radiation.

(2) Determine average yearly profiles for the above items for typical regions

(3) Correlate records and tree ring growth

b. Surface Water Resources Survey

The survey of surface water resources is concerned with the location, quantity and characteristics of fresh and brackish water surface runoff, and with possible surface water utilization schemes using retention and conveyance facilities.

The surface water survey should:

(1) Make a compilation of the topographic information available for the regions considered

(2) Locate all river basins and determine the areas covered

(3) Determine average runoff, absorption, permeability and evaporation coefficients for the various basins.

(4) Determine river flows, maximum recorded flood stages and minimum flows.

(5) Determine average flow profiles, average annual flows and dependable flows available for use.

(6) Evaluate possible hydrodevelopment sites

(7) Evaluate particle carry-over and sedimentation problems

(8) Perform a chemical analysis to determine composition and classification of surface waters

(9) Make a compilation of existing or projected water retention facilities with regard to:

(a) Location, size and type of facilities

(b) Cost of facilities built within the last 10 years

(c) Operational and maintenances costs

(d) Soil permeability and evaporation losses

(e) Adequate sites for reservoirs and their approximate capacities

(f) Sedimentation problems

(g) Evaluation of potential hydroelectric value

(h) Distance to water utilization points

(10) Make a compilation of water conveyance systems, such as canals, aqueducts and pipelines, either existing or projected, including information relative to:

(a) Location, sizes and capabilities

(b) Installation costs

(c) Operating costs

(d) Operational problems

(e) Right-of-way problems

c. Underground Water Resources Survey

In the natural water cycle, part of the precipitation returns to the water sources (oceans or large bodies of water) by means of underground rivers or porous strata. The strata or formations traversed by the underground flow will impart certain characteristics to these waters; these characteristics may allow such waters to be used without treatment or, alternatively, may require that the water be processed to remove the salt contents.

The preparation of a regional or national water plan requires that these amounts of water be known and considered; therefore, a survey of underground water sources is required.

The survey of underground waters should:

(1) Make a compilation and a classification of known underground water sources (springs and aquifers) regarding:

(a) Location of sources

(b) Estimated sustained capabilities of the sources

(c) Age of each source

(d) Utilization history

(e) Chemical analysis and composition

(f) Evaluation of as-produced costs for underground waters

(2) Make a compilation of existing geological information from surface formation surveys and core drillings

(3) Perform a geological and geophysical survey to determine promising aquifer formations

(4) Perform drilling and exploration program of promising geological formations, and evaluate information obtained.

d. <u>Seawater Sources Survey</u>

The largest source of water for desalination processes lies in the seas and oceans, which cover 75% of the world's surface.

Many coastal areas require fresh water for their development; therefore, the characteristics of the seawater supply and problems associated with the utilization of this seawater in desalination processes should be determined in a seawater sources survey.

The seawater sources survey should:

(1) Make a compilation and a description of possible sites for desalting plants

(2) Make a compilation of hydrographic information concerning:

(a) Tidal records, currents, and temperatures.

(b) Sea level datum, high mean and low tides and inundation levels.

(c) Erosion of the coastline and description of bottom

(3) Make a compilation of shoreline geological information including:

(a) Representative bottom samples

(b) Sediment information

(c) Geological profiles of underlying strata below shore and of marine sedimentary bottom

(d) Seismological information

(4) Determine the biology of marine flora and fauna, including information concerning:

(a) Algae, kelp and marine vegetation.

(b) Fish species and benthos fauna

(5) Determine the coastal traffic in potential site areas

(6) Determine the recreational value of beach at potential sites

(7) Analyze the seawater quantitatively and qualitatively, and evaluate turbidity and sedimentation causes.

(8) Collect temperature records, profiles and thermocline information.

(9) Evaluate special problems such as tidal waves and storms

4. Energy Survey

The amount of available or potentially available energy plays an important role in the development of a nation or region. The solution of water shortage problems by redistribution, by conveyance of natural waters or by desalination of seawater, is intimately related to the use or production of energy; therefore, the energy resources and requirements of a nation must be known, and coordinated with the solution of water shortage problems.

The energy survey should:

a. Determine the present and projected fuel resources, including size and location of known natural reserves such as coal, oil and gas and ores suitable for nuclear energy uses; perform a preliminary evaluation of fuel cost projections.

b. Determine the present and projected locations and capabilities of hydropower developments

c. Determine the location, production capability and production costs of present and planned energy production facilities.

d. Determine the location, capabilities and transmission costs of the existing and projected energy transmission facilities, such as electric transmission lines and oil and gas pipelines.

e. Make a compilation of the nation's present and projected energy requirements, including those for municipal, industrial and agricultural users, and of the present and expected distribution of large-demand load centers.

f. Evaluate the effect of energy development on the amount of water requirements, and determine the relationship between water requirements and energy development.

5. Economic Conditions Survey

The Foreign Assistance Act of 1961 authorizes loans for promoting the economic development of less-developed countries. In evaluating the technical and economic soundness of the project, AID considers the following:

- The contribution of the activity to the economic development and resources of the country

- The extent to which the recipient country is showing responsiveness to the vital economic, political and social development of its people and demonstrating a clear determination to take effective self-help measures.

To determine these factors, it is desirable to consolidate the available information on the economic conditions of the country in an economic conditions survey.

The survey of economic conditions should:

a. Determine the financial status of the country, including international credit rating, and perform an analysis of foreign trade, foreign cash and gold reserves.

b. Compile a history of international loan repayments and an analysis of political system and stability.

c. Prepare a description of the country's banking system, banks and agencies, integrating the banking system, reserves, loan terms and interest rates for short and long term loans. This should include a review of industrial and consumer credit policies.

d. Compile a wholesale commodity price index history in native currency and dollar equivalents, and an industrial production index measured in native currency and dollars.

e. Determine industry expenditures, history and projections.

f. Determine the average per capita income trends and relation to commodity prices in native currency and dollar equivalents.

g. Determine potential areas for economic development.

h. Determine and evaluate water requirements modifying factors due to changes in economic conditions.

## C. Water Development Plan

After the background surveys are completed, at least in preliminary form, steps may be taken to define the overall water shortage problems and to set forth possible solutions. Based upon the water resource surveys and upon the information on water desalination processes provided in Volume One of this manual, possible solutions should be selected, utilizing development of natural freshwater sources, water reclamation, and brackish or seawater conversion plants. If solutions based upon the development of natural freshwater sources appear to be economically feasible, these should be evaluated first since they will, in general, yield lower-cost water than desalination methods. Also included should be solutions which would yield electrical energy in addition to providing fresh water (dual-purpose electric power-water desalination plants) and solutions which would yield chemical by-products in addition to fresh water.

1. Possible Solutions

a. Development of Natural Freshwater Sources

To determine possible solutions to the water shortage problems, the development of the freshwater sources inventoried in the preceding surveys should be defined and reviewed.

This review comprises a concise compilation of resources, and a determination and preliminary evaluation of possible solutions. At this point, sufficient information would not be available for an accurate estimate of costs; however, solutions that are clearly not competitive should be omitted. This review should include:

(1) Appraisal of the magnitude, location and characteristics of the hydrological basins and streams either already developed or capable of being developed by the construction of dams, reservoirs or hydropower projects.

(2) Preliminary studies of the rational utilization of the hydrological basins and streams either already developed or having development potential.

(3) Preliminary studies of surface water collection facilities, including consideration of the production of hydroelectric power from such water.

(4) Preliminary studies of the utilization of freshwater aquifers either already being used or having development potential

(5) Determination of whether a well drilling program will meet water requirements.

(6) Studies relative to the size, location and capacity of the required water conveyance facilities between the point of collection and the point or points of utilization.

(7) Studies concerning interception of streams or aquifers to prevent salt contamination of the freshwater surface or underground streams.

b. Water Conversion Solutions

To determine possible water conversion solutions to the water shortage problems, a review should be made of the utilization of desalination processes for obtaining fresh water from the sources of seawater or brackish water identified in the preceding surveys (Subsection IX B).

This review should consider and evaluate the characteristics of the brackish and seawater sources, and make a preliminary selection of suitable water conversion processes for the particular applications. The descriptions and limitations of the available processes have been provided in Volume One of this manual. While definitive cost estimates will not be possible at this point, processes that are clearly not competitive should be omitted. This review should also consider the influence on the unit costs of the conveyance facilities between the plant site and the point of use.

This review should include:

(1) Appraisal of the magnitude, location and characteristics of brackish water basins and surface and undergound streams suitable for desalination processes or for blending with desalinated water.

(2) An evaluation of the feasibility of blending desalinated water with slightly brackish water resources -- and thereby lowering the brackish water salinity such that is becomes suitable for industrial, domestic or agricultural use.

(3) Selection of suitable brackish water conversion process(es) for the estimated range of water production requirements.

(4) Determination of possible brine and salt disposal problems for inland sites.

(5) Appraisal of the characteristics of possible oceanside sites for desalination plants, and of the problems associated with those sites.

(6) Selection of suitable seawater conversion process(es) for the estimated range of water production requirements.

(7) A determination of energy requirements, and an evaluation of benefits derived from dual-purpose (power-desalting) plants.

(8) Consideration of the distance and possible routing of the product water lines between point of production and point of utilization.

(9) Consideration of topography of terrain to be traversed by the product water lines.

(10) Determination of requirements for conveyance system canals, aqueducts and pipelines, as a function of the production range of the water to be conveyed.

(11) Consideration of the distance, possible rounting and requirements of the electric power transmission lines between the electrical transmission grid and the desalination facility.

2. Final Plan

To serve properly as the basis for subsequent work, the Water Development Plan document should include the following elements:

a. Requirements Section

This section should comprise the conclusions concerning water requirements, including an evaluation of the effects of a completely adequate supply of water. It should contain:

(1) A list of priorities and a water development timetable.

(2) A summary of present and expected municipal water requirements.

(3) A summary of present and expected industrial water requirements.

(4) A summary of present and expected agricultural requirements.

b. Resources Section

This section compiles the available information relative to:

(1) Solutions requiring the development of natural hydrological resources for fresh water.

(2) Eventual possibilities for reclamation schemes and water reuse.

(3) Solutions of water shortage problems by means of saline water conversion and information on the water sources for such processes.

(4) Conclusions regarding effects of energy requirements and resources on water development.

c. Background Information Section

This consists of the final reports prepared by each survey group.

# X. SELECTION OF MOST PROMISING SOLUTION

Section IX has described the compilation and analysis of the background information necessary to define and determine the magnitude of the water shortage problems existing in a nation or region. The final product of this work would be the Water Development Plan summarizing the background information on requirements and resources and setting forth a water development timetable and possible solutions to the water shortage problems. This section establishes the guidelines for the preliminary feasibility studies on the possible solutions, and for the determination of the most promising course of action based upon the results of these studies.

## A. Preliminary Feasibility Studies

The first step in the implementation of a Water Development Plan is the performance of preliminary feasibility studies on the possible solutions. This will furnish the Water Development Board with the information necessary to select the most appropriate and advantageous course of action. The consideration of each alternative solution should include the preliminary feasibility studies, evaluations and cost estimates necessary to determine the capital costs, annual costs and unit cost of the water. These studies should be made on facilities which would provide the desired production or capability in accordance with the Water Development Plan timetable.

In the examination of alternative solutions, design capacity is an important consideration. Either water conversion or the development of underground freshwater resources would follow the water development timetable in numerous but small steps; a large hydrological basin development would provide a large amount of water at once. Such considerations play an important role in the determination of the plant operating factors which, in turn, affect the unit costs.

### 1. Guidelines for Preliminary Feasibility Studies

Since the preliminary feasibility studies will be used both for comparing alternative solutions and as the foundation for more detailed studies on the selected alternative or alternatives, they should be performed on an equitable basis. To arrive at realistic comparative costs, sound estimating methods should be used. Factors that should be considered in the preparation of preliminary feasibility studies are discussed below.

a. Capital Cost

In preparing the capital cost estimates for labor, equipment, and materials and the other costs which constitute the investment required to construct and put the water facility into operation, the following factors should be taken into consideration:

(1) The assumed proportion of local participation in the supply of labor, equipment, materials and supplies, and the conversion of these costs into U. S. dollars using a realistic currency exchange rate.

(2) The amounts of imported labor, materials and equipment, also expressed in U. S. dollars using realistic exchange rates.

(3) Special construction problems may be caused by local conditions such as accessibility, climate and customs, and these may affect or delay the completion of the facility, thereby increasing the amounts of indirect costs and interest during construction chargeable to the project.

b. Annual Cost

The annual cost estimates should take into account:

(1) The prevalent financing interest rates for projects such as the alternative being considered

(2) The expected life of the water facility. In general, this will be longer for hydrological developments than for water conversion facilities.

(3) An assumed depreciation method for the type of facility, and a determination of the salvage value.

(4) The cost of the energy required by the water facility (for fuel, electricity, etc) and the value of the energy when produced by a dual-purpose plant or a hydropower development.

(5) The requirements and costs for labor and materials for the operation and maintenance of the facility

(6) Assumed periodic replacement rates due to normal wear of the facility

(7) Taxes and insurance costs.

The values assumed for items (1), (2), (3) and (7) determine the annual fixed charges chargeable to the facility. When the alternative is a dual-purpose plant or a hydropower development, items (4), (5) and (6) determine the annual operating costs or, in the case of the item (4), the operating credit.

c. Unit Cost

Water facilities are usually designed with sufficient capacity to supply future water demands. Thus, during the earlier years of operation, until the demand finally reaches the design capacity, it is likely that the plant operating factor may be relatively low. Since, in a feasibility study, the calculated unit cost of water is a direct function of the assumed plant operating factor, a realistic selection of an average factor covering the life of the facility is an important consideration.

d. Practicability Considerations

Only proven methods or commercially available processes should be considered in the feasibility studies. Methods which are in a pilot-plant development stage should not be considered unless positive assurance can be provided that the extrapolations made will be correct. The limiting technical and economic factors which Volume One of this manual identified for each of the several desalination processes should be considered in assessing the practicability of a particular process or proposed facility.

e. Satisfaction of the Water Development Timetable

Certain alternative solutions may require very long periods of time for completion; therefore, consideration should be given to the satisfaction of the water development timetable. In evaluating those alternatives that would provide considerably lower-cost water but would not meet the timetable, careful consideration should be given to the effects of a temporary delay in water development on the overall growth of the region or nation.

## 2. Preliminary Feasibility Studies of the Various Water Sources

Preliminary feasibility studies should be performed on those possible solutions which earlier studies selected as being most promising. Depending upon the circumstances in a particular nation or region, the possible solutions may belong to some or all of the following three categories: hydrological development, seawater conversion and brackish water conversion. This sub-section contains a detailed outline and discussion of a preliminary feasibility study on a seawater conversion alternative. Because of similarities between brackish water conversion and seawater conversion, the feasibility study on a brackish water conversion alternative is covered in lesser detail.

Although studies on hydrological development alternatives are important in arriving at the ultimate solution to a water problem and although they should be considered first since they will usually yield lower-cost water, they are not discussed in detail in this manual.

### a. Seawater Conversion

The purpose of the preliminary feasibility study is to determine unit costs of water produced in plants using the most promising seawater conversion process(es), for comparison with the unit costs of water produced by other alternative solutions. If more than one seawater conversion process is considered to be sufficiently proven and possibly competitive for the particular application, separate studies would be required on each. Each study should cover:

#### (1) Plant Site and Location

Seawater conversion facilities would be located only a short distance from the shoreline, to minimize the cost of intake and outfall facilities and to reduce pumping costs.

The following factors should be analyzed:

(a) Location, land availability and cost.

(b) Topography of the proposed sites

(c) Foundation conditions and seismic stability

(d) Climate

(e) Oceanographic information, tidal record and storms.

(f) Accessibility and proximity to existing roads and railways.

(g) Labor availability in the vicinity of the site, for the construction and operation of the facility.

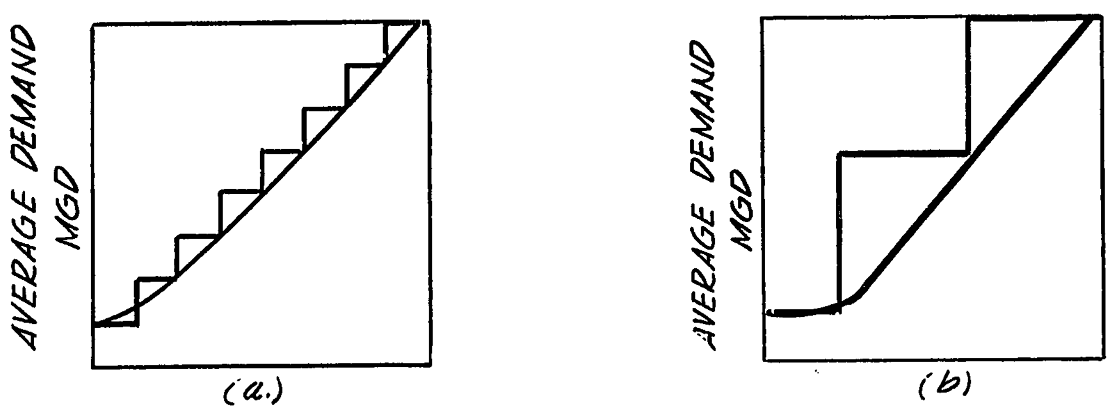
(h) Marine and shore life, conservation considerations due to environmental changes caused by the brine effluent salinity and temperature.

(i) Effects on the fishing industry

(2) Required Design Capacity

The estimate of projected average water demand over a long period of time will have been provided in the Water Development Plan. This average demand can be met either in small increments which conform closely to the projected curve or in larger steps that do not conform as closely to the curve. Figure X-1 illustrates these two methods of meeting the demand curve.

FIGURE X-1
METHODS OF MEETING THE DEMAND CURVE



Water conversion processes can be readily adapted to meet the water demand projection curve, as shown in View (a) of Figure X-1, since plants or plant expansions can be planned and built according to the incremental needs. Sometimes, however, economies of size can be realized by a larger seawater conversion plant even if the full output of the plant cannot be utilized during its early life.

Hydrological development would, in general, follow the pattern shown in View (b) of Figure X-1 since it would not be practical, for example, to build a small dam and canal system and to enlarge these facilities progressively in several steps. The same considerations apply in determining the size of the conveyance system required to deliver water obtained by conversion processes.

The actual design capacity for the water conversion facility should meet the following requirements:

(a) The facility should have capacity adequate to meet future increases in water demands until other new facilities are put in service.

(b) The design capacity should be such that the facility output combined with the capacity of the projected product water storage facilities could sustain the projected maximum daily demand for a limited period. For the purpose of a preliminary feasibility study, it can be assumed that these conditions are met when the design capacity is between 20% and 40% greater than the average demand predicted for the time when other plants are brought on stream.

This design capacity plus reasonable storage capacity (3 to 5 days) will meet the expected short-duration peak demands, and will allow shut-down periods for water plant maintenance purposes.

(3) Qualitative Analysis

Seawater salinity does not usually vary appreciably from the average of 35,000 ppm; however, its chemical composition and the suspended solids, sand, small mollusks, fish, algae and kelp should be taken into consideration when selecting a plant site. These factors could require or determine special intake and outfall considerations.

The saline content of seawater at certain locations (e. g., the Red Sea) is considerably higher than the average of 35,000 ppm. High salinity conditions might require certain modifications to the basic process (such as lower maximum brine temperature or lower concentration ratio in the multi-stage flash process) and would impose restrictions on the maximum brine temperature that could be sustained for long periods without scale formation.

(4) Energy Considerations

The Water Development Plan includes information on the projections for fuel resources and reserves, hydropower potential, energy demands, energy availability and energy costs over the period of time considered by the Water Development Plan. This information should be used to determine whether the water and power needs of an area can be better fulfilled by a single-purpose water conversion facility or by a dual-purpose power-water facility.

In general, if the region has a substantial potential market for energy, dual-purpose facilities would show advantages over single-purpose plants.

Single-purpose plants would be suitable for locations where the power-to-water demand ratio is very small or locations where the region has sufficient installed generating capacity and water is the commodity in demand.

The following factors should be considered in the evaluation between single-purpose and dual-purpose plants:

(a) Location of the facility with respect to the centers of consumption of water and electricity, water only and electricity only.

(b) Influence of the conveyance and transmission facilities required by both products

(c) Availability of fuel sources and cost of fuel

(d) Incremental energy demands of the region or nation and appraisal of the potential market for energy

The value of power produced by a dual-purpose plant and the manner in which the value of power affects the unit cost of water will be treated in Subsection X. A. 2. a. (6).

The cost of power required by single-purpose plants can be assumed to be the cost at the proposed plant locations.

(5) Selection of Suitable Seawater Conversion Processes

The preliminary feasibility studies should consider only commercially proven seawater conversion processes; a considerable amount of information is available for such processes and reliable estimates of capital and operational costs can be made.

Each process type has certain unique characteristics which must be considered for a specific application. These include practical minimum and maximum size ranges, heat and power consumption, cooling water requirements and simplicity of construction and operation. A detailed description of each process type has been provided in Volume One of this manual.

To select a particular process for the preliminary feasibility studies, the process characteristics should be matched with the particular design capacity requirements, energy and fuel availability, and other considerations for the plant application being studied. While it should be possible to select one particular process type as the most favorable, it might be necessary to perform studies on two processes that appear to be competitive.

(6) Dual-Purpose Plants

Dual-purpose power-desalination plants should be considered for locations that have requirements for both additional power and water, since such plants offer certain basic advantages.

The heat source (boiler) and its auxiliaries would have a higher rating for a dual-purpose plant than for a single-purpose plant with either the same electrical or water output. The large size and rating result in lower unit costs, because of economies of size. Another advantage is the fact that when the power generation and water conversion processes are combined in a dual-purpose plant, the heat rejected to the heat sink is a smaller percentage of the heat input than that in a single purpose water- or power-only plant; this, in turn, results in higher overall efficiency and lower fuel costs. Yet another advantage is the economies resulting from sharing of certain utility, administrative, maintenance and storage facilities, and operating and maintenance personnel.

Dual-purpose plants normally consist of a power plant comprising a steam generator, a turbine-generator and auxiliary plant equipment, and a water production plant utilizing a distillation or evaporation conversion process with turbine exhaust steam as its heat source. Freezing plants utilizing absorption-type refrigeration systems could also be developed into dual-purpose applications.

The characteristics of a dual-purpose plant require that additional factors be considered in its preliminary feasibility study. These factors are discussed below:

(a) Power Cost and Power Credit Considerations

Dual-purpose plants produce two different products, electric power and water; thus, the value or cost assigned to one product will affect the cost calculated for the other product. For example, if a fictitiously low value is assumed for power, the cost of water would have to absorb the power subsidy. The preliminary studies should be based upon a realistic and equitable assignment of cost to one product, so that a realistic cost may be calculated for the other product. One possible method for assigning costs is to assume that the cost of power in a dual-purpose plant is equal to the actual cost of production in a single-purpose power-only plant of the same capacity.

(b) Power to Water Ratio

The energy survey establishes the projections for power demands that can be met by additional generating units. The additional power generating capacity needed during the proposed lifetime of the water plant is used to determine the power-to-water ratio for the dual-purpose plant being studied. This ratio, which can be expressed in such units as kilowatts/million gallons per day (kw/mgd), plays an important role in the selection of the power-plant cycle arrangement in a dual-purpose plant.

(c) Power Plant Cycle Selection

While a large number of possible steam power-plant cycles are suitable for a dual-purpose plant application, all are variations of three basic cycles:

- The backpressure or noncondensing cycle, shown schematically in Figure X-2.
- The condensing-backpressure cycle, shown in Figure X-3.
- The condensing-extraction cycle, shown in Figure X-4.

In fossil-fueled plants, the typical range of application for each type of cycle, as a function of the power-to-water ratio, is as follows:

| | Power/Water Ratio (kw/mgd) | |
|---|---|---|
| | Min | Max |
| Backpressure Cycle | 2. | 8. |
| Condensing-Backpressure Cycle | 8. | 25 |
| Condensing-Extraction Cycle | 25. | No limit |

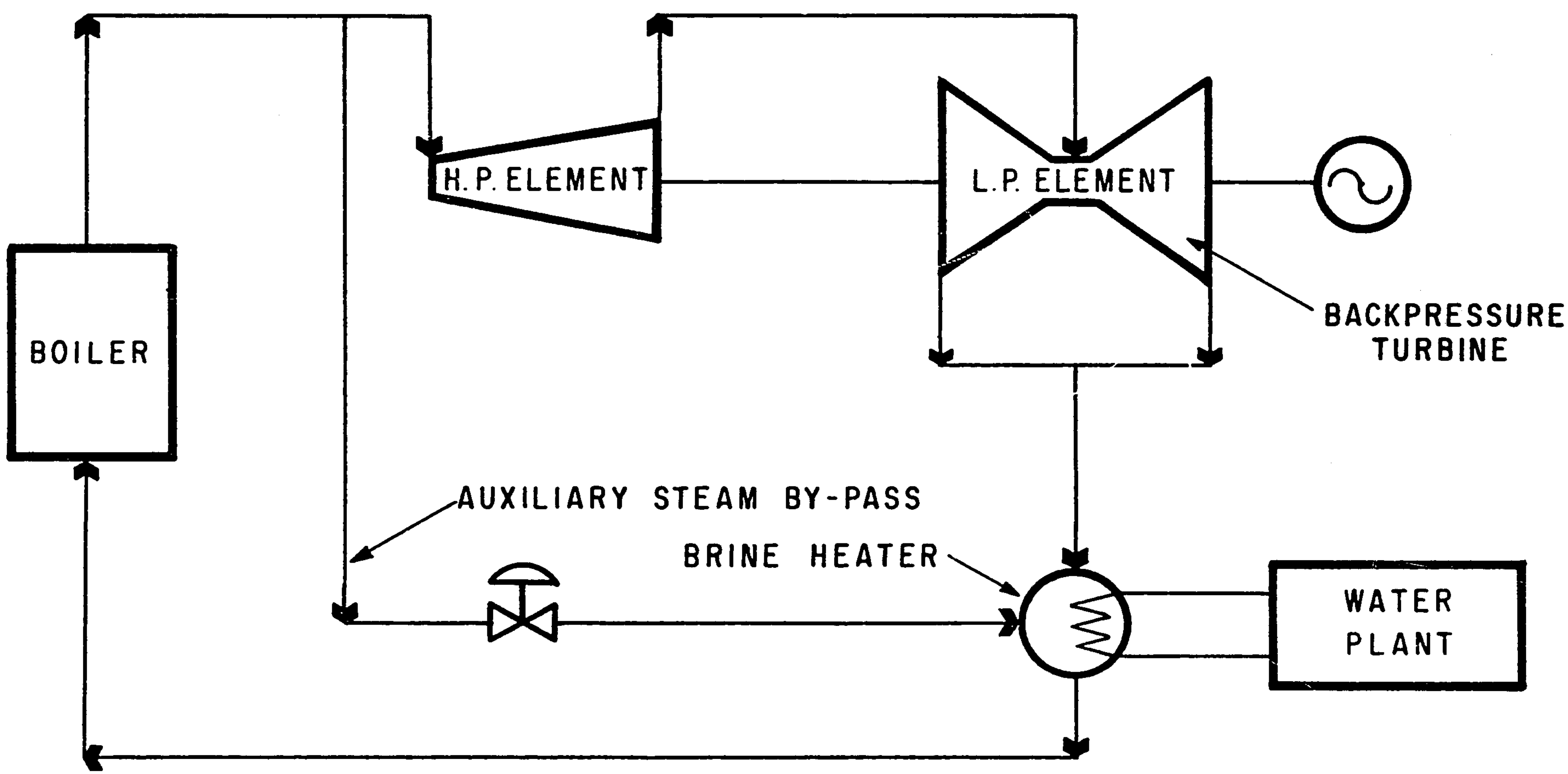
When the desired power-to-water ratio falls below 2, it is necessary to obtain at least some of the heat directly from the steam source; the plant then becomes a combination single and dual-purpose facility.

(7) Intake and Outfall Considerations

The type, size and cost of the intake and outfall system depend on the particular characteristics of the site as well as

FIGURE X-2

## BACKPRESSURE CYCLE




HIGH BACKPRESSURE:

LOWER POWER PRODUCTION
HIGHER WATER PRODUCTION

LOW BACKPRESSURE:

HIGHER POWER PRODUCTION
LOWER WATER PRODUCTION

FIGURE X-3

CONDENSING-BACKPRESSURE CYCLE

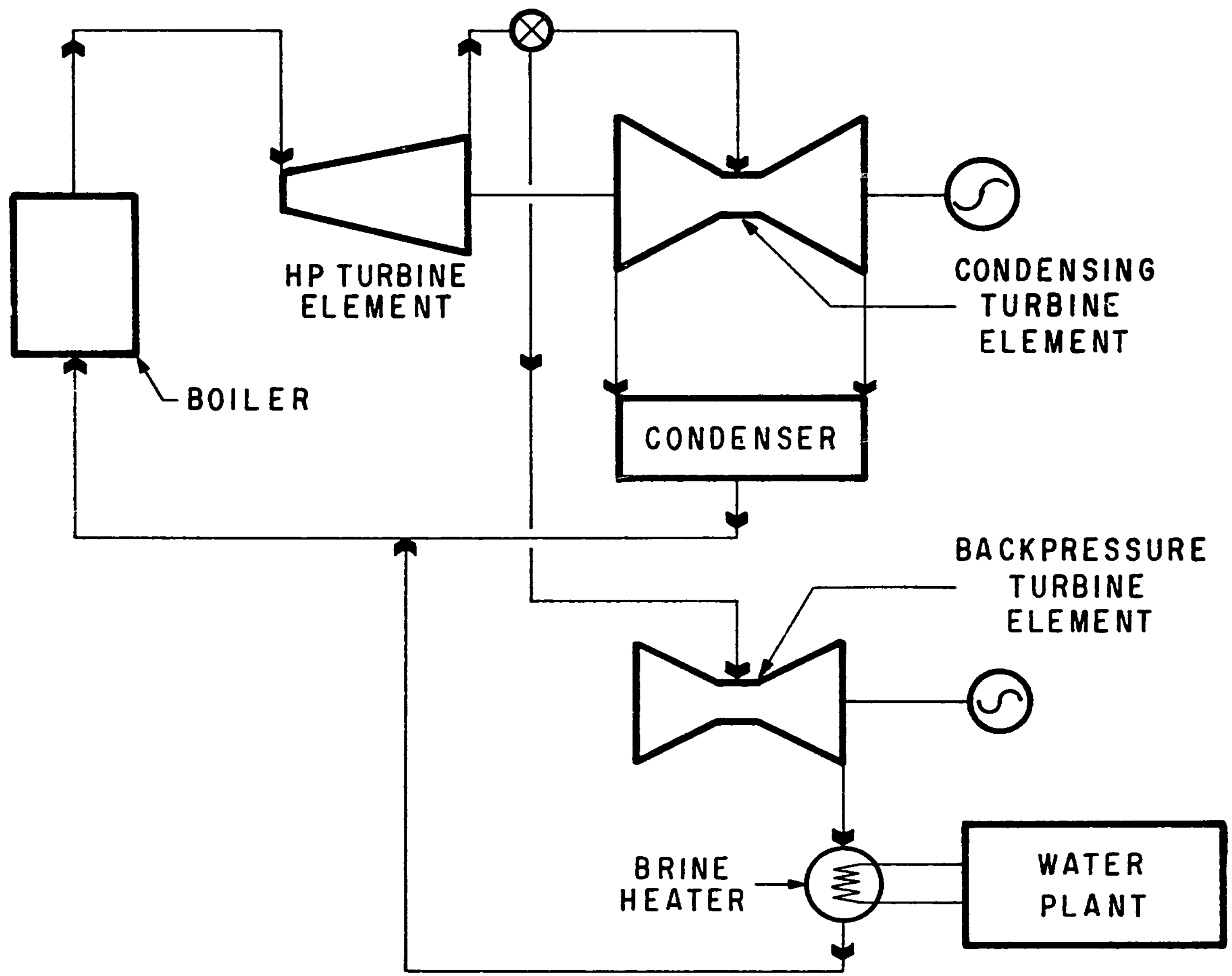
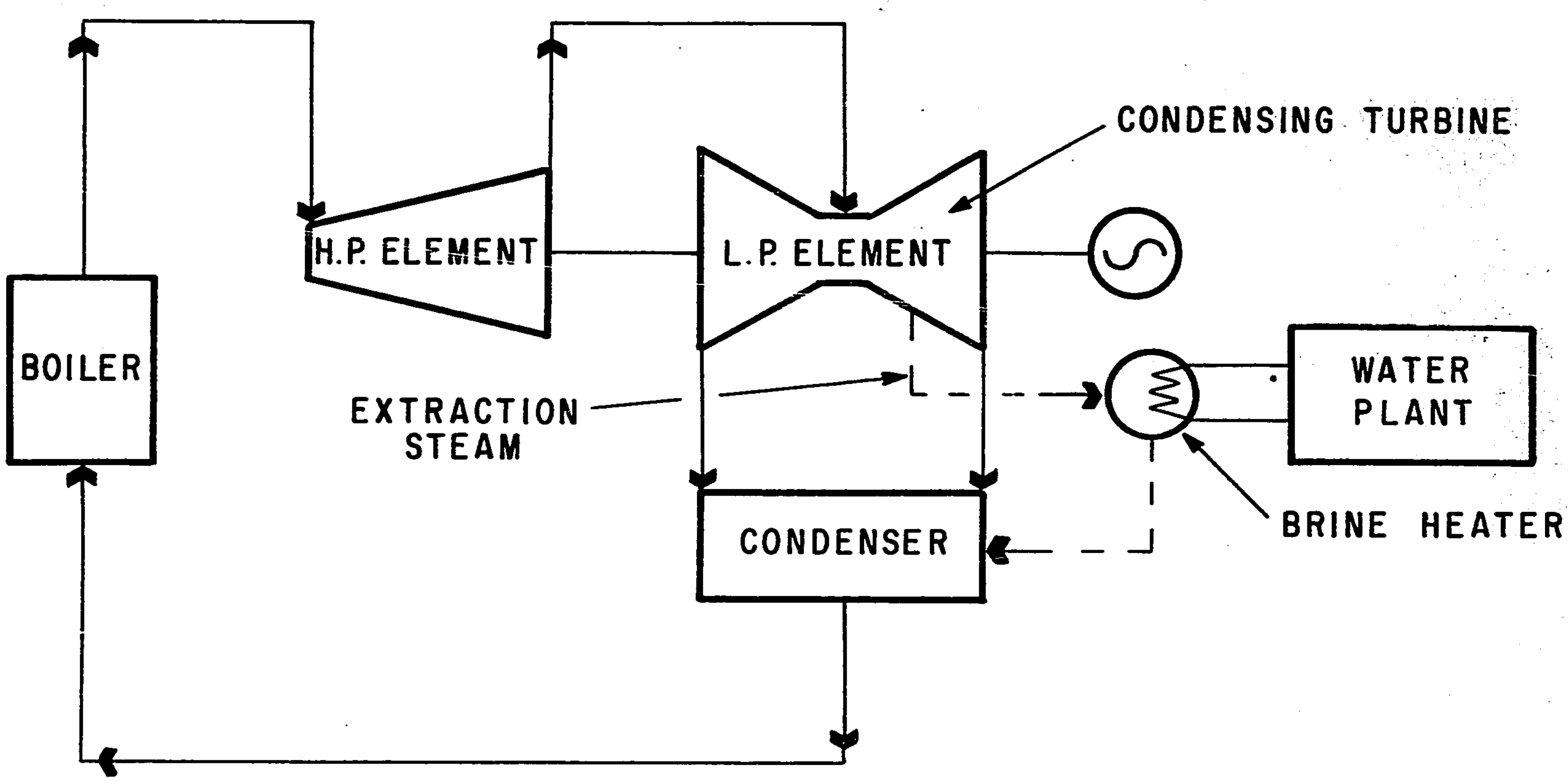


FIGURE X-4

## CONDENSING - EXTRACTION CYCLE



on the amounts of seawater required by the facility for conversion and cooling purposes. These seawater amounts depend, in turn, on the brine-to-product ratio and on the economy ratio of the conversion process.

The preliminary feasibility studies and cost estimates should be based on the use of submarine pipe intakes, unless it is clearly evident that a channel-type intake is feasible at the particular site and that recirculation of the plant effluent can be avoided.

Power recovery schemes should be considered in locations where, because of the coast ruggedness, the plant has to be located at a much higher elevation than the high-water mark.

(8) Product Water Conveyance System

The product water conveyance system includes the necessary facilities and structures, such as pumping stations, canals, aqueducts and pipelines required to deliver the product water to the center or centers of distribution. The conveyance facilities should also include the additional product water storage capacity required as a result of the conversion plant addition. It is assumed that the storage installations would be located near the center of distribution to allow for shutdowns of the conveyance system for maintenance purposes. The design capacity of the product water conveyance system should be established in accordance with the recommendations set forth in Subsection X. A. 2. a. (2).

Unless the distance from the water plant to the center of distribution is very short, it will be more economical to design the conveyance system with an ultimate capacity sufficient to handle the product of as many desalination facilities as might be built at that site over a period of 10 to 15 years.

A water conveyance system may comprise a single facility or a combination of facilities such as canals, aqueducts, siphons, pipelines and pumping stations. For seacoast conversion facilities, the center of distribution would always be located at a higher elevation that that of the conversion facility and, therefore, it would be necessary to pump the water at least to a point from which it could flow by gravity in canals or aqueducts.

(a) Canals

Canals are suitable when the following conditions exist:

1 Available Head

Between pumping stations, the height of the initial point above the terminal point is such that the initial pressure exceeds the terminal pressure by an amount equal to the friction losses plus the discharge head when the water in the canal is flowing at the design capacity.

2 Topography

The topography of the terrain traversed lends itself to a fairly straight route, and the construction does not require extraordinary amounts of earthmoving work or structures such as large siphons.

3 Land Cost

The right-of-way costs are relatively low.

4 Soil

The stability and quality of soil is suitable for canal construction.

5 Losses

The evaporation and permeability losses will not exceed a small percentage of the water carried.

(b) Aqueducts

Aqueducts are applicable under the following conditions:

1 Available Head

Same considerations as for canals.

2 Topography

Aqueducts are feasible under more rugged topographic conditions than those suitable for canals.

3 Land Cost

Aqueducts are adequate where right-of-way costs are higher than those of canals, because of the smaller space requirements.

4 Soil

Stability of the soil is adequate to support the conduits or structures; quality of soil is not an important consideration.

(c) Pipelines

Water can be conveyed from the supply source to the point of distribution by means of pipelines. The range of applicability of pipelines is quite broad, and they are not subject to conditions limiting the applicability of canals and aqueducts. Furthermore, modern construction and handling techniques allow the construction of pipelines in the most inaccessible regions. Capacities of up to approximately 35 mgd can be handled by pipelines using 30-inch pipe of standard manufacture. The ultra pure water resulting from most desalination processes must be "stabilized" to prevent corrosion problems in the water conveyance and distribution system. Stabilization of product water is achieved by passing the water through a bed of crushed limestone wherein it dissolves small amounts of calcium.

(d) Pumping Stations

Since seawater conversion facilities would not be located at an elevation higher than the point of distribution, the product water must be pumped to overcome the static lift as well as the friction losses. The pumping station will consist of an intake basin and the pumping units, controls and structures necessary to meet the conveyance system design capacity. Pumping stations should be assumed to be capable of delivering water at heads of 400 to 500 feet. If it is necessary to pump water to higher altitudes (e.g., over a coastal mountain range), several pumping stations will be required, and an economic evaluation of energy recovery systems should be considered.

(9) Estimates of Capital, Annual and Unit Costs

During preliminary feasibility studies, capital, annual and unit costs are estimated by a method which utilizes a

"Basic U.S. Cost" for each alternative arrangement considered. To suit local conditions, the Basic U.S. Costs should be adjusted to take into consideration the amounts of local effort and participation.

In preliminary feasibility studies, the capital and annual cost estimates made for the purpose of obtaining product unit costs must be sufficiently definitive to obtain realistic comparison of alternative schemes. However, since the project is not defined in detail, many assumptions will have to be made in formulating the estimates. While the absolute values of the estimates will have a large element of uncertainty, the assumptions made should be consistent for each of the alternative schemes considered, so that the estimates will have greater validity for comparison purposes.

(a) Capital Cost Estimates

Prior to commencing the preliminary engineering study, it may be desirable to determine the typical costs of desalination facilities. The cost information provided in the Appendix may be used as an aid for estimating typical capital costs of a proposed plant installation.

Estimates of capital costs of a specific proposed plant may be made during the preliminary engineering study using Basic U.S. Costs adjusted to correspond to the conditions existing in the area proposed for the plant.

To facilitate comparisons with other alternatives, the unit cost of product water should be calculated at both the production plant and at the distribution center. Therefore, in preparing the cost estimates, the conveyance system costs should be estimated separately from the costs of the plant and associated facilities. The estimating sheets furnished in Table X-1 make provisions for this separation.

The method for preparing the capital cost estimates for both the plant and the conveyance facilities are summarized below. The designations are those used on the estimating sheets.

1 Adjusted Construction Cost

a Components of Basic U. S. Costs

The components making up the Basic U. S. Costs are, the equipment costs (E), the costs for equipment installation and erection (I), and the cost for the structures and civil work for the plant, the intake-outfall facilities and site development (S).

b Adjustments for Local Conditions

Using correction factors (R= (local cost - U. S. cost)/(U. S. cost)) chosen to reflect local conditions, adjustments are made to account for the shipping cost of equipment brought from the U. S. ($R_E$), the additional equipment spares required ($R_{Sp}$), the difference in equipment installation and erection costs ($R_I$) and the estimated difference in structural and civil costs ($R_S$).

The Adjusted Construction Cost is the sum of the Basic U. S. Costs and the (positive or negative) Adjustments for Local Conditions.

2 Indirect Costs

These costs include:

a The Engineering, Design and Inspection Costs

These are a function of the Adjusted Construction Cost of the facility.

b Owner's Expenses

The Owner's Expenses will depend on the estimate of:

- Amount of inspection and coordination effort expected to be performed by personnel of the Operating Agency or Company
- Amount of operator training required by local personnel
- Amount of startup expenses expected (e. g., fuel, salaries, supplies, etc) until the plant attains commercial operation.

# TABLE X-1

## ESTIMATING SHEET NO. 1

## CAPITAL COST ESTIMATE FOR SEAWATER CONVERSION FACILITY

| | | |
|---|---|---|
| Design Capacity | ______ | Gal./Day |
| Conversion Process | ______ | |
| Brine/Product Water Ratio | ______ | lb Brine / lb Product Water |
| Performance Ratio | ______ | lb Product Water / 1,000 Btu |

**Adjusted Construction Cost**

**Basic U. S. Costs**

| | | |
|---|---|---|
| Equipment (E) | $ ______ | |
| Equipment Installation and Erection (I) | $ ______ | |
| Structures and Civil Work for Plant, Intake-Outfall Facilities and Site Development (S) | $ ______ | |
| Total Basic U. S. Costs | $ ______ | |

**Adjustments for Local Conditions**

| | | |
|---|---|---|
| Adj for Equipment Shipping (E x $R_E$) | $ ______ | |
| Adj for Equipment Spares (E x $R_{Sp}$) | $ ______ | |
| Adj for Equipment Installation (I x $R_I$) | $ ______ | |
| Adj for Structures & Civil (S x $R_S$) | $ ______ | |
| Total Adjustments | $ ______ | |
| Adjusted Construction Cost | | $ ______ |

**Indirect Costs**

| | | |
|---|---|---|
| Engineering, Design & Inspection | $ ______ | |
| Owners Expenses | $ ______ | |
| Interest During Construction | $ ______ | |
| Total Indirect Costs | | $ ______ |
| Total Before Contingency | | $ ______ |
| Contingency | | $ ______ |
| Total Capital Cost | | $ ______ |

## TABLE X-1 (Cont'd)

## ESTIMATING SHEET NO. 2

## ESTIMATE OF ANNUAL COST FOR SEAWATER CONVERSION FACILITY

### Fixed Charges

#### Fixed Charges on Depreciable Capital

| | | | |
|---|---|---|---|
| Interest | $ ________ | | |
| Depreciation | $ ________ | | |
| Insurance | $ ________ | | |
| Taxes | $ ________ | | |
| Subtotal | | $ ________ | |

#### Fixed Charges on Nondepreciable Capital

| | | | |
|---|---|---|---|
| Interest on Noninventory Working Capital | $ ________ | | |
| Interest on Inventory Working Capital | $ ________ | | |
| Insurance on Inventory Working Capital | $ ________ | | |
| Interest on Land | $ ________ | | |
| Taxes on Land | $ ________ | | |
| Subtotal | | $ ________ | |
| Total Fixed Charges | | | $ ________ |

### Operating and Maintenance Cost

| | | | |
|---|---|---|---|
| Labor | $ ________ | | |
| Materials and Supplies | $ ________ | | |
| Interim Replacements | $ ________ | | |
| General and Administrative | $ ________ | | |
| Fuel | $ ________ | | |
| Power | $ ________ | | |
| Total Operating and Maintenance Cost | | | $ ________ |
| Annual Power Credit (Dual-Purpose Plant) | | | $ ________ |
| Net Annual Water Cost | | | $ ________ |

# TABLE X-1 (Cont'd)

## ESTIMATING SHEET NO. 3

## CAPITAL COST ESTIMATE FOR WATER CONVEYANCE FACILITIES

Design Capacity ________ Gal./Day

**Adjusted Construction Cost**

**Basic U.S. Costs**

| | | | |
|---|---|---|---|
| Equipment (E) | $ ________ | | |
| Equipment Installation and Erection (I) | $ ________ | | |
| Structures and Civil Work (S) | $ ________ | | |
| Total Basic U.S. Costs | | $ ________ | |

**Adjustments for Local Conditions**

| | | | |
|---|---|---|---|
| Adj. for Equipment Shipping ($E \times R_E$) | $ ________ | | |
| Adj for Equipment Spares ($E \times R_{Sp}$) | $ ________ | | |
| Adj for Equipment Installation ($E \times R_I$) | $ ________ | | |
| Adj for Structures and Civil ($S \times R_S$) | $ ________ | | |
| Total Adjustments | | $ ________ | |
| Adjusted Construction Cost | | | $ ________ |

**Indirect Costs**

| | | | |
|---|---|---|---|
| Engineering, Design & Inspection | $ ________ | | |
| Owner's Expenses | $ ________ | | |
| Interest During Construction | $ ________ | | |
| Total Indirect Costs | | | $ ________ |
| Total Before Contingency | | | $ ________ |
| Contingency @ ____% | | | $ ________ |
| Total Capital Cost | | | $ ________ |

## TABLE X-1 (Cont'd)

## ESTIMATING SHEET NO. 4

## ESTIMATE OF ANNUAL COST FOR WATER CONVEYANCE FACILITIES

| | | | |
|---|---|---|---|
| **Fixed Charges** | | | |
| **Fixed Charges on Depreciable Capital** | | | |
| Interest | $ ______ | | |
| Depreciation | $ ______ | | |
| Insurance | $ ______ | | |
| Taxes | $ ______ | | |
| Subtotal | | $ ______ | |
| **Fixed Charges on Nondepreciable Capital** | | | |
| Interest on Noninventory Working Capital | $ ______ | | |
| Interest on Inventory Working Capital | $ ______ | | |
| Insurance on Inventory Working Capital | $ ______ | | |
| Interest on Land | $ ______ | | |
| Taxes on Land | $ ______ | | |
| Subtotal | | $ ______ | |
| Total Fixed Charges | | | $ ______ |
| **Operating and Maintenance Cost** | | | |
| Labor | $ ______ | | |
| Materials and Supplies | $ ______ | | |
| Interim Replacements | $ ______ | | |
| General and Administrative | $ ______ | | |
| Pumping Power Cost | $ ______ | | |
| Right-of-Way Leases Cost | $ ______ | | |
| Total Operating and Maintenance Cost | | | $ ______ |
| Total Annual Cost Water Conveyance Facilities | | | $ ______ |

TABLE X-1 (Cont'd)

ESTIMATING SHEET NO. 5

## ESTIMATE OF UNIT WATER COST - SEAWATER CONVERSION FACILITY

### Unit Water Cost at Conversion Plant

Design Capacity Conversion Plant ____________ Gal./Day(gpd)
Estimated Plant Operating Factor ____________ %
Annual Water Production ____________ gpd
x 365 x ____________ % = ____________ Gal./Year
Net Annual Water Cost (Est Sheet No. 2) ____________ /Year
Unit Water Cost at Conversion Plant

$$= \frac{\text{Net Annual Water Cost}}{\text{Annual Water Production}} = \frac{\_\_\_\_\_\_\_\_\ \$/\text{Year}}{\text{Gal./Year}}$$

x 100 x 1,000 = ____________ Cents/1,000 Gal.

### Unit Water Cost at Distribution Center

a) Design Capacity Conveyance Facility ____________ Gal./Day
b) Estimating Water Conveyance Facility Operating Factor ____________ %
c) Annual Water Conveyed = a) x b)
= ____________ gpd x 365 x ____________ % = ____________ Gal./Year
d) Annual Cost Conveyance Facilities (Est Sheet No. 4) ____________ $/Year
e) Unit Water Conveyance Cost = $\frac{d)}{c)}$

$$= \_\_\_\_\_\_\_\_\ \frac{\$/\text{Year}}{\text{Gal./Year}} \times 100 \times 1,000 = \_\_\_\_\_\_\_\_\ \text{Cents/1,000 Gal.}$$

f) Unit Water Cost at Distribution Center
= Unit Water Cost at Conversion Plant
\+ Unit Water Conveyance Cost
= ____________ + ____________ Cents/1,000 Gal. = ____________ Cents/1,000 Gal.

c Interest During Construction

This is the interest paid on the funds spent during the design, procurement and construction periods and during the period before the plant achieves commercial operating status.

3 Total Before Contingency

The Total Before Contingency is the sum of the Adjusted Construction Costs and the Indirect Costs.

4 Contingency

Contingency is an allowance for the uncertainties in the various elements comprising the capital cost, plus an allowance for overlooked items and for any increase in capital requirements resulting from site peculiarities; contingency is usually expressed as a percentage of the total capital cost.

The Contingency figure when added to the Total Before Contingency results in the Total Capital Cost of the facility. It should be noted that escalation has not been included in the capital cost estimates made during the preliminary feasibility studies.

(b) Estimate of Annual Costs

The annual costs consist of the annual Fixed Charges and the annual Operating and Maintenance expenses incurred by the water production facility. In the following discussion of these cost elements, the designations used are those given on the estimating sheets for the estimate of annual costs (see Table X-1).

1 Fixed Charges

In the computation of annual Fixed Charges, the rates applied to the depreciable capital items differ from the rates applied to the nondepreciable capital items.

a Fixed Charges on Depreciable Capital

These charges include:

- Interest, which depends on the type of financing and whether U. S. or local costs are used.
- The depreciation rate, which depends on the expected life of the plant, salvage value and depreciation method used.
- Insurance, which will depend on local conditions.
- Taxes, which also will depend on local conditions.

b Fixed Charges on Nondepreciable Capital

The Fixed Charges on Nondepreciable Capital (working capital and land) consist of:

- Interest charges on noninventory working capital or cash operating reserve (generally a sum large enough to cover expenses such as fuel, salaries, power, insurance prepayment, etc. for 45 to 60 days).
- Interest and insurance charges on inventory items such as materials and supplies, and on a fuel reserve required for operation of the plant for a period of 45 to 60 days.
- Interest on the facility land value, computed for purchase cost.

2 Operating and Maintenance Cost

The Operating and Maintenance cost includes:

a Labor

The labor costs depend on local conditions; where no local operating personnel are available, the labor cost should include the costs of the necessary imported personnel.

b Cost of Materials and Supplies

This cost can be estimated as a function of the product water output for each type of seawater conversion facility.

c Interim Replacement Cost

For each type of conversion facility, this cost can be estimated as a percentage of the equipment and materials capital costs.

d General and Administrative Expenses

This cost can be estimated as a percentage of the operation and maintenance personnel costs.

e Fuel Costs

The fuel cost is a function of the amount of heat required by the conversion facility, the assumed boiler efficiency (between 86% to 88% for modern boilers), the plant load factor and the cost of delivered fuel.

f Power Costs

The power cost is a function of the average power demand of the conversion facility, the cost of energy at the plant location and the plant utilization factor.

3 Power Credit (applicable only to dual-purpose plants)

The Power Credit is the amount of energy sold multiplied by the unit cost of power produced in an optimum single-purpose power plant.

The considerations mentioned in Subsection X. A. 2. a. (6) should govern the establishment of the power cost used to compute the Power Credit.

(c) Unit Cost of Water

The Unit Water Cost is defined as:

Net annual cost of water / annual water production.

The net annual cost of water consists of:

Annual Fixed Charges plus annual Operating and Maintenance Cost less Power Credit (dual-purpose plant).

The annual water production is a function of the design capacity of the water production facility and of the estimated average plant operating factor during the lifetime of the plant.

To allow direct comparisons between alternative water sources, the Unit Water Cost should be calculated at both the production plant and the distribution center. The cost estimate of the water conveyance facilities has been kept separate so that the two Unit Water Costs can be separately calculated. Estimating Sheet No. 5 (see Table X-1) provides the required guide to these calculations.

b. Brackish Water Conversion

The preceding subsection has provided a detailed outline of the steps necessary in the performance of a preliminary feasibility study for a seawater conversion facility. Because of the similarities between seawater conversion facilities and brackish water conversion facilities, the following discussion is limited to the differences between brackish water conversion and seawater conversion, and to the unique characteristics of brackish water conversion.

(1) Location and Design Capacity

The Water Development Plan document (see Subsection IX. B. 2) provides the basic information on the locations of the water requirements which may be satisfied by brackish water conversion facilities. A brackish water conversion facility generally would be smaller than one for seawater, for two basic reasons: the brackish water sources will usually not be sufficient to supply the requirements for a very large conversion facility at one location; the processes applicable to brackish water conversion are not so easily adaptable to large-scale plants. For these two reasons, the typical brackish water conversion facility would be planned to furnish the water needs of a municipality or other local area and would take its source from that local area. Therefore, a brackish water conversion facility may be more suitable for supplying water to meet local requirements than for supplying the needs of a region or entire country.

(2) Sources

The Water Development Plan indicates the possible sources of brackish water which may be suitable for conversion. If a location proposed for a conversion facility has a brackish water source sufficient to supply the local water requirements, a detailed study should be made to determine the characteristics of this source. The typical method of obtaining brackish water is by drilling wells. Consideration must be given to the fact that the composition of the water obtained from a well will vary with the depth of the well. The probable capacity of the wells and any possible effect on other existing wells or facilities in the area must be considered also.

The detailed chemical composition of the water at the particular location must be determined, since the types and amounts of impurities can vary substantially in brackish water. Furthermore, in the cases of water conversion methods which utilize membrane processes, small amounts of certain impurities (iron, manganese and silica) are particularly harmful.

(3) Suitable Processes for Brackish Water Conversion

Only certain of the conversion processes described in Volume One of this manual can be considered for a brackish water conversion facility. Common characteristics of these suitable processes are: equipment and plant are economical in relatively small plant sizes; and large amounts of cooling water are not required. The suitable processes are electrodialysis, reverse osmosis, freezing and vapor compression distillation. Ion-exchange demineralization could be used but, at present, is applicable only to water with relatively low dissolved solids content.

(a) Electrodialysis

This process is particularly suited to brackish water conversion, and is the only membrane process now in commercial operation on brackish water sources. Normally, it is used only on brackish waters with a salinity of less than 5,000 ppm, since the power consumed in the process is proportional to the amount of dissolved salts. The product water from an electrodialysis plant would have a concentration of approximately 500 ppm of dissolved salts. Iron and manganese in the brackish water may cause substantial membrane problems unless special pretreatment is provided.

(b) Reverse Osmosis

Although reverse osmosis has been developed to the pilot plant stage, the current experience and data are insufficient for this process to be seriously considered for a brackish water conversion facility. As further experience is obtained, however, this process may be considered for a proposed facility.

(c) Freezing

The freezing processes described in Volume One can be applied to brackish water conversion.

(d) Vapor Compression Distillation

The only distillation process which should be considered for a brackish water conversion plant is the vapor compression distillation process, since this process requires very little cooling water. A brackish water conversion demonstration plant employing this process has been in operation at Roswell, New Mexico. Process and equipment difficulties have been experienced there, but these problems may be caused by inadequate pretreatment of the particular brackish water source.

(e) Ion-Exchange Demineralization

Because of high cost, ion-exchange demineralization of brackish water has been employed to a limited extent only. Ion exchange would not normally be considered economically feasible for the demineralization of brackish water with a dissolved solids content above 1,000 ppm. Although recent developments have indicated that this feasible impurity level might be raised to 2,000 or even 3,000 ppm, ion exchange will not be given any further consideration in this manual.

(4) Brine Disposal

The method to be used for the disposal of the effluent brine from a brackish water conversion facility must be examined in detail. This brine cannot be returned to the source as in a seawater conversion facility. Methods that have been employed are plastic-lined disposal ponds and waste water wells. Care must be exercised to ensure that the effluent brine will not contaminate existing water supply sources.

c. Freshwater Development

As an integral part of the studies of water shortage problems, the available freshwater sources should be examined and evaluated to determine their development feasibility. The background information compiled in the Water Development Plan document can serve as a basis for studies on the development of freshwater resources. The studies should consider both the development of surface waters, such as rivers and lakes, and the development of underground freshwater sources by means of a well-drilling program. If requirements so dictate, dual-purpose hydroelectric projects should be considered.

Since adequate guides* exist for studies on the development of freshwater sources, the topic is not discussed in detail in this manual.

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* 1. Feasibility Studies, Economic and Technical Soundness Analysis, Capital Projects, M. O. 1221. 2, Department of State, Agency for International Development, Washington, D. C. 20523

2. Standardized Procedure for Estimating Costs of Conventional Water Supplies, Black & Veatch, Kansas City, Missouri, for the Office of Saline Water, U. S. Department of the Interior

d. Reclamation and Reuse of Water

In an area with an abundant supply of water, little consideration is usually given to the reclamation and reuse of water, since this generally cannot be economically justified. This applies both to municipalities and to industrial and individual users. If a water shortage problem develops, however, efforts should be directed not only toward the development of new sources but also toward the reclamation and reuse of existing supplies. Although this topic is not covered in detail in this manual, it should, however, be considered in the overall solution of a water shortage problem.

With adequate planning and engineering effort, appreciable gains in water conservation can be attained. A specific example of this is Kaiser Steel's Plant at Fontana, California which was designed and built with an efficient water reclamation and reuse system permitting steel production with an average net usage of only 1,100 gallons of water per ton of steel. In comparison, the average water usage is 32,000 gallons per ton of steel.

B. Preliminary Feasibility Summary

After completion of the preliminary feasibility studies on the alternative courses of action, including seawater conversion, brackish water conversion and development of available fresh water resources, a summary should be prepared to compare these alternatives on a common basis. This summary should include recommendations for the selection of a particular alternative or alternatives for the detailed feasibility study; it would be used by the Water Development Board in making its decision for the future program.

This summary should include the following elements:

1. The Unit Water Costs for the several alternatives should be compared on an equitable basis. The cost of water conveyance to the distribution centers should be taken into consideration in this evaluation. The capital costs required for the alternatives should also be compared as an aid in determining possible methods of financing the program.

2. A comparison should be made of the time schedules for the availability of water from the several alternatives studied. This

analysis should include a comparison with the time schedule of anticipated water requirements. It should also consider how the Unit Water Cost would be affected by a low plant operating factor during the first few years as a result of an oversupply of water, and how the development of an area would be affected by a temporary undersupply of water.

3. The summary should identify the uncertainties in the studies on the various alternatives, since these uncertainties would have to be cleared up prior to or during the detailed feasibility study; it should identify areas in which the technology is being developed, where successful development would result in lower capital and water costs; and it should identify areas which would benefit from additional development work or detailed studies.

4. The summary should identify the secondary benefits from the various alternatives, such as the production of power from a dual-purpose facility and the effect this power production might have on the industrial growth of the area.

5. The summary should include a specific recommendation of the alternative which appears to be the best choice for the detailed feasibility study. The recommendation should include a plant capacity range chosen to meet area requirements. The summary may recommend more than one alternative, if a particular alternative cannot be judged to be clearly the most attractive prior to the detailed feasibility study.

6. The summary should include a tentative time schedule for the proposed project, including planned dates for the completion of the detailed feasibility study, for the start of detailed design, for the completion of plant construction and for the start of commercial operation. Such a tentative time schedule would provide an overall time guide for the project.

7. The summary should set forth the basic scope of work for the detailed feasibility study. This basic scope of work would be utilized by the Water Development Board in the selection of an architect-engineer for the next phase; it would be utilized by the architect-engineer in his initial work phases.

8. If assistance from AID is to be requested for the detailed feasibility study, the data necessary to obtain AID review and approval should be prepared and included in the summary.

C. Determination of Course of Action

Utilizing the preliminary feasibility studies and the Preliminary Feasibility Summary, the Water Development Board should determine the subsequent course of action. The Water Development Board would make a request to AID for assistance on a detailed feasibility study if it decides that such is necessary at this point in the program. The Board also may conclude that an additional study or studies are necessary to clarify certain points in the preliminary feasibility studies.

# XI. DETAILED FEASIBILITY STUDY OF SELECTED SOLUTION

## A. General

A detailed engineering feasibility and economic study should be carried out on the alternative (or alternatives) selected in the preliminary feasibility studies (refer to Section X) as the most promising solution (or solutions) to the water shortage problems of a country or region; this section outlines the objectives and content of this detailed feasibility study. The Study Organization should assign the performance of this detailed study to an architect-engineer firm, selected on the basis of its qualifications to perform the type of study required and its experience in the related technology.

## B. Objectives

The objectives of this study would be:

1. To perform a detailed evaluation of the selected alternative (or alternatives), so that a decision on a specific proposed project can be made.

2. To develop all necessary technical and economic data on the proposed project, so that the financing agencies can evaluate requests for funding.

## C. Scope

The initial step in this study should be a compilation of all necessary data. Much of these data would already be included in the Water Development Plan document; however, more specific information may be required in certain areas. Included in the Appendix is a Questionnaire which contains a comprehensive listing of the data required in performing a detailed engineering feasibility and economic study on a seawater desalination plant.

The detailed feasibility study should include:

1. The preparation of conceptual design for the plant and the selection of plant capacity, based on both the water requirements in the area and the characteristics and limitations of the plant and site.

2. The solicitation and evaluation of preliminary proposals on equipment designed to meet the requirements of the conceptual design.

3. The evaluation of available sites for the plant, and the selection of preferred sites for preliminary plant layouts.

4. The identification of the possible problems associated with the construction of a plant on each of the preferred sites.

5. The analysis of the program schedule and the preparation of a more detailed schedule for the design and construction of the plant.

6. The preparation of the capital and annual cost estimates (This would be done after completion of the conceptual designs and plant layouts.)

7. The selection of a probable plant operating factor, and the preparation of the unit water cost estimate.

8. A preliminary analysis of the construction and manufacturing problems which might be encountered in the construction of the proposed plant in the particular country or region.

9. A determination of the amount of local equipment, labor and materials which might be utilized in the construction and operation of the plant.

10. A report containing a summary of all the information developed in the study and recommendations for further action.

D. Subsequent Action

If, after review of the results of the engineering feasibility and economic study, the Water Development Board decides to proceed with the project and to request assistance from AID, it should prepare the material necessary to request this assistance; this would include preparation of the Economic and Technical Soundness Analysis, and the calculation of Benefit/Cost ratios in the form required by AID. This material would be based primarily upon the information developed in the engineering feasibility and economic study. References may also be made to the surveys of background information included in the Water Development Plan.