ST/TCD/8

Natural Resources/Water Series No. 21

WATER RESOURCES PLANNING TO MEET LONG-TERM DEMAND: GUIDELINES FOR DEVELOPING COUNTRIES

United Nations

Department of Technical Co-operation for Development

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FOREWORD

The Mar del Plata Action Plan, which arose out of the United Nations Water Conference (Argentina, March 1977) recommended that, "In order to project future water needs it is desirable to have data on use and consumption and quality by type of user and also the information necessary to estimate the effect of the application of different policy instruments (tariffs, taxes, etc.) in influencing the various areas of demand. The demand for water for different purposes should be estimated at different periods of time in conformity with national development goals to provide the basis and the perspective for the planned development of available water resources."

The information on demand, and on use, consumption and quality of water are needed to allow the government to plan its allocations of existing supplies to meet future demand. The Mar del Plata Action Plan also recommends that governments, "Formulate master plans...to provide a long-term perspective for planning, including resource conservation, using such techniques as systems analysis and mathematical modelling as planning tools, wherever appropriate. Projects arising out of the national plans should be well investigated, and appropriate priorities should be assigned to them ...".

This publication has been prepared by the Department of Technical Co-operation for Development (DTCD) in response to the above recommendations. The document is aimed primarily at planners, economists and decision makers in developing countries whose responsibility it is to formulate long-term water resources development plans and programmes with limited financial resources and professional skills. It is neither a textbook, nor an exhaustive treatise on the subject of water resources planning. The main purpose is to help water resources engineers and planners translate their knowledge in specific topics, as well as the expertise which may be offered to them through technical assistance, into broad and realistic approaches to water resources planning and efficient water utilization. Policy makers and managers may benefit from this publication by realizing what role they can play in water resources development, in its broader sense, through interactive involvement in the planning process, from its earliest stages.

This publication presents some of the economic and technical experience of the staff of the Water Resources Branch of DTCD's Natural Resources and Energy Division as well as that gained by senior consulting engineers over many years of practical work in this field, under widely varying physical and human environments. Experience of this nature is obviously subject to personal interpretation, and cannot be all embracing in scope and thoroughness. Nonetheless, it is believed that the practical viewpoints, ideas and recommendations presented here would give readers a valuable insight and guidance in coping with the main problems encountered in water resources development.

The Department is indebted to O. Nagler, Y. Kahana and Z. Shalev, senior planners with Tahal Consulting Engineers Ltd. of Tel Aviv, Israel, for their valuable contribution to the present publication, based on their personal experience, as well as the experience of Tahal in general.

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I. INTRODUCTION

The objective of the United Nations Water Conference, held in Argentina in 1977, was to promote a level of preparedness -- nationally, regionally and internationally -- that would help to cope with the increased level of water demand by the year 2000 and help to avoid a world water crisis. Thus, the Conference identified certain priority areas for action in the realm of water management at the national and international levels. Among these, criteria for planning of water resources to meet potential future shortages were defined at the national, regional and local level.

Organizational arrangements for water planning are related to the country's approach to over-all water management responsibilities. The main difficulty in planning is to secure the necessary co-ordination among the different levels of government and water administrations that may share management responsibilities and among the different centres of government authority. The challenge is to satisfy as much as possible the competing demands for water with the available or planned supply. In the future, especially in water-short areas, planning will entail controls on demand and conservation measures, which will apply to all levels of government and user categories.

Water use is closely linked with the use of other equally important resources, such as land, and water supply services are part of broader integrated programmes of urban, rural and regional development. Consequently, the preparation of a water plan requires continuing institutional co-ordination, so that water management planning will fit into over-all development.

A. Central Planning of water resources

The advantages of having a central water organization are mainly associated with planning and co-ordinating activities to ensure better utilization of water resources. The central function of a water planner is to formulate policies, programmes and projects that will help to achieve national goals and objectives. In this context, the planning of water resources, understood as a continuing activity separate from execution and operation, can be carried out in connection with all water management activities. The general objective of water resources planning is the rational selection of water policies, programmes and projects that will help to achieve the social and economic goals of the nation.

One of the major limitations on all public planning, including water resources planning, is the lack of clearly-defined social, economic and environmental goals.

It is important to have a separate centralized planning agency to be responsible for the definition of national and sectoral goals and for policy planning, utilizing inputs from all the agencies concerned. The planning unit should be close to the country's chief executive and should have sufficient authority to define policies that will be carried out by the implementing or functional agencies.

The goals and objectives which the plan is expected to achieve should be clearly and concisely stated, with a brief description of how the plan will meet those objectives. The planning agency should assume leadership in seeing that clear goals are selected. This will entail sifting through inconsistent, incompatible and unrealistic goals submitted by the implementing agencies.

Policy planning, and water resources sector planning, should be separated from functional or implementation planning, design and construction, which will be the responsibility of the implementing agencies directly concerned with irrigation, industrial or municipal water supply.

The planning process seeks to achieve a balance between the general goals, as expressed in national and water sector plans, and the aims defined by the needs of implementing agencies or user categories. Therefore, it is important that the planning agency take into account all the competing interests when defining over-all goals and alternative policies within given budgetary constraints.

The final plan should describe alternative actions and the consequences of those actions. It should contain the planners' recommendations on specific courses of action, expressed as explicit structural or non-structural measures. The advantages and disadvantages of each alternative must be presented. The planner should assess each alternative according to the efficiency with which it could meet the stated goals and to the consequences of following that course of action.

Planning must be a flexible exercise, subject to continuous modification according to changing political, economic, social, technical and environmental circumstances. Planning must be seen as a continuing process with no final solution.

User organizations should be encouraged to take an active role in all aspects of water management, so that they are involved in and informed about various programmes of the implementing agencies. They should participate in decisions which affect them directly, such as setting the level of water tariffs, the introduction of rationing and the construction of new water works. The future success of any water resources development programme depends upon its acceptance by the affected community.

B. Components of the institutional framework

In accordance with the national aims, water implementing agencies and management institutions organize the water supply services for different purposes. In situations where there is competition among either water uses or water users, the institutional framework channels, and attempts to reconcile, the different interests of the users, present and future, of a given water source. In this context decisions are taken on how the water is to be used and by whom. The institutional framework is also aimed at facilitating the proper implementation of the country's policies and programmes in water resources.

Generally speaking, the institutional framework for water management comprises the bodies that establish the rules or legislation on how water resources are to be developed and used and the agencies with regulatory or political functions, all of which will depend on the individual characteristics of a country. Moreover, the framework will include the following elements:

(1) Specific rules or laws concerning the development and use of water resources;

(2) The bodies that participate in making decisions on programmes for the exploitation and use of water resources;

(3) The channels of communication and information from the various agencies that have responsibilities concerning water resources to other government agencies, including those that take decisions, and to the groups directly affected by water-management programmes, including the general public.

The legal framework should include rules that establish the order of priority for the various water uses, especially in those regions where there are water shortage problems. In determining who should have preference there must be a basic consideration for the economic and social factors in each region, and there must be enough flexibility to allow for alteration, as required, of the order of priority for municipal, agricultural, industrial, electricity-generating, aquacultural, navigational and recreational uses. It is understood that domestic use by its nature must in all cases have over-riding priority. A legal framework that is flexible will remain relevant for a longer period, permitting the introduction of incidental changes in the rules by means of administrative regulations.

C. Purpose of this volume

The following chapters of this book seek to establish linkages between the broad national goals and policies for efficient water resources utilization and development and the technical requirements for attainment of those goals, from data collection to project implementation to institution building. These linkages should be reflected in the process of planning for water resources development.

Chapter II, entitled Supply and Demand Forecasting, gives a description of ways to collect and evaluate data on current supply of and demand for water, and how to forecast those into the future. Chapter III, Formulation of Water Resources Development Plans, and Chapter IV, Implementation of the Water Resources Development Plan, present specific considerations which must be taken into account in formulating water resources plans.

Chapter V, Planning for Efficient Use of Water, suggests mainly technical measures, which can be taken to enhance the fixed supply of water in a country, including reduction in losses and improvements in quality. Chapter VI, Application of Institutional and Legal Measures, provides some alternative policy measures which could be introduced in the short term to reduce future demand for water. The last chapter presents some conclusions and recommendations. It is hoped that the presentation of policy recommendations and field-level requirements will be useful to both planners and water resources technicians in developing countries.

The annexes provide some guidelines to the methodology described. Annex I presents a summary of how to assess demand for water, while Annex II provides three case studies describing the application of planning techniques.

II. SUPPLY AND DEMAND FORECASTING

Water management strategies for the future, and planning for efficient use, depend heavily on accurate assessment of existing water supply and demand and forecasts of demand for water in the future. In some industrialized countries, projections of water use (demand) were based on past trends and past policies, leading to enormous estimates of future water requirements. In reality, the water "requirements" of a society are very small, to cover drinking and cooking, fire fighting and other essential needs. Additional demand may be stimulated or depressed by government policies.

Realistic demand projections have to be related to financial resources available for expansion of water supply and government policies regarding conservation and expansion, as well as present capacity of the system and existing demand. Of course, other factors which have a bearing on future water use include population levels and distribution, per capita energy consumption, rate of growth of national income and technological developments. Many of these factors can be represented in computer models, which produce a range of "alternative futures" which are related to different policy decisions taken now.

Depending on what decisions are made by government authorities, future demand-supply gaps can be forecast for certain countries or regions within a country. Critical areas can be identified which are likely to have water shortages in the 1990s. These critical areas could then be the focus of planning exercises in water management to meet shortfalls.

A. Assessment of available water resources

It is assumed in this chapter that a country's quantity of water resources is, for practical purposes, fixed. Additional sources of water would involve great expense through treating polluted supplies, constructing new works or using non-conventional sources (to be discussed in Chapter V). This section deals with the evaluation and assessment of natural sources of water, i.e., water available directly from the source (a river, spring or aquifer) rather than indirectly (from reclaimed sewage or desalination).

Surface water and ground water are usually closely related: aquifers are recharged by streams, ground water discharges into streams, springs arise from underground. The term surface water relates to all water appearing on the surface (lakes, rivers, springs) and ground water to all water which is found beneath the surface. Both are part of the hydrologic cycle, and the information needed to evaluate their quantity and behaviour encompasses all elements of the hydrologic cycle: solar radiation, precipitation, hydrometry, soils, geology, evaporation. In addition, chemical changes affecting the quality of water and its suitability for various uses must also be studied as part of water resources assessment.

Some observations on methods and approaches to water resources yield evaluation (or assessment) are presented below. No attempt is made here to exhaust this subject, as it is fully covered by a rich literature. The main purpose is to present the subject of water resources assessment from a practical point of view for the water resource planner.

1. Surface Water

(a) Data Collection and Processing

Surface water flows result from the response of a catchment area, or basin, to precipitation. To assess the quantity and time-distribution of surface flows, it is necessary to assemble and analyze all relevant data on these three elements: precipitation, the catchment area, surface flows. More specifically this information should cover the following subjects:

Meteorology:	Precipitation	- rain, snow, hail, dew
	Temperature	- dry and wet-bulb measurements
	Hygrometry	- vapour pressure, relative humidity
	Solar Radiation	- short wave and long wave, direct and refracted
	Wind	- velocity, direction
	Evaporation	- standard pan evaporation records
Pedology:	Structure, permeability, water retention capacity of various soil types	
Terrain:	Topographic maps of the catchment area	
Hydrometry:	Hydraulic properties of river channels Stage/discharge relationships at control sections and streamflow gauging stations Streamflow measurements	
Sediment transportation:	Bed-load and suspended sediment load measurements	

Some of this information may only be required for special purposes. For instance: solar radiation, wind, temperature and vapour pressure data are required for computation of evaporattion from lakes, using a heat balance model; for the more common purpose of surface water yield calculations these data may not be necessary.

Rainfall and run-off records are the most important data to be used as a basis for catchment yield forecasting. In many instances, and mainly in developing countries, such data may not be available, or may be inadequate or too short for the catchment in question. Any records from adjacent catchments, or from areas further away with similar climatic and hydrologic features, will be of help. In particular, rainfall records, which are often more readily available, and for longer periods than streamflows, should be collected from sometimes remote stations which can still be correlated with whatever records may be available for the studied area.

Various statistical methods can be used to analyze rainfall records and, if necessary, reconstruct and extend historic records with values computed by statistical inference methods, in order to generate a continuous record for a longer period. For this purpose records from rain gauges outside the studied catchment may be required as a reference in correlation analysis. By such methods, statistically generated, or synthetic, sequences of rainfall can be used as a basis for estimating run-off over a long period.

It is important to remember that streamflow measurements at gauging stations do not necessarily represent the natural yield of the catchment upstream of the measured section. This would be the case when anywhere upstream a significant interference with the natural terrain is evident or may have occurred in the past. Past effects of soil cultivation, streamflow diversions or impoundments can be detected if a continuous record of historic flow measurements exists for a downstream station. In such a case a persistent change in the long-term record should be discernible. If this is the case, and if present interferences in the catchment may change in the future, the historic flow sequence should be corrected by adding, or subtracting, the computed amounts of water diverted, increased run-off from built-up areas, or changed run-off due to soil cultivation. The adjusted sequence can then be used as a basis for forecasting purposes. If it is planned to continue the upstream diversion or interference in the natural flow regime in the future, the forecast flow sequence should also be adjusted accordingly. In addition, rights to divert streamflows, or exploit ground water in excess of present utilization must also be studied and taken into account.

Wherever practicable, computerized data storage and retrieval should be introduced as early as possible in the process of data collection. For most practical purposes desk-top and mini-computers would suffice for storage and processing of all hydrological data which a water resources planning unit may need. In most cases, meteorological and hydrometric data would originate from a separate government authority, and the water resources planners need only obtain these data and utilize them. The computer hardware of the planning unit should thus be selected so that it can accept magnetic media (disks, diskettes) from other sources. It is advisable for the planners to know in advance the structure of files of meteorological or hydrometric records obtained from other authorities, before acquiring for their own use any preprogrammed data processing or mathematical model software, to facilitate utilization of data for planning purposes.

(b) Catchment Yield Calculations

Catchment yield calculations are required in water resources planning for the following main purposes:

(i) Estimating mean monthly and/or annual water quantities available at a given point from the upstream catchment area; this information is essential for any attempt to draw up a water balance for a water resources system;

(ii) Generating a statistical basis for operational studies of storage systems, usually on a month-by-month basis, and for operational studies of conjunctive use of surface and ground water resources;

(iii) Generating a statistical basis for probability analysis of peak floods, in daily or hourly units, as a basis for selection of a design flood and determination of spillway capacity, dam safety, flood hazards, water quality changes, etc.;

(iv) Predicting sediment yields of the catchment area, on the basis of generated streamflow series and observed sediment concentrations vs. discharge rates;

(v) Developing advance flood warning systems on the basis of daily or hourly rainfall/run-off statistics;

(vi) Planning river regulation structures and operational regimes, based on daily or hourly flow series, for purposes of power generation, navigation, flood control, pollution control and diversions to irrigation or water supply projects;

(vii) Estimating the ground-water replenishment component of the catchment, which is necessary for ground-water studies.

Where reliable streamflow and rainfall measurement data are available for several points in the area, or in adjacent areas, for a good length of time, it is possible to compute sufficiently reliable statistical parameters for a probability analysis of flows, on a daily or monthly basis, from which most of the above-mentioned design values can be derived.

This statistical approach is seldom practicable in developing countries, for lack of sufficient reliable data. The problem of adjusting historic flow records to upstream diversions and other interventions in the catchment area, also complicates the application of this approach. However, a first approximation of catchment yields and peak flows can be obtained by simple induction from data on adjacent or similar catchments, or by calculation of run-off from rainfall, assuming some reasonable values for run-off coefficients, evaporation, concentration time, etc. A statistical analysis of available records can also reveal gaps and inconsistencies which must be accounted for in the process of data reconstruction and synthesis.

The more practical approach is based on the analysis and simulation of rainfall/run-off relationships of the investigated catchment area. In principle, this analysis consists of the following steps:

(i) Generation of synthetic daily rainfall series, based on historic rainfall, for all rain gauges in the area and interpolation for other points in the area, to obtain representative series related to sub-catchments. In the absence of rain gauges in the area, use weighted interpolations of records from adjacent and similar areas can be used to generate representative rainfall series for the entire catchment or sub-catchment.

(ii) Adoption of one of several commercially available catchment simulation computer models, and transformation of daily rainfall series into daily run-off series.

(iii) Calibration of model parameters by a series of runs, attempting to obtain a satisfactory representation of historic flow events from historic rainfall data. When calibrated, the model can be run with synthetic rainfall series to generate synthetic run-off series. Ground-water replenishment can also be computed as a by-product of model runs.

(iv) Derivation of monthly series, monthly and annual means from synthetic daily run-off series.

(v) Computation of probabilities of peak floods from daily run-off series.

(vi) From an observed flood event (hourly or smaller time units), the unit hydrograph can be derived and applied to a selected synthetic daily peak flood, to obtain a design flood curve.

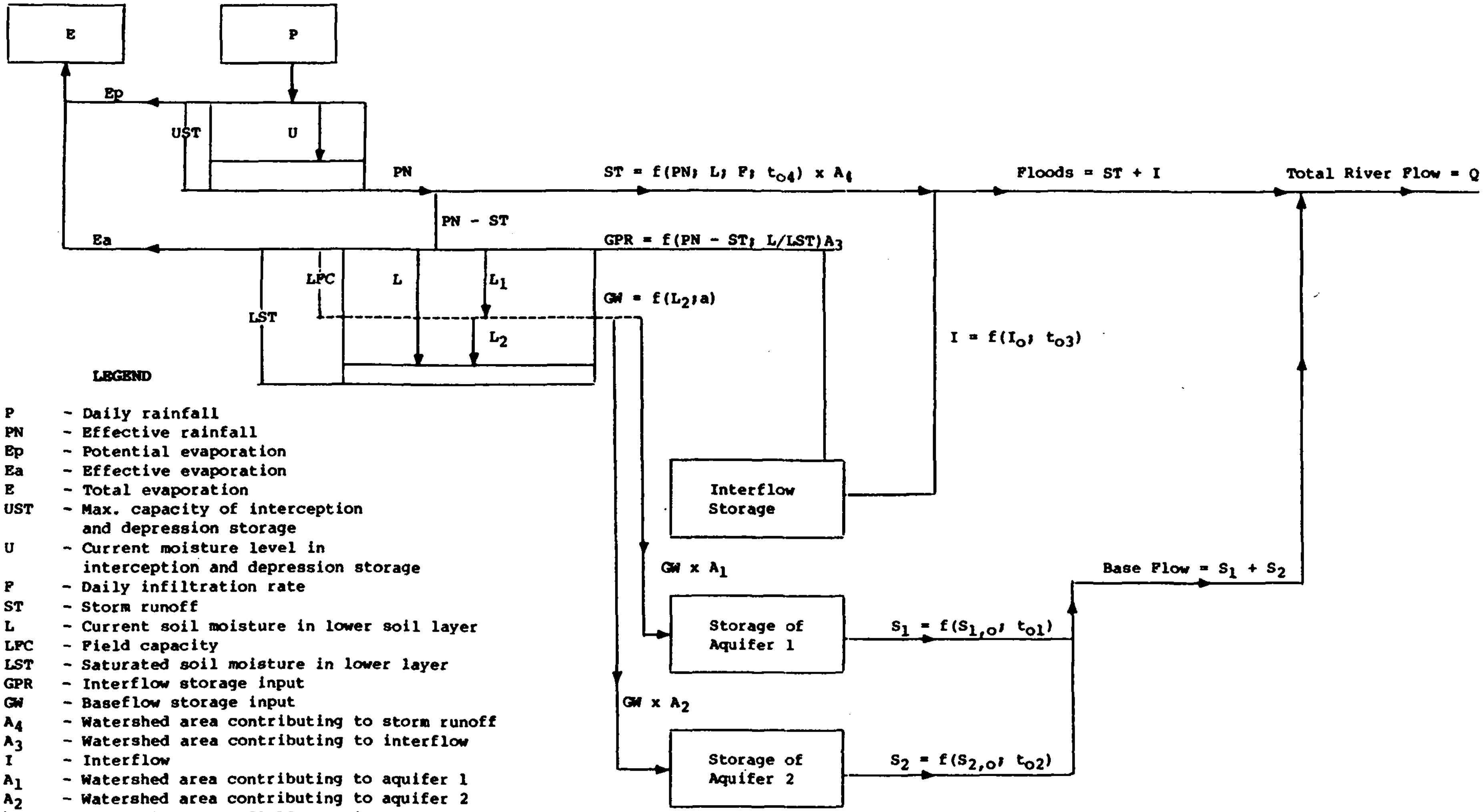
(vii) From the observed sediment load vs. flow records, a sediment rating curve can be derived for the entire catchment, from which sediment yield series can be generated, and accumulation rates computed.

Catchment simulation models are generally based on a moisture accounting procedure. The catchment is represented by a series of national reservoirs, overflows, conduits and outlets, one cascading into the other. The various elements of this conceptual model represent the process of rainfall accumulation on the surface and in the soil, evaporation and transpiration, overflow to deeper layers or to the river when soil or surface moisture storage become saturated, and, in the process, retaining water in the soil. Figure 1 depicts the conceptual elements of such a model.

Each element in the model is assigned an initial numerical value, representing evapotranspiration potential, surface retention of rainfall, soil moisture retention potential, etc. These values are adjusted in the course of calibration, but must be kept within reasonable bounds.

Two well-known models of this type are the Stanford model and the Sacramento model. The original Stanford model performs moisture accounting calculations on the basis of hourly rainfall records, and is thus seldom applicable to conditions prevailing in developing countries. However, a version of this model has been developed for use with daily rainfall records and was satisfactorily applied in numerous cases. The Sacramento model is similar to the Stanford model but operates in daily units.

Whereas daily rainfall records are usually collected by plain gauges, easy to measure and record, hourly rain observations require recording instruments. In addition, a much closer network of gauges is required to represent adequately hourly rainfall distributions over a catchment area, compared to daily rainfall, which is distributed more uniformly over the area.



LEGEND

- P - Daily rainfall
- PN - Effective rainfall
- Ep - Potential evaporation
- Ea - Effective evaporation
- E - Total evaporation
- UST - Max. capacity of interception and depression storage
- U - Current moisture level in interception and depression storage
- F - Daily infiltration rate
- ST - Storm runoff
- L - Current soil moisture in lower soil layer
- LFC - Field capacity
- LST - Saturated soil moisture in lower layer
- GPR - Interflow storage input
- GW - Baseflow storage input
- A_4 - Watershed area contributing to storm runoff
- A_3 - Watershed area contributing to interflow
- I - Interflow
- A_1 - Watershed area contributing to aquifer 1
- A_2 - Watershed area contributing to aquifer 2
- L_1 - Soil moisture at field capacity
- L_2 - Increment of soil moisture above field capacity
- a - A detention function during drainage process
- I_o - Current moisture in interflow storage
- t_{oi} - A depletion characteristic time of storage i
- S_i - Baseflow storage i output
- $S_{i,o}$ - Current moisture in baseflow storage i

Figure 1. A schematic presentation of the hydrometeorological model

Another model, code named CHERRIE, has been developed at the University of Delft, the Netherlands, and has also been satisfactorily applied in several cases. This is a non-steady open channel flow model, which simulates the flow of water in a system of open channels, taken to represent the network of streams in a catchment area. To run this model, rather detailed data on the slope, length and cross-section of stream reaches is required. It uses design catchment yield sequences for various sub-catchments (computed by the Stanford Model, for instance), to generate a series of flood flows.

Numerous other computer models are available as an aid to surface water hydrological studies. The choice of a model would depend on the purpose of the study, the quality and amount of data available, computer systems available and technical skill of the users. In any case the user should be capable of computing without the help of a computer at least some of the results which the computer would produce much faster and in great quantity, so that he can check the computer results, to make sure that no grossly mistaken data or assumptions have been fed into the computer.

A very powerful and yet relatively simple computational aid to planning streamflow utilization schemes (as well as ground-water schemes) is simulation. Streamflow sequences can be run through a set of equations describing the planned scheme to obtain simulated results of scheme operation for any combination of design parameters, over selected lengths of time. The attainable level of utilization can be defined as that which would maximize the desired outcome (e.g., irrigation, power supply) while minimizing risks (e.g., inundation, failures) and negative impacts (e.g., excessive concentration of pollutants), while maintaining given constraints (e.g., water rights). These values can be readily derived in the form of probability distributions from simulation runs.

A special field of applied mathematics related to surface water development is storage regulation. Setting optimal rules of operation for reservoirs designed for flow regulation, flood control, irrigation and power generation, is a rather complex mathematical task, especially in the case of a multi-reservoir system. Operation rules must, however, be devised, not only for actual operation, but for planning purposes, because they determine the storage volume and the exploitable yield of regulated streamflow utilization schemes. If a mathematically optimized operation policy is not readily achievable, simulation of the operation of the system with various, less refined, rules can be applied as a means of testing various storage volumes and selecting the values which would best meet target outputs under given constraints.

2. Ground water

(a) Data collection and interpretation

Some of the data which should be collected for the evaluation of surface water resources, as detailed in the previous section, are also necessary for evaluation of ground-water resources, e.g., precipitation, evaporation, soil structure, streamflow measurements. All these factors affect the ground-water balance. In addition, geological information and data on the hydraulic properties of aquifers are indispensable for understanding the ground-water regime and planning its exploitation.

Most ground-water studies, especially where new areas are concerned, would include exploratory drilling, geophysical soundings and other field investigation techniques. Based on findings from these investigations and on all other available information, the results of ground-water investigations for a water resources development project should cover the following topics and be presented by the following documents:

(i) A conceptual model of the ground-water basin

Data should be collected from all existing and specially drilled (test) boreholes, including: *in situ* geological tests and well logs, core samples, pumping tests, geophysical tests, water quality analysis, and geochemical studies. These data--combined with surface geology surveys, aerial photography, topographical maps, soil and vegetation surveys, surface hydrology and records of rainfall, pumpage and recharge--should give a picture, or a conceptual model, of the underground layers, presence and extent of aquifers and aquitards, hydraulic properties and flow regimes.

This conceptual model should be depicted by the following graphic presentations:

a. A physical map, showing location of wells, aquifer boundaries, natural recharge zones (geological outcrops, rivers contributing to ground water) and ground-water outlets (to springs, rivers, lakes and seas), with an indication of ground-water flow directions. Location of geological cross-sectional diagrams should also be indicated on this map.

b. Geological cross-sectional diagrams, showing existing boreholes, stratigraphy and hydrological boundaries, ground-water table, aquiferous and non-aquiferous layers and ground-water flow directions, accompanied by a legend which defines hydrogeological properties of the various strata.

c. Water table contour maps for selected dates in the past, including, where necessary, a distinction between phreatic and artesian water levels or piezometric surfaces.

d. Ground-water level hydrographs for the longest period of available records and for all wells with reliable measurements.

e. Ground-water quality maps, indicating, where relevant, salinity or pollution sources, directions and areal extent.

(ii) A ground-water data bank

The ground-water data bank must include, for every borehole, the following:

a. Well data: location, ground elevation, date drilled, construction details, purpose (production, recharge, exploration, observation), water quality (principal indicators), conclusions from latest pumping tests (in terms of well yield and drawdown), recharge absortion rate (if relevant).

b. Time series of pumped quantities, water levels, water quality and recharged quantities (where relevant).

(iii) Listing of constraints to ground-water exploitation in the investigated area, such as:

a. Effect of lowered regional water table on yields of existing and planned wells and on pumping costs.

b. *Reduction of ground-water contribution to existing surface* water sources (springs, rivers, lakes) and consequent infringement of water rights.

c. Increased seepage from adjacent streams into the aquifer, consequent reduction of downstream streamflows, and infringements of existing water rights.

d. Undesirable environmental impacts such as drying of aquatic flora and fauna habitats (as well as the beneficial effects of drying marshy lands and improving land drainage).

e. Negative effects on ground-water quality from increased influx of contaminants from known areas of man-made pollution, or from moving bodies of salty water which may be in contact with the fresh ground water, or by drawing a coastal sea water interface into the aquifer.

f. Possible soil subsidence as a result of lowering the water table around wells or wellfields.

The process of assembling all this information and interpreting it for practical purposes will vary in intensity, duration and accuracy of conclusions, depending on allocated budgets and manpower resources, on amount and quality of prior information and on urgency and purpose of the studies. Ground-water investigations are seldom initiated for the sake of pure science; there is usually a practical purpose involved. Hence, even when prior information is meagre and funds for field investigations short, the hydrologist would be expected to give some indication of development potentials and implications. The crystallization of a conceptual model of the ground-water basin(s) in question, including the various graphic aids listed above, would thus be a gradual process, as would be the accumulation of information in the data bank and the definition of constraints. As this process evolves, the recommendations for ground-water development will become more and more accurate and reliable. In most instances there will be some prior information which would enable some estimates of ground-water potentials to be drawn up as a basis for further action, using elementary hydrological reasoning.

For instance, in a study done in 1963, at the beginning of the Ghazvin Area Development Project in Iran, a preliminary balance was based on a rough *water table contour map, assumed transmissivity values and area of cropped* lands. A check on the results was obtained by calculating the evaporation and (small) surface outflow from a large marsh which forms the drainage basin for the entire alluvial aquifer. When sufficient geological information becomes available to delineate the area of an outcropping aquiferous layer, which dips from a mountainous region to beneath a geologically younger layer in a valley (such as the limestone aquifer in Israel, beneath the coastal plain), an estimate of the yield of this aquifer can be based on calculated amounts of precipitation on the outcrop area.

A totally different situation prevails in many parts of West Africa, where geological formations are often very fragmented and discontinuous. In spite of abundant rainfall, ground-water storage and well yields are usually rather shallow and small, and are mainly utilized for domestic water supply. Investigations for ground-water development are limited in this case to locating suitable drilling sites, which are usually found in rather limited zones of geological fractures and joints. It was found that changes in vegetation often indicate the presence of such zones. Regional ground-water models and water balances are of little relevance under such conditions.

It is advisable to establish a computerized ground-water data bank as described above, at an early stage of data acquisition. Data base programmes have been specially developed for this purpose, within which both static information and time-dependent data can be stored, updated and processed for various purposes.

Numerous computer programmes are available as an aid to calculation of regional ground-water development potentials and water quality changes, as discussed below, in addition to programmes designed to assist the hydrologist in interpreting hydrological tests of individual wells and well-fields, and in other computations.

(b) Computational tools

Computer programmes have been developed and applied in numerous cases as an aid to assessing ground-water potentials and predicting quality changes and sea-water intrusion (in coastal aquifers). Both quantitative and qualitative problems can be dealt with by either two- or three-dimensional, and by single- or multi-layered models. Sea-water interface models are also either single- or multi-layered. A multi-layered model is required where there are distinctly different layers in the aquifers, expected to affect the movement of water and solutes toward pumping wells.

As soon as a conceptual model of the investigated aquifer can be formulated, in terms of horizontal and vertical dimensions, geological or other hydraulic boundaries, and principal features of the flow regime, a "finite elements" or a "finite differences" algorithm can be applied, to simulate the flow of water in the aquifer. For this purpose the aquifer is divided into a mesh of single- or multi-layered cells, each of which is assigned assumed values of: transmissivity and storativity; natural inflow (rainfall, streambed infiltration, or boundary inflows); outflow (through boundary cells into an adjacent aquifer, evapotranspiration or drainage into surface water bodies or streams); and water level at a selected date in the past. The model must be calibrated through an iterative process of adjusting the assumed constants of each cell and its boundary conditions until a sequence of historical inflows and outflows to the aquifer is translated by the computer programme into a sequence of water levels. Calibration is satisfactory if simulated water levels are sufficiently close to historical water levels in the same aquifer cells.

The array of aquifer constants obtained by calibrating the model constitutes an approximation of actual hydraulic and other properties, and may deviate from the conceptual hydrogeological model, but it is appropriate for practical purposes, once the model is shown to be capable of reproducing historical water levels from historical inflows and outflows. At this point, the balance of inflows and outflows, plus changes in storage, constitute a reliable basis for planning increased ground-water exploitation and utilization of aquifer storage as a part of a regional water resources system, as discussed below.

(c) Limits to ground-water exploitation

A balanced exploitation of an aquifer will be maintained as long as mean annual pumpage does not exceed mean annual replenishment, less a certain amount of outflow which may have to be allowed in order not to violate some of the constraints mentioned above. It may be possible to pump out more than the computed replenishment from one part of the aquifer, and less elsewhere, if this would better suit the water supply or irrigation plans. The lowered water table at the more exploited part causes ground water to flow from other parts toward that area. This possibility is conditioned by the presence of favourable hydraulic connections between different parts or layers of the aquifer. In any case, however, abstracting water from any part of any aquifer reduces natural outflows (springs, streams, seaward flow) somewhere else, or affects pumping by existing wells, although the effect may take some time (years) to be discerned. In this regard, a marked difference exists between alluvial or fine-grained aquifers, on the one hand, and rocky, mountainous, fragmented or porous aquifers, on the other hand. Whereas fine-grained aquifers usually exhibit a slow regional water level response to pumping, rocky aquifers propagate water table drawdowns across the aquifer in a very short time.

The safe exploitable yield of an aquifer, or any part of it, is thus limited by the natural replenishment as well as by quality constraints, water rights, environmental and other impacts. Early knowledge of limiting factors which should be considered in planning ground-water development, is thus essential.

In many cases ground-water exploitation in excess of the safe yield can be sustained for several years, but it must be planned in light of future effects, and balanced exploitation must eventually be re-established. During the years of over-pumping a one-time storage of ground water is being used, which may sometimes be an advantage for regional water resources development (see section V.C). A lower steady-state water table is established when balanced exploitation is restored. This can be attained by either reducing pumping or inducing recharge, or a combination of the two.

In the case of a coastal aquifer, where natural ground-water outflow takes place through a layer of fresh water overlying the sea-water/ground-water interface, sustained over-pumping causes a slow inland movement of the interface and a reduction in ground-water outflow. When properly planned and managed, a temporary unbalanced exploitation of a coastal aquifer can thus result in a long-term gain in the water balance, in addition to the utilization of the one-time storage.

Where ground-water bodies of various salinities exist in the same aquifer, or are somehow in hydraulic contact, the total exploitable amount of water from the aquifer may depend on possible uses for water of different salinities. If brackish or saline ground water can be utilized, those waters can be directly pumped out and supplied. Alternatively, the withdrawal of fresh water can be increased and the aquifer's salinity allowed to increase to a certain level (as a result of drawing saline water into wellfields). Either way a higher total ground-water exploitation will be achieved, compared to a conservative policy of exploitating only the least saline waters. This option requires, however, very careful planning and monitoring, to avert excessive deterioration of the salinity of the fresh water.

Regional aquifers are sometimes sub-divided by widespread geological horizons into sub-aquifers, which may still be partly connected hydraulically. By drilling wells to pump only from the lower sub-aquifers it may be possible to delay the effect of pumping on the regional water table. If a process of ground-water contamination from the surface is detected, and the aquifer is geologically sub-divided, pumping from a lower sub-aquifer can also avert the pollution hazard, at least temporarily.

When ground-water exploitation approaches a state of imbalance, it is advisable to employ aquifer simulation techniques in order to plan ground-water management policies. With the aid of a properly calibrated simulation model, it is possible to test various patterns of areal and temporal distribution of pumping and artificial recharge, under a wide range of assumptions, including various climatic sequences, and to select a suitable development plan that would ensure a long-term balanced exploitation within given constraints (see section V.C). In addition, with the aid of such computational tools, possible detrimental effects of ground-water exploitation on the quality of water can be predicted and averted.

B. Demand Forecasting

With greatly increased water use and water pollution problems throughout the world, as well as widespread drought, it is certain that many areas will face increasing water scarcity in the immediate future.

Water management and planning will have to take into consideration such techniques as: waste-water reuse; recycling; non-conventional water resources, such as desalination; and water pricing to reduce demand. There will no doubt be a substantial upward trend in water costs and prices, which should affect levels of demand, particularly by the larger consumer categories, such as the agricultural sector.

Traditionally, water supply engineers and planners had emphasized the provision of adequate amounts of water from known sources. Considerations of efficiency in use, water quality and demand management were of secondary importance. Much attention was given to the statistical measurement of flows, the hydrological characteristics of streams and the engineering aspects of physical structures and their related costs. The once-through flow principle prevailed, Governments absorbed the major portion of costs when water was publicly supplied and rate structures favoured consumption rather than constraints on use.

More recently, Governments have had to search out new approaches, since the availability of water can no longer be taken for granted. It is becoming increasingly apparent that water should be viewed as a factor input of the production process and that efforts should be made to find optimum combinations of those inputs.

Although water statistics are far from adequate, the reasons for the persistent increase in the demand for water are clear: (a) the growth in population, estimated at an average rate of 1.6 per cent per annum from 1985-1990 on a global scale, and decreasing somewhat thereafter, which implies a doubling of demand every 55 years, other things being equal; (b) the accelerating influence on consumption of improved standards of living stemming from increased rates of urbanization; (c) the growth taking place in water-related commodity production and service industries relative to the economy as a whole. On the other hand, demand has not risen as rapidly as past trends would lead us to expect, since there has been some movement in the direction of recycling and conservation, especially in developed countries and water-short developing countries.

Planning frameworks can assist governments to adjust the socio-economic and physical structures of their countries to the changing patterns of water uses. Forecasting the demands for water is the basis of long-term planning for water resources, and enables Governments (a) To anticipate water problems in areas of the country or in sectors of the economy; (b) To recognize those factors that might be changed in order to forestall problems; (c) To recognize those factors which have an effect on water use but have not generally been used to influence water policies or practices.

1. Estimated future trends

The trends and outlook for water use, and the likelihood of a water shortage, are impossible to predict, particularly on a global scale. The local and regional outlooks will necessarily be very different, and will depend on water management policies and technological innovations.

Since it has been accepted that neighbouring water supply systems, involving both ground and surface water sources, are interconnected, it is useful to analyze outlooks for water on a large scale, such as for large national or international river basins. It should be borne in mind, however, that water supply and demand cannot be compared or balanced with each other on a global scale.

The different categories of use have quite different effects and significance in the over-all water management system of an area. Domestic and industrial uses usually return the largest portion of withdrawn water quantities to the natural source. This causes a significant change in the quality régime unless a high degree of treatment is given to the effluent waste waters. Agriculture consumes most of the water used for irrigation, returning only a small part to the source. Hydropower plants leave in the streams virtually the whole amount used, and have almost no effect on the water quality. The spectrum of uses by major components must, therefore, always be specified if aggregate amounts of per capita usages of various regions are compared.

In some countries where water uses have already approached the physical limits of local water availability or where per capita usage is already at an exceptionally high level, per capita withdrawal uses are not expected to increase. In countries such as Israel and the United States, specific values of industrial and urban water withdrawals have decreased due to a broader application of reuse techniques.

Since it is an inherently consumptive use, irrigation may be expected to become the key issue in water resources development on a long-term basis. Many developing countries have established large-scale irrigation schemes during recent decades to ensure adequate food production for their populations. While technological developments may greatly reduce irrigation water losses, no cost-effective solution has yet been found to reduce losses from transpiration of water in large-scale agricultural production. In water-short areas, it may be highly desirable to develop projections on the long-range irrigation demand and its impact on the water management system. With the objective of conserving water in mind, all alternatives for attaining increases in food production should be considered, including shifts from irrigated to dry-land farming.

Although irrigation may be of primary concern in a long-range perspective, in most developing countries the tasks relating to rural and urban water supply are equally important and pressing. At the mid-point of the International Drinking Water Supply and Sanitation Decade (1985), a World Health Organization survey (WHO, 1987) covering the populations of 114 developing countries (excluding China), found that 25 per cent of the urban populations of those countries were not adequately served by water supply services and 41 per cent of the urban populations did not have access to adequate sanitary services. The picture is more dramatic in rural areas, where 58 per cent of the population did not have access to clean drinking water supply in 1985, and 84 per cent were without sanitation services. The primary difficulties in meeting demand are related to the mobilization of internal and external capital needed for investment, the development of appropriate operation and maintenance systems and training programmes for people at the local level. Projections will have to take into account expanded demand for water supply and sanitation services.

In the case of industrial water supply, governments are in a position to influence the quantity and quality of water used. The costs of industrial water supply and waste water disposal are usually minor elements in the over-all picture of industrial investment and production costs. Governments may be able, therefore, to shift to the respective industries the burden of applying the advanced water treatment and recycling technologies required by increasing shortages of water or by environmental considerations. The introduction and implementation of regulatory measures and economic incentives coupled with the promotion of research and the application of advanced technologies may guide industrial water uses in the desirable direction and improve or prevent the pollution of waters by industries.

2. Alternative scenarios in water demand projections

The number of variables directly and indirectly affecting the economic demands for water is very large. Governments are shaping or influencing a great many of these variables by the powerful tools of economic and monetary policies. Although the share of public versus private funding varies from country to country, government decisions basically determine the capital available for investments in the water resources field in almost every country.

By its fiscal and monetary policies, the Government determines the levels and types of taxes and influences the levels of interest rates. In addition to establishing monetary and fiscal policies, the Government greatly affects the economic demands for water by its policies relating to licenses, franchises, trade practices, quality standards, rights of use to public and private properties, effluent charges, waste treatment and disposal criteria, recycling and reuse policies, conservation programmes, mineral and ground-water rights, transfer privileges, health programmes and regulation of production practices.

The national system of water law and the respective legislative measures also have an important bearing on the level of water demands by encouraging or discouraging efficient practices of water use.

Since it is virtually impossible to visualize developing any meaningful estimates of changes in policies and policy directions in the future, the forecasting of economic supplies of and demands for water is a problem inherently characterized by uncertainty. Thus, to forecast supplies and demands, it is necessary to specify combinations of mutually-consistent policies and evaluate the implications of each set separately. Use of alternative scenarios requires considerable discretion in the development of policy specifications, because of the relatively large number of possibilities involved.

Planning to meet future demand for water should envisage a range of alternative futures for the region under consideration and a spectrum of alternative plans to provide for such futures. Much of this can be accomplished by the use of a computer, and methodologies are described in chapter III and elsewhere. Effective plan formulation should include a description of the advantages and disadvantages of alternative plans and their relative effectiveness in meeting stated objectives and goals. From those options, decision makers should be able to select a proper course of action, including a combination of structural and non-structural measures.

It is important under current circumstances that every country, developing and developed, include environmental quality in its planning process. The increasing interdependence of water systems across national boundaries, and the importance of water quality for the future of all nations, makes it imperative that water quality measures be introduced now.

The assessment of potential technological advances and their impact on water demands is another equally important and difficult facet of outlining alternative future scenarios. The direction of water use and control over the years will depend to a large extent on technological innovation, and the value of research on technological developments related to water use and/or supply cannot be over-emphasized. Some significant changes in water technology have occurred, and plans for developing and using water in the future should take into consideration the effects of technological development. These are discussed in chapter V.

3. Demand Assessment

A summary of the methodology which can be used to carry out demand assessment is presented in Annex I.

C. Constraints to accurate forecasts and relevant plans

Planning in developing countries must be conducted under relatively difficult conditions: inadequate data, insufficient procedures and personnel, inadequate financial resources and unenforceable legal framework. Despite the constraints, most water-short countries have already begun the process of planning to meet long-term demand for water. This section will describe some of the constraints, and chapters III, IV and VI will provide some suggestions on ways to overcome those constraints.

1. Technical constraints

Following the format of the United States National Water Commission, in its study on Water Resources Planning, various constraints to effective planning in most developing countries are listed below.

(a) Data limitations

Adequate reliable physical, socio-economic and environmental data are essential to the planning process. There are now well tested methods for collecting physical data, and bilateral and multilateral agencies are willing to provide technical assistance in setting up meteorological and hydrological networks for long-term data collection. Many government agencies collect data, and the quality of data and methods of collecting and recording data vary widely. In the era of the micro-computer, it seems that a standardization of data collection, recording, storage and retrieval methods would enable agencies to use and exchange data among themselves, making integrated planning easier and more effective. Data management programmes should stress widespread usability and the importance of publicizing the source, availability and reliability of existing data (see section IV.C).

While much of the physical data required for planning is already being collected systematically in many countries, it is more difficult to collect or define the socio-economic and environmental data needed to make forecasts of water resources requirements. Planners in developing countries need to be aware of the importance of defining the necessary indicators, so that existing data can be used or specific government agencies can be assigned to collect what is needed.

(b) Inadequate procedures for data analysis and plan formulation

Even when data are relatively accurate and complete, the procedures and personnel involved in analyzing the data may not be adequate to use them effectively in predicting the future for planning purposes. As mentioned earlier, forecasts of future water demand can no longer be based simply on a continuation of past trends. Rather, alternative futures for water use must take into account different assumptions for growth rates of population and national income, per capita energy and food consumption, technological developments, water pricing policies, consumer habits and lifestyles, various government policies and environmental impacts of present policies.

One of the major problems facing developing countries is the lack of professional personnel trained in analyzing the environmental, social and economic aspects of resource management. Training of planning personnel in the water resources sector may be a priority in countries where water is a critical input to productive sectors or where water shortages can be foreseen.

The insufficient use of interdisciplinary and systems approaches to evaluate alternatives is in fact the principal technical constraint to plan formulation. Water resources planning must be placed in the context of over-all development planning in a country in order to maximize benefits from development expenditures. Successful multi-sectoral planning requires greater use of the systems approach.

The systems approach involves much more than mathematical modelling; it enables the decision maker to examine the system as a whole, focusing on the interdependence between elements of a system, rather than discrete units. It is a tool to provide information to decision makers, which should allow them to make informed choices from a broad array of alternatives. However, it should always be kept in mind that such approaches are no substitute for sound judgement and policy leadership. Procedures for plan formulation are described in more datail in chapter III.

(c) Evaluation procedures

Planning could be made much more effective by an improvement in evaluation procedures which would relate achievements to the over-all goals and objectives of the plan. Often planning has been oriented toward individual projects and achievement of economic efficiency, ignoring broader social goals. Evaluation methods must increasingly take into account the achievement of environmental, health and other non-monetary benefits of a plan. An inventory of data on past projects--how they have met their objectives, whether the results were socially beneficial, their economic performance--would assist planners in predicting what would happen "with" and "without" a given project. Such an inventory of evaluations, kept on a computer, could prevent a repetition of past mistakes.

2. Institutional constraints

Institutional constraints include aspects of organization, financing, cost-sharing and law.

Among the organizational problems is that there is a serious lack of clearly-defined goals and objectives, as well as procedures for establishing them. A central body is needed to analyze the range of sub-goals and sub-objectives submitted by individual agencies and to establish goals acceptable to the wide range of affected interests. The agencies can play an advocacy role and can act as a liaison with the public to keep issues such as a clean environment among the priority objectives.

Another institutional constraint to planning arises from overlapping responsibilities, rivalries among government agencies, and the "constructon bias" of many of the agencies. This results in a layering, or list, of proposals, rather than an integrated system involving trade-offs and resolution of conflicts. The "construction bias" of many of the implementation agencies has caused an excessive reliance on structural or engineering solutions, rather than on non-structural or policy solutions. This has probably been a very costly approach to meeting future "demand requirements".

Financing constraints apply not only to every aspect of planning, but also to every aspect of development. It is necessary to develop better cost-sharing arrangements among agencies in the planning process to make plans more equitable and effective in fulfilling the national objectives. It is important to share existing data and personnel skilled in the planning process among implementation agencies. Moreover, planning for large multi-purpose, multi-objective projects should involve all the concerned agencies, each of which would be responsible for its own field of expertise. Cost-sharing must be based on both the costs incurred by the individual agency as well as the benefits expected from the project.

The legal constraint often arises because planning agencies have very little influence or authority compared to the large implementation agencies. The planning agencies are seldom in a position to impose standards or enforce recommendations drawn up and agreed upon. This is why it may be worthwhile to create the planning body close to the chief executive of the country. With strong backing from the centre, the planning body may have sufficient influence to see that its recommendations get implemented.

III. FORMULATION OF WATER RESOURCES DEVELOPMENT PLANS

The advantages of having a central water authority or organization are mainly associated with planning and co-ordinating activities to ensure better utilization of water resuorces. The central function of water resources planning and water resources planners is to formulate rational water policies, programmes and projects that will help to achieve the social and economic goals and targets of the nation.

The planning process should be systematic, creative and flexible, so that it can adapt to changing conditions and can encourage the participation of the public and government agencies from the outset. The planning process must permit the expression of the interests of various public and private groups at regional and national levels. It should also provide the framework for negotiating the participation of each party in the financing of programmes, so that it is possible to finance the works and promote greater efficiency in water use.

The planners should be able to call upon an interdisciplinary technical group which will seek to balance and incorporate economic, technical, social, environmental, institutional and political considerations. This group should have broad knowldge of the existing situation, so that it can propose specific measures to overcome obstacles, but should be independent enough not to be bogged down by the day-to-day operations of the implementing agencies.

A. Planning framework

1. Scope of the plan

Defining the scope of a planning exercise is important in the preparation of a managable and coherent plan.

Multi-sectoral national planning involves co-ordinated planning of public activities in all sectors of the economy, including agriculture, industry, transportation, water resources and energy resources.

Sectoral planning involves integrated planning for all functions within one sector, such as water resources. Section C of this chapter describes master planning for water resources development. In that section, "intrasectoral" refers to planning in the context of one water utilization sector (i.e., irrigation) and "intersectoral" to planning of more than one water utilization sector (i.e., domestic water supply, industrial use and irrigation).

Functional planning is planning to meet a specific need within the sector, such as flood control or preservation of wild rivers.

The multi-sectoral approach analyzes the variables related to national economic and social development and conditions common to all regions of the country, such as: the institutional and legal framework; population; total capital available and government budgets; specialized human resources; and technological needs. Sound multi-sectoral planning should provide a co-ordinating mechanism for the preparation of individual sectoral plans.

The following sections of this chapter describe the basic concepts involved in planning, including guidelines, design flexibility, the planning process and computational tools; economic considerations, including uncertainties, intangible factors and water as a production factor; and master planning for water resources development. The following chapter deals with implementation of the water resources plan.

2. The planning domain

There are no simple or universally applicable formulas for planning regional or national water resources development to meet long-term demand, because of the differences in climate, geology, and terrain between countries, as well as within countries, coupled with differences in social structure, traditions, education, economic and political conditions. Disregarding these differences and blindly adopting solutions which may have been appropriate elsewhere would most likely result in failure, sooner or later. An essential condition for good long-term water resources planning is that the planner thoroughly acquaint himself with the physical and human environment within which he is expected to exercise his technical skills. He should not only master the technological and economic aspects of water resources engineering, but be aware of possible immediate and long-term influences by social, economic and political realities on the choice of alternative solutions.

Pressures on exploitation of water resources are constantly increasing, owing to population growth, increasing demand for agricultural and industrial commodities, rising standards of living and growing awareness of health and sanitation. Important lessons can be learned from countries or regions where excessive pressures on water resources have resulted in severe, sometimes irreversible, conditions, such as overdrawn ground-water storages, sea-water encroachment into aquifers and rivers or heavily polluted rivers and lakes. In several developing countries, uncontrolled over-exploitation of lands and woods, and over-intensified farming patterns, have further contributed to the destruction of water resources by accelerating run-off which goes to waste, soil erosion which blocks rivers and fills dams, and accumulation of chemical fertilizers and pesticides which poison aquifers and streams. To exacerbate the effects of over-exploitation of water sources, a major threat to the quality of ground-water and rivers is created by growing quantities of urban and industrial waste water.

The capability of developing countries to cope with these problems is hampered by the shortage of data, scarcity of professional manpower resources, organizational shortcomings, shortages of capital and recurrent finance, instability in internal and international policies, and often lack of adequate and far-sighted planning, taking into account the varied factors which should affect water resources planning.

Some of the lessons from past experience, which planners of water resource systems in developing countries are advised to learn and apply are briefly discussed in the following sections, and further expanded in other chapters.

(a) Organization and co-ordination

Water resources planning deals with various types of water utilization, which can be divided into five major sectors: domestic, industrial, agricultural, power generation and river navigation. In most countries each of these sectors is managed by a different authority or organization, and this division is often further divided between regional and local authorities.

Water resources planning bodies are organized in different ways in different countries. Some have set up a special central planning authority, while others maintain a rather fragmented planning process, carried out in different ministries or organizations, which seldom cover all the aspects of water resources planning.

Successful long-term planning for water resources development requires a high degree of co-ordination between different authorities. A concerted effort is required by all sides to assist the planners, who should preferably be organized as a separate and independent entity, by providing information, defining targets and objectives, reviewing plans and formulating policies.

(b) Comprehensiveness

As the utilization of water resources intensifies, and the competition between sectors and regions on limited resources increases, a plan to utilize these resources in a balanced fashion and conserve their quality must be as comprehensive as possible. All present and possible future water demands, and all sources of water, including reclaimed waste water and other non-conventional sources, must be considered.

Development plans should not only show how demand can quantitatively be met by supply, but how the system will operate under certain realistic assumptions, including: affordability to users, availability of recurrent finance for operation and maintenance (O & M), capability of the institutional framework to cope with new or expanded water projects, availability of the necessary O & M staff and preparedness of farmers to intensify irrigation practices.

In addition to the necessary physical facilities and their costs, development plans should present required infrastructural facilities, organization and management systems and training programmes, and describe how the implementation of such non-structural elements of the plan is expected to develop in harmony with the implementation of physical structures. A national or regional water resources master plan is an indispensable step toward the attainment of economic, social and political goals, and should be formulated and constantly updated, even when data are scarce and development targets may not have been properly defined at the political level. A master plan is an important framework for development and a tool for comprehensive planning.

(c) Data

Water resources planning must rely on data about numerous factors affecting the formulation of plans: climate, streamflows, ground water, population, economics, etc. The reality of developing countries often means lack of adequate records, from which water resources planners should draw conclusions and project future trends.

Whereas there are certain statistical and analytical techniques by which lack of climatic and hydrologic data can be overcome in order to establish a fairly sound basis for water resources planning, it is more difficult to do so with respect to social or cultural processes, such as trends in migration of population, and economic factors.

A realistic water resources development plan should explicitly recognize the effect which incomplete data may have on recommended actions and compare alternative plans, based on a range of assumed design parameters and forecasts. The plan should provide policy makers with alternative solutions, with an assessment of the economic and other consequences of choosing one or another of the options. For this purpose, all relevant information on existing and past water resources development projects must be carefully analyzed and the performance of present systems must be scrutinized, in order to detect the true causes for the failure of certain projects to reach their goals, and to ensure that new plans avoid or minimize such causes. A water resources development plan should also define areas of insufficient data, and include measures designed to obtain required information by research, measurement, statistical analysis and experiments.

(d) The hardware bias

The term 'hardware bias' was coined several years ago to describe a tendency, evident much too often in numerous developing countries, to invest huge sums of money in structures, such as dams, diversions, canals and pumping stations, which were designed to supply large quantities of water to lands or to users who had not been adequately prepared to absorb so much water or to operate and maintain the facilities properly.

Water resource planners, as a consequence of this tendency, often find themselves preoccupied with plans and programmes to rehabilitate underutilized, neglected or misused irrigation systems and water supply facilities which have deteriorated owing to improper operation and maintenance, or with completion of projects which have been planned too ambitiously and could not be completed with existing resources.

Much too often large water resource development plans had to be revised a few years after commencement of implementation, as it soon became apparent that the original goals could not be met by proposed projects. The sunk costs, which could have been utilized in a more productive way, have become a liability to the national economy, and the planners are challenged with the task of devising plans to make proper use of existing facilities while answering demands which have not been met by the original plans.

(e) The human factor

Water resources planning to meet long-term demand in developing countries must be done with frank awareness of the limited availability of professional technical manpower. To cope with this reality, development plans should be adjusted to realistic projections of numbers of operators, mechanics, supervisors, artisans, technicians, surveyors, engineers, accountants, economists, chemists, scientists and managers, who would be available at all stages of planning, design, implementation, operation and maintenance of systems and facilities in all water-related projects. In addition, training needs, intended to develop the necessary skills within the various water sectors, must be assessed, preferably by specialists in this field, and training programmes and facilities be presented as an integral part of national or regional development plans.

The importance of giving due consideration to the human factor in water resources planning cannot be over-emphasized. Some of the most glaring examples of projects which have failed, or have not fulfilled expectations, stem from lack of awareness to these factors, be it in the premature introduction of advanced irrigation systems, for which farmers have not been trained or supported and equipped to accept, or shortage of O & M staff, or lack of engineering skills at the local level.

These conditions often result in two additional undesirable phenomena in developing countries:

(i) Planners find it beyond their capacity, even if they recognize the importance of the human factor, to resist political pressures to carry out plans, even though they may be doomed to failure for lack of adequate staff and organization;

(ii) Planners and decision makers alike tend to rely too much on the advice of foreign experts or agents, whose knowledge of local conditions can seldom match that of local professionals.

3. Guidelines

(a) Setting goals and targets

Goals define general objectives or policies (e.g., raising the income of farmers; improving the health of the population), while targets quantitatively define what one desires to achieve (e.g., tons of food to be produced; number of people to be served).

Goals of regional and national water resources development are usually part and parcel of government policies on issues such as economic independence, land settlement, public health and income distribution, or are directly derived from such policies. The role of water resource planners in this regard is chiefly to interpret policies in terms of water resource development targets, and, more importantly, to point out possible constraints to development, which policy makers should be aware of. In addition, water resource planners should be able to resist pressures to adopt over-ambitious targets for the water sector. Such pressures can result in excessive utilization of available water sources, water quality deterioration, or consumption of construction and production inputs in excessive quantities, thus straining the ability of the water sector to maintain or complete the implementaton of existing projects.

Examples of this situation abound. Iran, for instance, had completed in the 1960s a number of large-scale combined hydroelectric and irrigation projects, which were subsequently under-utilized for several years. Until the early 1970s Venezuela had completed irrigation projects which could irrigate hundreds of thousands of hectares of land, but most of the projects could not be utilized for lack of supporting services, and the country had to increase importation of agricultural products. A similar situation prevails in the irrigation sector of Nepal. In addition to the waste of capital, the existence of irrigation projects with excess capacity tends to encourage application of excessive amounts of water to parts of the command area of the systems, thus creating severe problems of water logging and degradation of land fertility.

In most of the poorer developing countries, however, such as in the sub-Saharan region, water resources development goals are by necessity less far-reaching. In these countries, where rainfall is adequate for growing enough food to meet the modest requirements of the indigenous population, the emphasis in water resources development may for quite some time be on the provision of drinking water, since large-scale irrigation projects often prove to be uneconomic and organizationally premature.

Goals and targets of the water sector must be seen in the context of national goals in general, and defined with due regard to the goals and targets of other sectors. This requires co-ordination at policy making levels, where a complete picture of the resources available for development, including capital, human resources and power supply, should be kept.

Development targets in the water sector are based on demand forecasts. A realistic approach to future trends and projections is essential as a basis for sound development programmes. This requires careful examination of past developments, including organizational capabilities and manpower resources, and adoption of well-founded assumptions for future projections (see Annex I).

A fundamental difference exists between demand forecasting for irrigation water and urban or rural water supply. Since in irrigation the water is one of several production inputs, the required amounts of water will depend on agricultural development plans, which will in turn be subject to availability of land and other production factors, and on numerous economic and organizational considerations. The economic feasibility of irrigation projects and the choice of irrigation methods would thus determine the agricultural demand for water resources (see also section V.A). A critical factor in computation of irrigation water requirements is irrigation efficiency. Here again, lessons from the past must be applied in a critical way to future projections.

Forecasts of urban and rural water requirements cannot be directly related to future economic trends. They should be based on population forecasts, per capita consumption rates and other factors, as discussed in Annex I.

In numerous existing water supply systems in developing countries, water losses are so high (see section V.A) that it will often be more economical to invest in waste reduction than to develop additional sources to cover the rising demand. This option should also be considered in setting targets for water resurces development.

(b) The planning horizon

Long-term planning of water resource systems is generally assumed to have a time horizon of 20 to 30 years. However, in developing countries, due to many uncertainties with respect to economic, social and political developments, and because acute immediate problems dominate the concern of the authorities as well as the general public, a much shorter planning horizon is more suitable for practical purposes. Under such conditions, numerous plans prepared in the past on the basis of a 20 or 30 year planning horizon, had to be revised (sometimes several times over) in the course of a staged implementation programme. In some cases, design parameters, adopted on a long-term basis proved to be inappropriate for the immediate future, while in other cases funds were insufficient to implement facilities designed for long-term requirements. Other changes also occurred which did not allow the implementation to proceed as planned.

Consequently, it is advisable, under such circumstances to consider a planning horizon of 5 to 10 years as a basis for planning, but to allow in the design sufficient flexibility to expand and modify facilities as and when necessary to cover future requirements. The planning effort should concentrate on the shorter time span, in order to offer better solutions to immediate problems, but a view of the longer term should still be maintained. In addition, longer term projections of demand and benefits (or revenues) may still be necessary to justify economically capital investments in structures and facilities whose economic life time is considerably longer than 5 to 10 years. Still, the shorter planning horizon should determine the main dimensions of the system in question, and reduce the scope of investments in facilities which may otherwise be under-utilized for many years.

(c) Design flexibility

Water resource development plans to meet long-term demand should allow maximum flexibility to enable changes in the design to be introduced in response to future deviations from assumed design values (demand forecasts, water yields, population, irrigation requirements, economic scenarios) and to various other possible unforeseeable developments. In a development project designed with sufficient flexibility, the planning process would be continuous over many years, because it would be necessary, and indeed desirable, to observe changes in design parameters and assumptions and accordingly introduce the necessary design modifications or reschedule subsequent implementation steps.

The need for flexible design is especially apparent in developing countries, where the accuracy of demand projections is rather low and socio-economic and political developments are difficult to predict. Long-term planning with sufficient flexibility is in a sense equivalent to short-term planning, as described in the preceding section, which is a necessity in the circumstances prevailing in developing countries. Some of the measures which can increase flexibility in project design are discussed in section IV.A.

(d) The planning process

Water resources planning to meet long-term demand encompasses a wider range of subjects than planning of specific projects, for which targets and boundary conditions are usually better defined and narrower in scope. The scope of water resources planning includes, in addition to water-related issues, interactions between the water sector and other sectors of the economy or the social structure, as well as interactions and trade-offs between different water-related sectors.

Water resources development plans serve as a framework for the planning of specific projects and as a basis for activities other than physical development, such as water resource investigations, establishment of data bases, institutional development and economic policies.

Broadly speaking, the following phases define the process of planning water resources development to meet long-term demand:

(i) Data must be collected and interpreted, including: geology, hydrology, soil surveys, topography, population, waterconsumption, irrigation practices and water requirements, water quality, prices and costs, development plans of other sectors, human resources, cultural and traditional patterns, organizational structures, laws and regulations.

(ii) Current conditions must be analyzed in order to understand processes and constraints which may influence the success of water resources development plans, such as: shortfalls in technical personnel, organizational shortcomings, economic and financial constraints, legal and procedural processes, training needs, conditions of roads and communications.

(iii) Boundary conditions must be defined, as well as interactions between the water sector and other sectors of the economy and within the water sector (irrigation, water supply, hydropower generation and river navigation). The main aim is to clarify the effect of present and potential developments in one sector on the other, such as may result from competing demands for the same resources (capital, labour, land, power), or conflicting uses of the same sources of water (irrigation vs. power generation, navigation vs. power generation; see also section III.C). Also under this heading of boundary conditions, one should mention the need to dispose of water drained from irrigated lands, urban waste water and heated cooling water from thermal power plants.

(iv) Goals and targets should be defined, as discussed above, delineating the geographical boundaries and the scope of projects, determining the planning horizon, projecting water requirements for various purposes and defining economic scenarios for the evaluation of the viability of projects.

(v) Environmental impacts of development programmes must be assessed in the plans in general terms (detailed impact statements should form part of specific project plans), including both negative and positive effects on flora and fauna, scenery, water, air, noise, land values, transportation and communication routes, recreation sites, archaeological sites, cultural and traditional values. An early recognition of these effects, and consideration of mitigative measures, may save considerable time and effort in later planning stages.

(vi) Available surface and ground water resources must be analysed, including projected changes in quantity and quality over time, and other potential sources should be assessed including reclaimed waste water, irrigation return flows, desalinated brackish and sea water, rain-water harvesting (rooftops, paved surfaces) and precipitation enhancement. Estimates should be made of water saved by leakage reduction, recirculation (in industries and thermal power stations) and by improved management and conservation measures in urban as well as irrigation systems.

(vii) Specific projects should be identified and preliminary planning begun, subject to the above-mentioned considerations and limitations, as a basis for assigning priorities within and among the various water utilization sectors and vis-a-vis other sectors of the economy (see section III.C). More detailed plans would be elaborated in the process of specific project planning.

(viii) A water resources development master plan can then be formulated by analyzing interrelationships and trade-offs between projects and between water utilization sectors, establishing a priority order and an investment schedule (see section III.C), and presenting economic and general justification reports to the decision makers and to lending agencies.

(ix) Programmes should be formulated for further investigations, research, data processing, periodic updating of design criteria and revision of original development plans, if and when needed. Training programmes should be formulated according to the needs of the water sector.

The lines dividing these planning phases are not rigid. For instance, the definition of a project's geographical boundaries may be a function of the amounts of water required at a specific site or area. Where adjacent sources are insufficient and more remote sources have to be tapped, the area for which hydrological and other studies will be necessary as part of the planning process will be expanded. Similarly, planning of specific projects and analysis of available sources of water may be closely related where large urban concentrations are involved, because sewage effluents should be considered as a possible source of irrigation water. Also, mitigative measures designed to alleviate negative environmental impacts, may affect the formulation of project plans.

The planning process in a developed country would often be considerably different from the process in a developing country. In developed countries priority would often be given to environmental hazards, water pollution, sewage disposal and reclamation. In developing countries these considerations may not be important to the policy makers. Rather the main concern is often the availability of water to meet immediate and long-term demands, as well as rehabilitation and consolidation of existing systems, waste reduction, institution building and training needs.

The planning process is in itself a step in the evolution of the water sector in developing countries, as it sets in motion activities, such as data collection and analysis, hydrological investigations, projections and economic studies, which build up a cadre of planners and institutionalize planning methods and procedures. Planning can also strengthen the ties and improve communication and feedback between authorities in the water sector and in other sectors of the economy, and related public and private institutions.

As the process of water resources planning advances, reports by the planners to the authorities are usually required, to serve several purposes, such as: enabling the authorities to exercise control over the planning process and review assumptions made and achievements attained; establishing co-ordination and mutual understanding of problems and objectives; enabling the authorities to incorporate water sector requirements in national plans, to plan budgets and mobilize funds.

The sequence of reports would usually begin with a reconnaissance report, which sets out to define the study area, describe in general terms the present situation, main problems and trends, and formulate development goals and possible solutions. Next, a pre-feasibility study would be necessary to summarize findings on water resources potential, alternative engineering solutions, demand forecasts and problem areas. Cost estimates of alternative plans may be presented, but the economic feasibility analysis would be deferred to the feasibility study stage. At this point, a preferred plan is selected and a rigorous proof of its economic and financial viability presented. The feasibility report is the starting point for negotiations on financial arrangements needed to commence project implementaton. As mentioned earlier, non-structural development measures, organizational and institutional aspects and environmental implications should all be part and parcel of water resource plans and should be explicitly stated at all stages of reporting.

(e) <u>Computational tools</u>

With the growing availability of computer hardware and software, even in developing countries, numerous computational tools can be applied to assist the process of water resources planning. In addition to standard computer programs, available for basic statistical and engineering calculations, the following are some of the types of special-purpose computer models which have been developed as an aid to water resources planning (see also section II.A.):

(i) The water resources data base is designed to store information and time series of observation data on ground water and surface water, and to produce various statistical reports.

(ii) Rainfall/run-off models are designed to simulate and project streamflows on an hourly or daily basis, using input rainfall data and a set of parameters describing the hydraulic properties of the catchment area.

(iii) Ground-water simulation models are designed to simulate and project the movement of ground water in single or multi-layered phreatic or artesian aquifers, by a multi-cell representation on the hydraulic properties of the aquifer, using series on natural and artificial recharge, pumping, evapotranspiration, boundary inflows and outflows.

(iv) Models of ground-water pollution processes are available.

(v) Pipe network analysis models can give an optimal solution to the problem of expanding an existing network or designing a new one.

(vi) Hydraulic analysis of a system of open channels can be modelled.

(vii) Multi-objective analysis can relate agricultural production to irrigation development.

(viii) Integrated planning of agriculture and water allocations, involving crop yields, produce values, production costs, water transfer costs from a number of sources to a number of irrigated zones, can be used to compute the optimal combination of areas of various crops in each zone, given land and water availability constraints.

(ix) Models can be used to determine optimal planning of water allocations, transportation, resource development and storage management, subject to a set of constraints (hydrological, hydraulic, water demand, capital) and using unit values of benefit for water supplied and losses for water shortages.

(x) A multi-criteria economic ranking model can define a set of water-related projects, including weights which allow subjective preferences of projects (or types of projects) to affect the final priority ranking (see section III.C.).

(xi) Optimal operation rules for seasonal storage reservoirs can be determined.

(xii) Simulation models can be made of water resource systems with several sources, reservoirs, transfers and supply areas.

B. Economic considerations

1. Basic concepts

Economic evaluation of water resource development projects is an integral part of the planning process and is indispensable for the presentation of projects to lending agencies, for budget submissions, for priority ranking of project options, as well as for the comparison of alternative project designs and staging the implementation of projects.

For all of these purposes there are certain standard economic criteria which can be used in the economic analysis of projects, as discussed below.

The Benefit/Cost Ratio (BCR) is the ratio between total present value of annual benefits of a project, throughout its economic lifetime, and the total present value of project costs, i.e., construction and annual operation and maintenance costs. A BCR smaller than 1.0 indicates an economically non-viable project. The economic lifetime of a project is defined as the period prior to the time when the cost of keeping the project in service begins to exceed the annual benefit.

The Net Present Value (NPV) is the difference between the present value of the stream of net benefits (income minus operating expenditures) and the stream of project investments. The higher the NPV of a project, the more economically viable it is.

BCR and NPV are practically equivalent as a criterion for economic evaluation of projects. However, BCR is not a correct criterion to compare projects with significantly different degrees of capital intensity, and therefore the NPV is preferable in that case. In comparing alternative projects, the difference in NPV would indicate which is the least-cost solution.

The investment per unit of water produced annually (say $ per m^3) and the economic cost of a unit of water, or its real price, are two other indicators used in the economic evaluation of water projects.

The Internal Rate of Return (IRR) is the interest rate at which the present value of the stream of net annual benefits and the stream of annual expenditures become equal. The use of IRR is convenient to water resource planners because there is no need to decide what rate of return to use for the economic evaluation, whereas in present value computations an interest rate must be assumed.

For a project to be considered economically viable from the point of view of the national economy, its IRR should be higher than the real interest rate. In addition, a project should be included in a sectoral or national development programme only if there is no other project which is not included in the programme and has a higher IRR.

The realities of water resources planning in developing countries often leave the planner a rather narrow space for application of economic evaluation techniques. When a set of organizational and financial constraints, or government policies, dictate the scope of water resources development projects, economic analysis is used primarily as an aid to the search of a least cost solution, and the NPV is usually adopted as a yardstick for this purpose.

In economic analyses done for presentation to international lending agencies, the rate of interest will usually be specified by the agency involved. This rate may be different from the interest rates prevailing in the free market in the country, and from the rate proclaimed by the government as a basis for internal economic considerations. Since there may be doubts as to what interest rate actually represents the worth of capital to the national economy, it is good practice to analyse the costs and benefits of projects under two or three different interest rates. However, it should be borne in mind that too high an interest rate would give economic preference to postponement of capital investments, and too low an interest rate would lead to design with excess capacity.

It is important to remember that economic benefits from water resource development projects are a measure of the difference between a future with and without the project. Hence, in addition to analysing present conditions, as a reference point for various projections, the picture of the future of the region in question without the project should also be clearly defined. All developments which are likely, or expected, to occur in the future in that region without the project should be considered, and the impact of the project measured in relation to this future situation.

2. Dealing with uncertainties

Economic uncertainties prevail in most cases with respect to basic factors such as fuel and power prices, costs of construction and operation inputs, prices of goods and services produced by a project and the economic lifetime of a project. Moreover, uncertainty exists in water projects with respect to numerous phenomena, including future climatic conditions, hydrology, population growth and water demand. It is, therefore, advisable to define a range of reasonable values, and combinations of values, or projections, for the various uncertain parameters, and analyze the economics of projects against the background of various economic and physical settings, or scenarios.

Another very enlightening technique in economic analysis is the use of sensitivity tests. By computing the value of a certain economic indicator of a project, say NPV, at different levels for one of the basic assumptions (such as interest rate, fuel price or water yield), while maintaining other assumptions unchanged, the sensitivity of the selected indicator to the underlying assumptions can be exhibited. The economic soundness of a proposed project is proven if the values of selected economic indicator(s) remain within acceptable bounds in all (or most) sensitivity tests.

3. Intangible factors

The economic benefits of urban or rural water supply projects are very difficult to quantify, even though it is obvious that proper water supply is essential to good health and thus saves lost hours and days due to sickness, and sometimes human life, which could otherwise be used productively, and also saves hospitalization and health care expenditures. Consequently, in considering alternative investments in water projects, supply to villages and towns receives high priority in government policies. Economic indicators should, however, be computed for alternative water supply schemes in this sector in order to determine priorities. BCR or IRR values in these cases are based on calculated revenues from water sales, rather than on the producton value of the water (as in irrigation), and thus constitute financial rather than economic indicators.

Economic factors alone seldom determine the fate of proposed water resource projects. Non-economic considerations may determine which projects will be implemented or what capital budgets will be allocated to the water sector or to its sub-sectors. Such considerations include political issues, geographical preferences, security, tribal and traditional values or connections, social pressures, electoral considerations, natural calamities, historical land or water rights, and environmental quality preservation requirements. It is the role of the planner to recognize such factors and either adapt project designs and development programmes accordingly, if possible, or present in the plans the implications of intangible factors on the design and economics of projects. Decision-making officers should be made aware of the economic or financial consequences of modifying designs or programmes according to these factors. Preferably, the process of selecting projects for implementation within a limited budget should include a phase of interaction between the planners and the politicians, or representatives of the public, in such a way that due weight will be given to their views in the selection process. Several formal methods for multi-objective analysis of development projects have been devised whereby the weight of non-quantifiable considerations is duly taken into account in the analysis (see also section III.C.).

The price of water to the consumer often becomes another area where political considerations interact with economic or engineering practices. Whereas it is an economically sound and desirable practice to charge users for the real cost of water supplied, including capital as well as operational expenditures, governments often undertake to subsidize the cost of water to consumers as part of a policy of reducing the cost of essential commodites, for economic or political reasons. This is often true in developing countries, where it is commonly accepted that a family's expenditure on domestic water supply should not exceed 2 to 5 per cent of its income.

4. Water as a production factor

Water supplied for human consumption constitutes a finished product. It is not used for any further purpose. On the other hand, water supplied to agriculture and industry is a production input, creating, or helping to create, certain products which in turn generate income. In planning water resources projects which have a major component of supply to agriculture or industry, a broader approach to planning water resources development can be adopted, in order to reach the right decisions on development levels and on timing and setting priorities for investments.

An example of this approach is the combined planning model of agriculture and water which was applied in Israel. Water is the main constraint to the development of agriculture in Israel. It is also a national resource, controlled and allocated by Government authorities through a central conveyance system which connects nearly all water resources and agricultural zones in the country. An inter-regional competition model was developed, which represents 14 zones, three agricultural sectors and several possible crops in each zone. Water was treated as one of several production inputs, including also land, labour and capital. The optimum allocation of crop areas in each region was computed, through a linear pregramming algorithm, for various levels of constraints on inter-zonal transfers of water, prices and costs, market conditions and development budgets. While a solution by this model was not immediately accepted as a development strategy, it did serve as a good basis for policy making and co-ordination in the agricultural and water sectors of the country.

As water resources development advances, the cost of developing additional water increases at a rate which is called the marginal cost of water. When quantifiable benefits can be attributed to the provision of these additional amounts of water (e.g., when it is supplied to agriculture, industry or power generation), the economic rationale of development states that as long as the increase in benefits, or the marginal benefit, exceeds the marginal cost, the investment is economically sound.

When water resources for irrigated agriculture constitute a constraint to development, any measure to increase the benefit per unit of water will be economically justified as long as its cost per unit of water is lower than the marginal cost of water. This consideration should motivate introduction of higher efficiency irrigation methods (see section V.A.), less water-intensive crops, higher yield varieties, and, in general, more efficient agricultural practices.

C. Master planning for water resources development

1. The master plan approach

The planning which is described in ths section is sectoral planning, specifically a water resources master plan. While planning must be thought of as a continuous process without a final solution, the master plan approach to water resources planning makes an attempt to identify an ultimate solution to meet existing and future demands for water. It defines development needs, over a reasonable planning horizon, and describes paths to be taken to achieve the ultimate solution.

The master plan approach encompasses several important elements. In the first place, it must be based on a knowledge of the water resources that can be made available at various stages of the planning horizon, as well as on reasonable demand forecasts. Therefore, a nation-wide survey designed to define the available surface and ground-water resources and expected demands is often the first step to be taken.

Once such an inventory is available, beset as it may be with many uncertainties, the actual planning process can begin. It will be of an iterative nature, initial concepts being constantly reviewed and reshaped in accordance with forthcoming updates of the resources and demand estimates, and with unforeseen problems that may crop up. Initially, planning will concentrate mainly on partial solutions destined to solve the most urgent problems and those that will have the greatest effect with the minimum investment of effort and cost. Each of these partial solutions, however, must be planned to become an integral element of, and fit into, the ultimate over-all plan. Later, and in accordance with the development of needs and demands, more ambitious and costly schemes may be undertaken that will integrate the partial schemes into more comprehensive regional schemes and finally, perhaps, into an over-all national scheme that lends itself to easy and efficient management and distribution of the available resources.

A water resources development master plan should be as comprehensive as possible, so that it can become a framework for planning of individual schemes and ensure that development options will not be precluded by other developments, or be omitted from national policies, legislative acts and long-term economic measures.

A water resources master plan designed to meet long-term water demand must define development requirements in all water utilization sectors, and establish the order of priorities and optimal allocation of available funds to the different sectors, within general guidelines and policies. The process of priority ranking may include the following steps:

(a) Determining the development requirements in each sector in the medium- and long-term planning horizons (say 10 and 20 years) and drawing up an inventory of projects, including existing plans and newly identified schemes, to meet development needs;

(b) Estimating the cost of the entire inventory, on the basis of existing plans or preliminary designs, which could be prepared on the basis of representative sample schemes;

(c) Ranking the projects within each water utilization sector on the basis of their economic viability, as assessed according to a set of criteria which reflect both the monetary and non-monetary benefits of projects;

(d) Assessing the capital resources that would be available for each sector within the time horizon set for the development programmes;

(e) Preparing an investment schedule.

Step (d) above necessitates an intersectoral analysis and establishment of the quantitative equivalent of the various types of benefits in the different sectors. Some of the sectors will be of a social service character for which the benefit is non-monetary (e.g., number of persons enjoying improved health as a result of a proper water supply or a sewerage system) and others being production sectors (hydropower, irrigation). Appropriate cost and benefit values of yet unplanned projects can be inferred from current project plans, as far as they exist. Certain assumptions may have to be made in step (d) about national policies and preferences, which should be reflected in the resulting development programme.

2. Competing and complementary water utilization schemes

Consumptive uses of water are necessarily competitive. A single unit of water can either be consumed in urban use or for irrigation, but not for both. Yet, return flows from these uses to the same basin or to a nearby or underlying ground-water basin can be put to multiple use.

On the other hand, water used non-consumptively, e.g., for hydroelectric energy generation, can be used repeatedly in a series of dams. Moreover, a large upstream reservoir and hydroelectric plant considerably reduces the need for a large reservoir for downstream hydroelectric plants, since the latter would receive already-regulated flows.

As regards water quality, any downstream consumptive use of contaminated effluent discharged into the river will increase treatment requirements, whereas upstream river flow regulation by hydroelectric plants usually augments low flows and reduces treatment requirements.

Upstream irrigation or municipal supply schemes may conflict with downstream power generation. However, if such supply schemes are downstream, they would benefit from the controlled releases for power generation, but may compete on the time of release. Downstream municipal supply is more compatible with electricity generation than irrigation, because of its different temporal distribution. The sharp peak in irrigation water demand, as opposed to the relative uniformity over time of municipal demand, is less compatible with the maximization of firm power production.

A proper analysis of the interrelationships among uses and among existing and potential projects requires a basin-wide model. Such a model must include all the components of water resource systems: water users and the linkages among them; the spatial and temporal distribution of the flows; long-term trends in demand and development of resources; and economic evaluation of costs and benefits. The interrelationships among projects can be expressed in terms of potential trade-offs, indirect costs or indirect benefits, which are affected by the competing or complementary use of water by alternative projects.

For instance, the reduction of hydroelectric power production by an upstream irrigation project may be expressed as energy lost per volume of water consumed (in kWh/m^3). The value of a unit of water used for irrigation should be debited with the economic value of the lost kWh.

Conversely, the additional river flow available for irrigation in the critical month in a year, as a result of an upstream hydroelectric power plant with a regulative storage, should be counted as an added benefit of the hydroelectric scheme, on the basis of the additional irrigable land.

3. Priority analysis

(a) Principles

As an illustration of a priority analysis of a large set of projects, the following discussion describes a procedure employed in a water resources development master plan study done by Tahal Consulting Engineers, Ltd. for the Government of El Salvador, which involved a multi-criteria analysis, devised to cope with many projects designed to serve multiple purposes (see also section VII.C). The multi-criteria priority ranking served as a framework for the preparation of a comprehensive development programme for water-related projects, and provided a basis for determining the timetable for implementing proposed projects under given budgetary limitations.

The procedure for ranking the projects involved five main steps:

(i) Ranking according to intrasectoral priorities;

(ii) Eliminating low-priority projects in basins where water availability was less than the total demand in a target year;

(iii) Estimating the financial resources available for all water sectors and for different planning horizons;

(iv) Allocating the over-all budget among the various sectors, based on an intersectoral analysis;

(v) Sequencing and timing the implementation of projects in accordance with budget constraints.

Several values to be computed in the ranking process express unquantifiable social or political factors. Assumptions regarding these factors may have to be made at first, and modified as required through an interactive process with decision makers at the national level.

(b) Intrasectoral ranking: Projects within the same water utilization sector

The intrasectoral ranking comprised three steps:

(i) Definition of criteria for evaluating benefits. These criteria express all the benefits - economic and other - attributable to each project, which may cover a wide spectrum and cannot be measured by a common yardstick.

The criteria were of three main types:

- Economic parameters reflecting the direct and indirect economic benefits and costs of a project, according to the relevant water utilization sector (or sectors, where a project served more than one purpose);

- Benefits which could not be quantified in monetary terms, which might be related to environmental and/or social objectives;

- Geographical considerations reflecting national planning priorities, which might be related to political objectives.

(ii) Assigning a value to each project and each of its evaluation criteria. This consisted of two categories:

a. Evaluation of economic benefits and costs of projects:

- Estimating projects costs, on the basis of actual plans or by statistical inference from similar projects;

- Evaluating project benefits where water constitutes a production factor, either directly (irrigation) or indirectly (fuel savings from alternative power plants);

- Estimating indirect costs and benefits which arise from the influence of projects of one water-using sector on another (such as irrigation projects affecting downstream hydropower potential).

b. Evaluating project benefits which cannot be expressed in monetary terms. This was based partly on values reflecting the gap between the existing and desired situation, and partly on a subjective evaluation by the planners. Evaluation of costs and benefits related to environmental and social objectives of water resources projects are discussed in more detail in United Nations (1987a.)

(iii) Intrasectoral ranking. This procedure comprised two parts. The first part involved normalizing the values of project benefit evaluation criteria. The normalized values can be expressed as follows:

$$d_{ij} = \frac{X_{ij}-m_i}{M_i-m_i}$$

$$m_i \leq X_{ij} \leq M_i$$

where:

i - index representing the criterion

j - index representing the project under examination

X_{ij} - benefit evaluation value of project j according to criterion i

m_i - minimum benefit expected according to criterion i

M_i - maximum benefit expected according to criterion i

The maximum and minimum values of benefits within each criterion can be taken as those actually found in the inventory of projects considered. The normalized value of the benefit of project j according to criterion i is in the range $0 \leq d_{ij} \leq 1$. It is thus a dimensionless relative index resulting from the comparison of a single project's benefits with the benefits of other projects measured by the same criterion.

The second part involved determination of the composite total rating of each project with more than one benefit criterion. The composite total rating was expressed as the sum of the weighted benefits over all the criteria i:

$$t_j = \sum_i P_i d_i \qquad \sum_i P_i = 100$$

where t_j is the total rating of project j, $0 \leq t_j \leq 100$, and P_i is the weight assigned to criterion i, $0 \leq P_i \leq 100$. The composite total rating of project j determined its position in the intrasectoral ranking, the rank being higher the higher its rating value.

The criteria used for ranking projects within each water utilization sector were selected specifically for that sector according to the main domain of benefits of projects within that sector (e.g., income per unit of water or land, number of persons served). In addition, weights (P_i) were assigned to the various criteria, to reflect assumptions as to the social and economic preferences of the decision makers.

The ranked projects were listed in a descending order of priority, along with the cumulative costs which showed the total budget allocation required to implement all the projects on the list preceding and including the one under consideration. Thus, once a budget were allocated to the particular sector, the list of projects to be implemented within that budget would simply be the set of projects from the top of the list down to the project whose cumulative budget equalled the allocated sum.

This listing could also be used to show the cumulative benefit of the projects according to each criterion separately, i.e., cumulative benefit against cumulative investment.

The cumulative benefit of projects vs. cumulative budget can be depicted by budget performance curves, which show the benefit by single criterion for each sector against the level of budget allocated to that sector. Figure 2 illustrates budget performance curves computed for various water related sectors, in the framework of the water resources development master plan study for El Salvador. A step-by-step description of the preparation of the master plan in El Salvador is presented in Annex II. The modified ranking curve for urban and rural water supply is a result of an adjustment made in the inventory of projects, by screening out alternative schemes which serve a common purpose, on the basis of their computed composite total rating, T_j. Similar adjustments were necessary in the case of projects having explicit functional or physical interconnections.

(c) Intersectoral analysis: Projects within different water utilization sectors

The purpose of this analysis was to determine the most effective distribution of available development funds among the different water utilization sectors, by assessing the budget "performance" in each sector.

The problem again, as in the case of intrasectoral ranking, was the difficulty of bringing to a common denominator the different kinds of benefits of the various sectors, in order to compare the performance of the budget in the different sectors. This was done by evaluating the trade-offs between the different kinds of benefit.

The definition of benefit criteria and trade-offs among them should be determined from the viewpoint of national planners. It is to be expected that the priorities of the national planners will change over time in accordance with the dynamics of the country's economic growth, and this can readily be reflected in updated versions of the master plan by re-assigning benefit values and weights.

The process of allocating funds among the various water utilization sectors was broken into four steps:

Step 1. Division of funds between the service sectors (urban water supply, urban sewage, industrial waste water) and the productive sectors (irrigation, industry and hydroelectric power generation).

Step 2. Division of the production sector funds between the irrigation, industry and hydroelectric sectors.

Step 3. Division of the services sector funds between the water supply and sanitation sectors.

Step 4. Division of the sanitation funds between urban sewage and industrial waste-water sectors.

Benefit criteria representing different sectors in the intersectoral analysis were defined as follows:

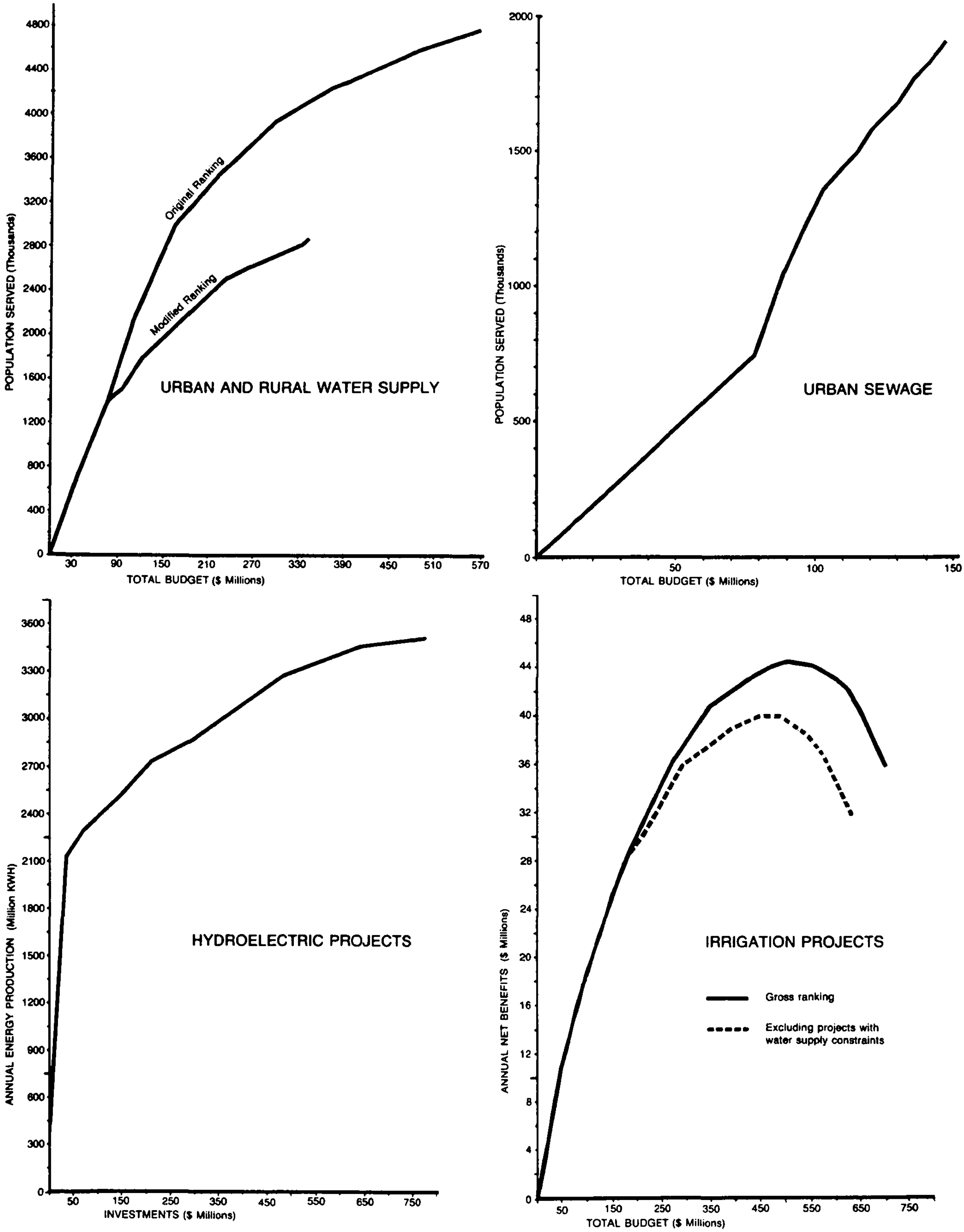


Figure 2. Budget performance curves

Water supply: persons served

Irrigation: increase in national income from sales of irrigated crops

Hydroelectric projects: kWh generated annually

Industrial waste-water treatment: removal of pollutants (population equivalent of sewage-discharged pollution)

Urban sewage: persons served or degree of removal of pollutants

Transformation curves. For each of the above steps, transformation curves were prepared for different budget levels. The transformation is between the benefits generated, at the same budget level, by the two sectors or groups of sectors, among which the available funds were divided in that step (see figure 3).

According to the criteria adopted for the intersectoral analysis, each sector was taken as contributing to a single benefit, except in the case of sewage projects. The latter were taken as contributing both to the number of persons served and to the reduction in pollution load, assuming that treatment is an integral part of the sewage system. Both these benefits were taken into account in deriving the transformation curves.

Indifference curves and the expansion path. These curves express trade-offs between benefits, i.e., what benefit decrease in Sector A would be acceptable in return for a benefit increase in Sector B. The tangency point between the transformation and indifference curves gives the division of benefit between the two sectors and hence the required division of funds between them. The line joining the tangency points for the various budget levels is the desired expansion path (see figure 3).

Usually the transformation curves are convex and the indifference curves concave because of reduced marginal benefit, in which case there is only one tangency point between a particular transformation curve and the highest indifference curve. In cases where the intrasectoral and intersectoral benefit criteria are different, the transformation curves are not always convex threoughout their range, in which case there may be more than one tangency point.

Indifference curves are not always available since these must be derived on the basis of interactive planning. Therefore, for an initial analysis the indifference curves and expansion path were estimated within the context of available information. For this purpose it was assumed as an approximation that in the immediate future the development in the different sectors would be proportional to the gap in each sector between the target and the current situation. Therefore, the expansion paths were expressed by straight lines connecting the current situation with the maximum development on the benefit scales.

An illustration of the four steps of intersectoral budget allocation analysis is given in figure 4, which is reproduced from the Master Plan for Water Resources Development in El Salvador.

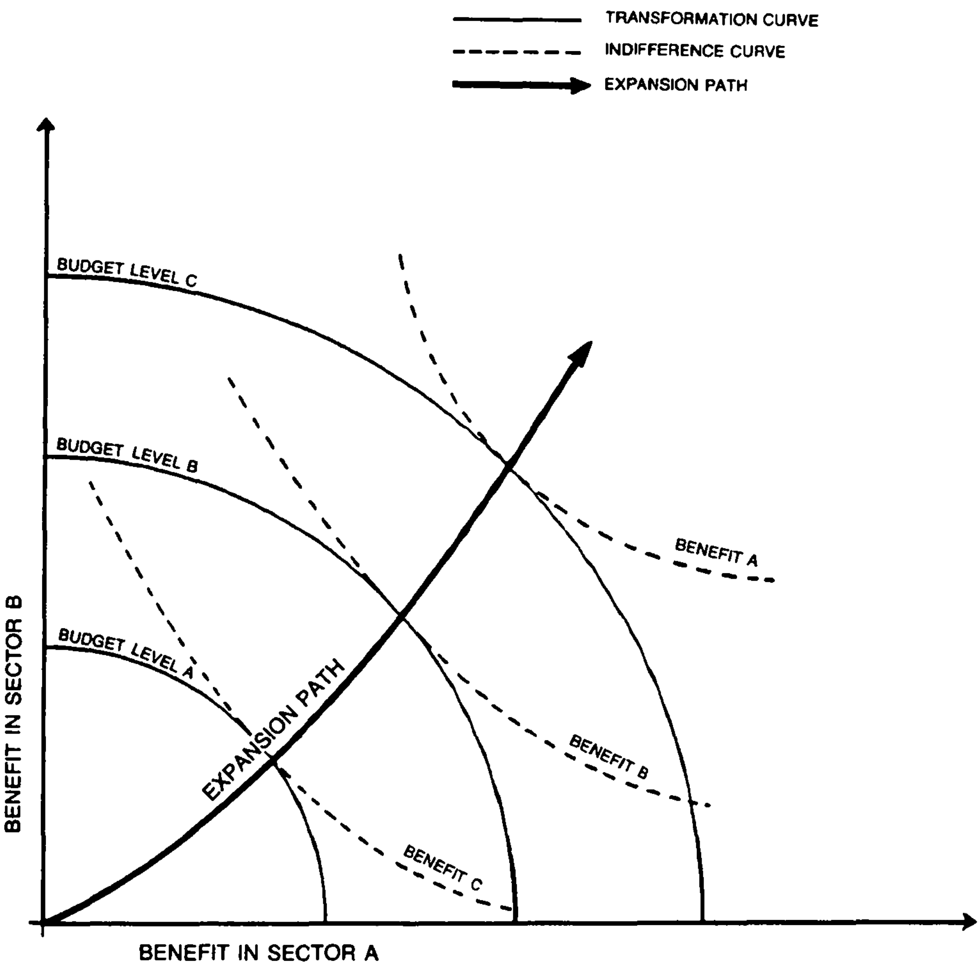


Figure 3. Transformation and indifference curves: Expansion path

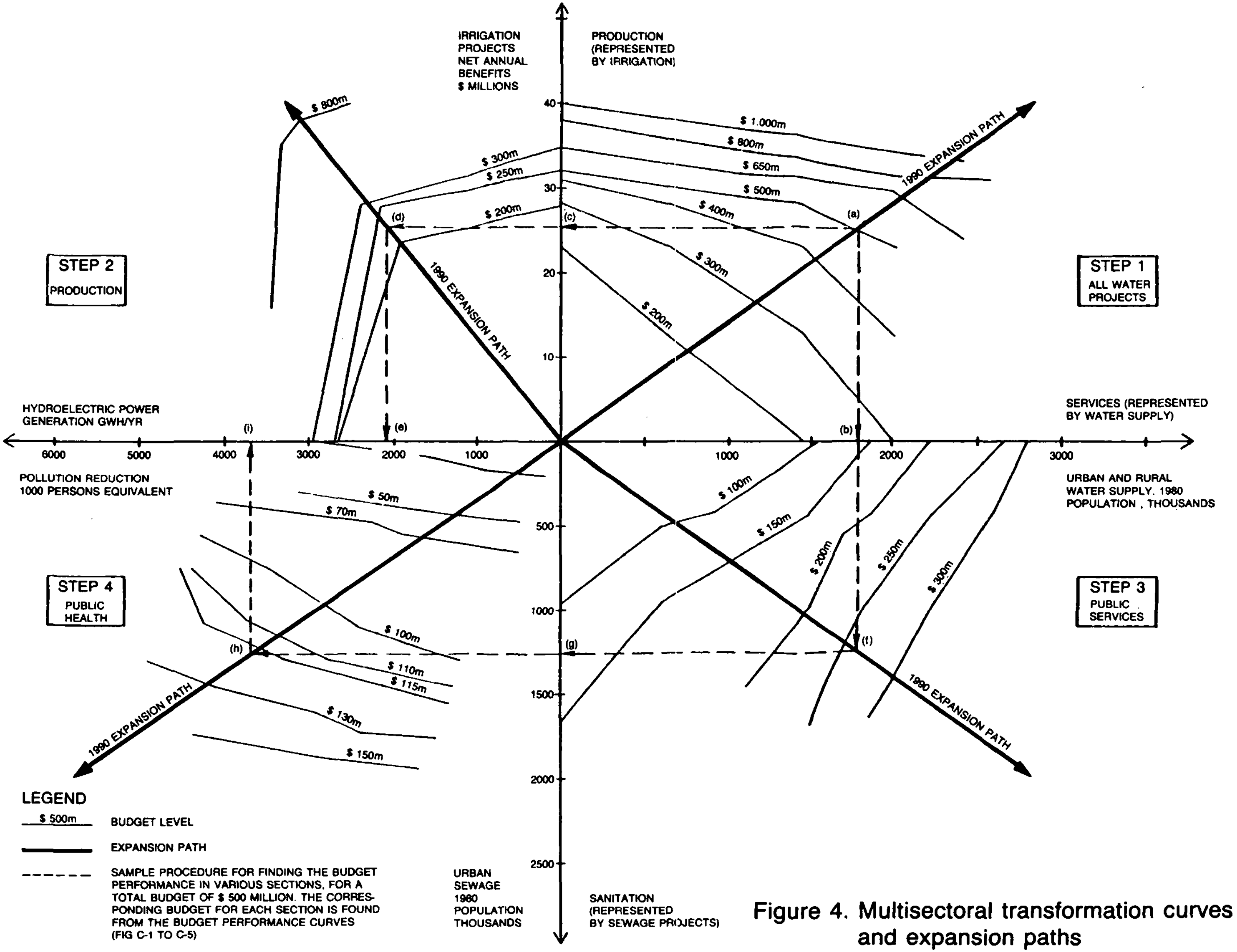


Figure 4. Multisectoral transformation curves and expansion paths

D. Criteria for effective planning

The planning process should produce action documents keyed to the goals, needs and desires of the region and the country for which planning is conducted. A centralized group should be responsible for developing policy recommendations and directing sectoral planning, while implementation agencies should retain responsibility for functional planning within their own water utilization sectors.

The following criteria for a good plan (with some modification) are based on suggestions made by the United States National Water Commission, but they seem to be applicable to developing countries as well:

1. The document should be a real plan, which displays alternative courses of action for selection by a decision maker and recommended courses of action.

2. An accurate and succinct statement of goals and objectives should be included, with a description of how the plan will meet those goals.

3. The plan should cover a rational planning area (according to planning objectives) and should provide the basis for interaction between that area and other areas.

4. The plan should have adequate detail to fit the type of action proposed, but not more detail than needed for the purpose.

5. The plan should fit into a multi-sectoral plan or, at least, it should not inhibit intentionally attainment of obvious objectives in other sectors.

6. The plan should illuminate the alternatives that were considered, with advantages and disadvantages of each. Those alternatives included in the plan should be related to given policies.

7. The plan should specify the extent of resources and how they may be used. It should include reliable information on direct and indirect costs and benefits, as well as intangible consequences of various courses of action.

8. The plan should have enough flexibility, so that it can adjust to meet uncertainties. It should have a proper balance between early action plans to meet short-term needs and more flexible options to meet long-term demand. Irrevocable allocations of water should be avoided if possible.

9. The plan should be politically, technically, financially and legally implementable.

10. The plan should have adequate public involvement. The alternatives that are presented should be developed through discussions with the various public interest groups throughout the planning process.

11. The plan must be technically sound. It should include a good data base, sound technical and economic analyses and designs that will work.

IV. IMPLEMENTATION OF THE WATER RESOURCES DEVELOPMENT PLAN

As the development of water resources in a region grows, so does the interdependence among new projects, especially in areas of water shortage. In this situation, increasing demand puts stress on existing supply and the reserve of sites suitable for the construction of additional water installations begins to run out. Consequently, the development of water resources calls for a level of analysis that is beyond the individual capacity of the various user sectors, while at the same time the interdependence among the new projects makes it necessary for water management to be carried out in an integrated form for the whole water basin.

As projects increase in size and in interdependence, there is a parallel increase in their absolute and unit costs. The constant increase in these costs may exceed any savings possible through economies of scale, and this means that it becomes more important both to manage the existing systems with care and to be prudent in selecting and planning new projects. Thus, more care must be exercised in considering the broadest range of alternatives for all projects, and multipurpose proposals must be included.

In some countries, projects for water-resource development are hampered by the basic problem of the lack of enough studies and data to make it possible to take the proper decisions at the right moment. Planning for improved sources of data is discussed in section C of this chapter.

In formulating a national water plan, consideration might be given to listing the projects in order on the basis of indicators that can point to the future course of the activities they involve. However, the shortage of studies and the different degrees of precision and accuracy in the cost and benefit estimates means that a theoretical optimization proposal might be inappropriate and unrealistic. Thus, it is desirable to draw up such a plan on the basis of the studies necessary to fill the outlines of plans and programmes.

Two phases can be clearly distinguished--the study or design phase, and the execution and operation of the project. In the first phase, there may be a number of decisions to consider in preparing projects, involving the carrying out of various studies in order to arrive at higher levels of preparation until reaching the feasibility level. Subsequently, in the second phase, a series of decisions is needed to begin the execution of the projects and the activities involved in their operation.

In the light of the foregoing considerations, one can consider a project-generating process in which the agencies responsible for the planning, execution and operation of the projects are linked to a process in which there is a systematic flow of information and decisions. In the centre of this flow is the catalogue of projects resulting from this planning methodology.

A. Project planning

Water resources planning in developing countries should correspond to a set of criteria distinct from those used in industrialized countries. These criteria should reflect prevailing constraints on physical, financial and human resources and the need to allocate critically sparse resources to programmes that, on the one hand, correspond to short and long-term socio-policital objectives, and, on the other hand, promise to be the most cost effective. Programmes which fulfill both these criteria often cannot be reconciled, and a balance must be struck by trading off planned achievements of one objective with another.

1. Elements specific to developing countries

The main conceptual elements of water resources project planning specific to developing countries and related practical planning approaches are summarized below.

(a) Spreading investments over time according to budgetary constraints, while attempting to maximize benefits. Ground water should be utilized wherever possible, especially during early stages of development, to attain scheme divisibility and deferment of costly surface water schemes, which are likely to remain under-utilized for many years. Ground-water resources can be exploited, over a certain time span, in excess of the computed mean annual replenishment, using reserves stored in the aquifer. In this way, heavy investments in development of additional sources of water can be deferred for several years (as, for example, in the case of the Israeli Water System or in Ghazvin Area Development Project in Iran). The exploited reserves can be restored at a later stage of the development process, when regional impounding schemes or inter-basin transfers become justified and operative, and imported water can be recharged artificially into the aquifer (see also section V.C). An aquifer can also be used as a conveyance system, because surface waters that would otherwise have to be transferred by constructed conduits, can be recharged into the aquifer at one point and pumped out of it at another point, closer to the supply area.

Another advantage of ground-water over surface-water schemes is that the source (the aquifer) constitutes a natural reservoir, facilitating supply according to demand fluctuations. A special application of this approach can be effected by pumping ground water from an aquifer with the purpose of replacing spring outflows by pumped supply, timed to satisfy a peaked demand curve.

(b) Assuring the divisibility of schemes into elements which can be implemented gradually. The divisibility of schemes based on surface water should be assured where possible, by staged implementaton, starting out, for example, with construction of run-of-the-river facilities, to be superseded eventually by a dam-reservoir complex, or with the design of dams that can be raised in future.

(c) Phasing large projects, avoiding over-design of systems and minimizing idle sunk costs. Construction of pipelines, pumping and treatment plants and other facilities should be phased. It is easier to develop in stages piped conveyeance systems then open channels, because the carrying capacity of pipelines can be increased when necessary, up to a certain limit, by installing booster pumps along the line. Open channels, on the other hand, must usually be constructed from the outset according to gradients and cross-sectional dimensions that suit the maximum design capacity. For ease of implementation of later stages of conveyance systems, sufficient rights-of-way must be assured from the outset.

Planning and design procedures can be simplified through the introduction of uniform design methods, to enable the use of standard construction elements (modules) which can be implemented gradually. This approach would also reduce construction costs and greatly facilitate operation and maintenance.

(d) Promoting sustainability of the project through involvement of the community. Before implementation of the project, the fullest possible consideration must be given to the socio-economic factors affecting project planning, implementation and operation. Where involvement of the community is appropriate, they should participate at the planning, design, operation and maintenance stages.

It is crucial to ensure that the community (or individuals) benefitting from the planned projects can afford to (and are willing to) pay for at least operation and maintenance of the water system which they will receive. It has been found that a community which assumes full ownership of a project generally takes more responsibility for the project than the community which feels it is a project of the government.

Nevertheless, the responsible government agencies should have budgets for recurrent costs, particularly for expensive spare parts, either through revenue collection or subsidies, to cover emergencies or systems in very poor rural areas.

Physical systems should be designed with a view to minimize needs and levels of service and maintenance. No effort should be spared to arrive at the best possible solution to facilitate an easy management and operation of the system. This applies both to the number of elements that require frequent servicing and to their operational simplicity.

2. Staged development of water resources development schemes

Staged development of water resource schemes is particularly important where the water is needed for large-scale irrigation development. Mainly in developing countries, such irrigation schemes have often been typified by a considerable time lag between construction and water utilization. This has been caused by the slow process of adaptation of farmers to new and more intensive farming methods. Delays are inevitable in the establishment of supporting services necessary to establish irrigated land tillage, crop raising and harvesting, pest control, fertilization, transportation and marketing of produce. Moreover, the farmers' organizations required for the proper management of irrigation schemes are slow to evolve. The scarcity of technical human resources and facilities needed to plan and implement irrigation systems is another cause of delay. Thus, in order to reduce unused investments, irrigation systems should, as far as possible, be planned with the possibility to implement them gradually.

Gradual development facilitates the introduction of institutional and legislative measures which may be necessary for proper management, operation and control of water resources schemes, as well as development of human resources, research and extension services. Where there is lack of experience, gradual development of physical systems reduces risks of failure and enables accumulated experience to grow in step with the needs.

Ground-water development usually involves expensive and time-consuming field investigations and studies. Gradual development of ground-water utilization schemes can proceed in parallel with the advance of research and conceptualization of the aquifer, thus reducing the risk of implementing physical structures on the basis of insufficient research.

Staging the implementation of large scale projects is also important for the priority analysis and sequencing of capital investments, as discussed in section III.C above. As far as possible, plans of large projects should be divided into stages, in such a way that each stage can be identified with a portion of the over-all objective and benefits of the complete scheme. In that way, project stages can be treated as independent projects in the sectoral analysis, and capital investments can be scheduled more evenly and cost effectively between candidate projects and sub-projects.

3. Developing marginal sources of water

As water resources development advances, sources of water which are more and more costly to develop are harnessed. However, a common error made by planners is to overlook possibilities of developing sources of water, sometimes referred to as marginal, which often prove to be less expensive to develop than increasingly costly conventional sources. Reclaimed sewage is one example, if irrigated agriculture can utilize reclaimed sewage (which would otherwise flow to waste) and in return release fresh water for domestic utilization. Similarly, brackish water can be incorporated in a regional water project by mixing it with less saline water, in proportions enabling the utilization of the mixture for certain purposes. Alternatively, regional water schemes can be designed to utilize sources of different salinities and qualities for different uses, all combined and managed as one system. Another example, often true for conditions prevailing in developing countries, is waste reduction in urban systems. Investing in waste reduction will often prove less expensive than expanding the supply, to meet demand, by additional structures and new sources.

Water contamination hazards and environmental impacts of water resources development should not be overlooked in developing countries, even though pressures on water resources are generally less critical there, compared with the highly industrialized and urbanized developed countries.

A major water quality concern in developing countries stems from low-efficiency irrigation which often causes massive transportation of pollutants from fertilizers and pesticides into downstream rivers and aquifers, as a result of large amounts of surplus irrigation water.

B. Assuring proper operation and management

1. The human factor

Instructions and guidelines exist in different forms and levels of detail for managerial practices, accounting, staff management and plant operation and maintenance. Those subjects will not be expanded upon in the context of this publication. For planning purposes, however, the importance of ensuring that such instructions and guidelines be implemented cannot be overstated. In this regard, development of human resources is the most important aspect of planning for proper operation and management of water resource systems. Other planning aspects, i.e., provision of infrastructural facilities and support services required for system operation and maintenance, are an integral part of the engineeering plans of water resource projects.

Many schemes and projects, conceived and executed with international assistance, have deteriorated after some time because of the lack of suitable human resources for their proper operation and maintenance. To bring about a change in the situation, there is need for improvements not only in the level of technical know-how and formal and practical training, but often also in the motivation of the personnel engaged in water resources development and management, from the highest planning and managerial levels to the lowest technical level of field operators.

(a) Professional personnel

With respect to the top and intermediate professional echelons, a very rigid hierarchy of command and decision making can often stifle motivation and a sense of personal involvement in the tasks to be performed. Staff meetings at fixed intervals with open discussions on specific technical subjects can instill in members of the professional echelons a feeling of personal involvement in the decision-making process. The institution of periodic (weekly or bi-weekly) seminars in which topics relevant to current problems are presented by a staff member or a guest lecturer are another important instrument in the professional advancement of the staff, and participation in such seminars should be regarded as a privilege. The subjects of the seminars should be chosen in accordance with needs. It is suggested, however, that they include not only acute problems but also subjects that can educate the professional staff in practical approaches to water resources problems, and in anticipating future developments in the wake of ongoing and future projects, and actual and potential development policies.

The impact of academic training courses abroad through medium-term and extended scholarships has often been below expectations. This is partly because the knowledge or skill acquired can only rarely be applied without change in the home country, and training time is too short to convey to the trainee the wide experience and the independence of thought that he or she needs. In many cases, scholarships are granted not on the grounds of the most pressing needs of a project or a service, but because of a deeply-rooted tradition, manifested by international agencies, that scholarships must be part of a training programme. Sometimes scholarships are even given as a kind of reward. It appears that in many cases greater benefits can be derived by bringing a foreign expert to the country involved for the combined purpose of giving practical advice and training a certain number of local professionals. Where no professionals with basic training are available, intelligent technicians can be encouraged to go abroad for formal studies toward an academic degree.

(b) Technical personnel

On the level of the field operators, it is believed, and it has been proven in the field, that as soon as a technician understands the importance of the routine tasks he is supposed to perform, he will do so with a much greater degree of motivation. The introduction of an equivalent of what in agriculture is known as extension can provide a greater feeling of support from above, and maintain, at the same time, an adequate measure of control. The technician can be trained not only to make observations, but also to decide whether their results are reasonable, so that spurious data are re-checked even before this is requested, possibly with excessive delay, by the evaluating professional. Substantial improvements in the data collection system can be derived from an appropriate attitude to the field operators.

On the field technician's level, too, constant training and refresher courses are necessary. Attending such courses should also add prestige and some material benefits to the participants. The possibility of bringing the training facilities to the field instead of bringing the technicians to some urban centre greatly increases the possible scope of training and reduces, at the same time, the loss of actual work time and the interruption of field operations because of the absence of personnel for training purposes. It also provides the possibility to assist the field technician in the solution of acute problems he encounters in the course of his work.

One of the major difficulties in the monitoring of water resources is the appropriate maintenance of installations. In many cases, a breakdown of an installation is fatalistically accepted by the technician, or even welcomed by him because it obviates the need for further attention. Even a motivated technician may not be capable of repairing a defunct installation by himself. It will be the task of the system management to find the ways that will assure prompt reporting of technical failures of installations and to provide equally prompt repair services. A failure to do so will further strengthen the fatalistic approach of the field operator and complete the vicious circle.

It appears, therefore, that the efficient operation of the field service and of the central agency are to a great extent interdependent and interactive. No central agency can expect good service from its field personnel if it only expects to receive without contributing from its side in terms of demonstration of genuine interest in the field operations and their results, and provision of feedback and appropriate logistic and educational support.

Obviously, no fixed recipes should be expected. Much will depend on the social structure and traditions of the country involved. Disregard for these by a foreign consultant will invariably lead to failure. Project plans concerned with the development and management of water resources must include a strong component of training, both formal and on-the-job training. An approach to training programmes which is guided by principles such as those developed in Israel under its Training and Visits (T & V) agricultural extension method, which have proven immensely successful in many countries, can be easily adapted to the field of water resources management and water systems operation.

The principles underlying the T & V agricultural extension method can be translated in the following way to an approach to training of water supply and irrigation system operation and maintenance (O & M) staff:

(i) Creation of an identifiable series of training links for transmission of know-how from the specialists to the site operators;

(ii) Training of trainers through periodic classes and on-the-job instruction sessions by engineers and other professionals, who will visit the regional or district centres of the water supply or irrigation authority;

(iii) Periodic visits of trainers to selected sites or installations, to instruct selected contact operators in O & M tasks, including small repairs, servicing and operation of facilities, record keeping, stock management, reporting to superiors and passing instructions to the lower echelon staff, i.e., site operators and servicemen, watchmen and labourers;

(iv) Periodic visits by contact operators to all installations within their area of responsibility, to instruct and supervise local operators and labourers;

(v) Introduction of detailed personnel performance evaluation and reporting mechanisms, from bottom to top echelon personnel, and adjusting training programmes accordingly;

(vi) Simplification of the tasks expected to be performed by operators, as well as their supervisors, in line with their educational background and technical capability, as well as the physical means at their disposal (tools and transportation);

(vii) Identification of causes for frequent failures in plant operation, and emphasis in training on the prevention of such causes, as far as they can be traced to human error or mismanagement.

2. Technical factors

In planning water resource systems, certain technical options should be considered in an attempt to reduce the dependence of system operation and maintenance on the limited number of technically trained staff.

For example, gravitational water conveyance, rather than pumping, can be used to eliminate electrical and mechanical facilities which require specialized O & M staff, spare parts and power supply. Moreover, manual rather than automated control and monitoring devices can be used in pumping plant, treatment plant, flow and level regulation devices. Similarly, centralized pumping and regulation facilities can be used in certain cases to reduce the number of O & M staff and travel distances.

Analysis of alternative project plans should include detailed estimates of O & M inputs and manpower requirements. A realistic assessment of their availability, as well as the economic consideration of alternatives, should determine the preferred alternative.

Other elements of project design which may be critical to its operation and maintenance include: staff housing, access roads, fences, lighting, workshops and stores, transportation and communications. These elements are too often overlooked in planning studies, and the result is that many projects are properly constructed but soon afterwards begin to deteriorate because of inadequate maintenance.

C. Planning for Improved Sources of Data

As discussed in chapter II, lack of adequate data poses one of the main constraints to accurate forecasts and relevant plans. The design of a system of information collection and storage, in conjunction with adequate analytical tools, will make possible the introduction of a rational planning process.

Analytical tools and mathematical models cannot in themselves lead to an integrated and feasible plan, because of the complexity of the technical, social, economic and institutional factors that must be considered in preparing a water development plan. On the other hand, any methodology with the proper analytical tools and adequate data will be seriously constrained because of the sheer volume of information that will have to be processed. The desirable approach should combine analytical tools within the information system and models as part of an over-all methodology that will allow the preparation of realistic plans on the basis of all available information. The computer models used should allow consideration of non-quantifiable variables, such as social or environmental factors, using such tools as graphic presentations.

The inclusion of the design of an information system among the aims of planning involves explicit acceptance of the interdependence between the information available and the planning process it feeds. An initial step in the design of an information system is the creation of a data bank to meet immediate, as well as long-term, needs. Immediate data needs can be identified by the group responsible for the information system and the working group responsible for the different stages of the planning process. The latter should be able to specify the relevant variables and parameters, on the basis of available information and the various analytical tools to be used, and to suggest how they are to be processed, stored and brought up to date.

1. Creation of a good data bank

A good data bank is a good data base with a lot of users who need it and know how to use it. A good data base contains long chronological series (without gaps) of accurate and reliable data related to all parameters of interest to the users. While no country has yet attained such an ideal data bank, it is what developing countries should aim to establish.

Almost all countries have at least a rudimentary network of rain gauges or stream gauges collecting data on precipitation and surface water. Whatever information is available can be used as a basis for the establishment of a water resources data bank. When an inventory is taken of the existing network, gaps and data needs can be defined.

(a) Collection networks

Most countries have been collecting quantitative data on surface water for a reasonable period of time. In most countries the earliest water data collection activities have focussed on providing hydrologic information for water planning and development in the traditional sense. That purpose has now been substantially widened. Water is a key aspect of the environment and, in many cases, a key to development. Hence, the need to greatly expand the scope of water-related data collection and dissemination.

There are deficiencies even in the traditional data observation and collection methods, however. It is important to conduct a survey of the existing data collection network to see if all stations are functioning properly. For measuring precipitation, rain gauges need to be checked for appropriate location and proper functioning. Planning for improving the network with additional gauges can be phased over time.

In stream gauging, the level of rivers is monitored in order to predict the flow of streams. It is assumed that a permanent correlation between the level and flow of the river can be determined. While the technician may be able to predict the character of the flow of a given stream with accuracy equivalent to a 10-year record, the data may be inadequate in coverage of small streams, low flows or strategic points between stations. Moreover, the relationship between level and flow will change when the stream flow is affected by siltation, tidal effects, small streams, or man-made diversions.

There is a need for continuous monitoring or at least daily sampling of both water quantity and quality at a substantial number of stations. The monitoring of water quality is essential for the selection of effective anti-pollution control measures and for enforcement purposes.

As for ground water, coverage at even the "general inventory" level is incomplete in most countries. Ground-water quality is only beginning to be a concern of most water authorities. As a basis for collection of good ground-water data, daily tests of water levels in wells and water quality before and after use will be needed in specified areas. Pumping tests will yield the "co-efficient of infiltration", giving data on recharge according to soil type. Efficient conjunctive use can only be managed with good data as the extent and recharge ability of aquifers.

In addition to the traditional networks collecting hydrologic data on available water resources, it is important to improve data collection on demand for water by major users. In water-short areas, planning has to focus on demand management right now.

(b) Inventory of stations and available data

A comprehensive inventory of data collection stations and data available at each station should then be put into the computer as the initial step in establishing the data bank. The inventory should include: location of the station and date it started operating; whether it is functioning properly; all the types of data collected there; and how the data are recorded. All relevant data collected at the various stations should eventually be transferable to the centralized data bank.

Using the inventory, it becomes easy to identify gaps in the network, gaps in data and discrepancies in data. The identification of gaps in the data base is already a part of planning and project studies. The planning body can be responsible for assessing and identifying present and future data needs and including those needs in current planning exercises. As for gaps in data, additional stations may be required, non-functioning stations will have to be removed or reconstructed, and some stations may have to be moved. Discrepancies in data may be identified by cross-correlation, using models developed specifically to answer certain water resources-related questions.

Planning for improved collection of data should be an integral part of the planning exercise. In most countries, the areas of greatest need include data on water quality, environment, socio-economic indicators and water use aspects.

(c) Centralized data bank for integrated planning purposes

The data collected will only be relevant if they are used for planning or management purposes. Therefore, data required should ideally be collected in a format that can be entered directly into a central computer located in the planning unit.

Integrated water resources information systems designed for planning purposes will have data on surface and ground water, quantity and quality, demand and supply, all stored in the same system or in several systems interconnected to form a network. This is particularly important in water-short areas where conjunctive use and efficient management are critical. Data on other factors directly affecting water supplies, such as climate, topography and soils should be an integral part of the data bank. Moreover, a few essential data on social indicators (population growth rates, health indicators, energy use, transportation) will have to be extracted from other data banks in order to make reasonable projections of future water demand.

Since planning exercises will increasingly focus on broader interrelationships among all the sectors of society concerned with water, water agencies will have to co-operate with general data collection and statistical agencies. When specific data need to be collected for water resources planning and management, a transfer of funds to the data collection agency may be required. As the need to integrate hydrological, environmental, social and economic data grows, it will become more important to store the data on compatible computers which are linked to a central system used by planners.

The Institute of Hydrology, Wallingford, UK has developed a software package specifically for data bank purposes called HYDATA, which is a general hydrological processing and analysis system for all types of surface water hydrological data: river level, current water measurements, river flow, rainfall, reservoir storage and general climatic data. A second software package called GRIPS (Groundwater Information Processing System) is designed to store and assist in the analysis of all types of ground-water data. Delft Hydraulic Laboratory in the Netherlands has developed an excellent data base called HYDAT. This data base can operate easily with such mathematical models as HYMOS and Sacramento. Such packages are operated on modern mini- or micro-computers through a series of easy-to-use menus displayed on the computer screen, from which the user selects the functions required. Thus, the user needs only a miminum of knowledge of the computer operating system, the structure of the data files and how to run individual programs. The ability to retrieve data selectively and present it graphically or in tabular form is an integral part of the systems.

An excellent example of an integrated data system is the Texas Natural Resources Information System (TNRIS), within which is the Texas Water Oriented Data Bank (TWODB). The system, developed by the Interagency Council on Natural Resources and the Environment, has used as a model the United States Geological Survey's National Water Data Exchange System (NAWDEX). All participating agencies make up the linked network, and a "Systems Central" provides a co-ordinating point of contact. Interagency co-operation is required to avoid duplication of effort and because no one agency can cope with every aspect of water resources.

The basic advantage of implementing such an integrated system is that the large users (agencies) continue to maintain internal data storage and retrieval systems for data which they collect and use. A "systems central" serves as an interface between those major systems so that data and information can be transferred upon request between agencies. The systems central also provide a central index available to all users and computation services as desired by user agencies.

Among the data stored in the computer-processable files of the TNRIS of direct relevance in water resources planning exercises are the following:

I. <u>Base data</u>

Digitized water well locations
Remote sensing data
Geographical profile

II. <u>Meteorological resources</u>

Precipitation - hourly, daily, monthly
Minimum and maximum temperatures - daily, monthly
Pan evaporation - daily, monthly
Lake surface evaporation - gross, net

III. Biological resources

Micro-organisms - bacterial water quality, rivers, lakes, streams
Coastal zone biological information

IV. Water resources

A. Surface
Streamflow - daily, monthly
Sediment load - daily, monthly
Coastal zone hydrographical information
Surface water temperature - daily
Surface water conductance
Surface water run-off

B. Sub-surface
Water level measurements
Ground water quality

C. Man's activities
Water use by hydrographic unit
Reservoir contents - daily, monthly
Municipal return flow
Industrial return flow
Waste discharge data
Municipal and industrial water use
Permit master file
Water use file
Waste or waste-water operator data
Community profile - water utilities information

V. Geological and land resources

Soils
Water injection
Agricultural land use

VI. Socio-economic resources

A. Social
Census
Community profice - population and education

B. Economic
Earnings and income
Business statistics

Among the benefits of an integrated systems-type approach to linking various agencies with users which have been identified by the TNRIS are the following:

(i) More consistent format, quality, standards and scales of data;

(ii) Improved inventory and cataloging of existing data;

(iii) Improved co-ordination of on-going and planned programmes and information processing efforts;

(iv) Less duplication of data storage;

(v) Elimination of conflicting data;

(vi) Improved research and development activities using imagery processing, data reduction and modelling techniques;

(vii) Greater hardware and software compatibility.

More information on this integrated data system can be obtained from the Water Oriented Data Programs Section, Interagency Council on Natural Resources and the Environment, P.O.Box 13087, Austin, Texas, 78711, USA.

2. Use of models

Many types of models have been developed which generally can use data directly from the data bank, and which can assist in answering specific questions and identifying discrepancies in data. Some of these have been mentioned in chapters II and III.

Other excellent models in surface and ground water have been and are being developed through the co-operation of well-known hydraulic laboratories in Denmark, the Federal Republic of Germany, France and the Netherlands. These combined models will be some of the most elaborate yet developed.

Such models are extremely useful in identifying problems or errors in data collection. They process all the data collected and try to make sense out of the given values. For example, in trying to relate precipitation, flow and infiltration, the models can cross-check data from all sources, and make a chronological graph of all the values. The user can visualize all parts of the stream and can pinpoint a data collection station which is obviously not reliable. If the user cannot calibrate the model, he knows that either his hypothesis is incorrect or there is a problem in his data collection network.

The types of information useful to planners which can be derived from such models are: minimum flow in a river to be expected in a given time period (for prediction of droughts and contingency measures); maximum flood in the given time period (for setting up warning systems and emergency measures); and mean value of yearly discharge (for predicting inflow to a dam, designing reservoir capacity and managing waters stored in dams).

3. Provision of relevant information to decision makers

The objective of collecting basic data is not to develop a long list of specific data needs, but to maintain relevant data to meet the changing needs of users and decision-makers.

A good programme for basic data must include data collection, storage, retrieval, dissemination and a means for anticipating future needs. One of the major considerations is to let potential users know what data are available so they can obtain them when needed. In order to ensure that the right kinds of data are available when needed, it is essential that planners make known what data they need for effective planning and decision making. The ultimate use of basic data is to provide a sound basis for decision making, and the basic data requirements will change as the decision-making framework changes.

As countries develop, their planners will require more integrated data, showing inter-relationships among precipitation, ground water, streamflow and water quality. Planning to meet future demand will require information on water use, population, income and other socio-economic factors. Multi-objective planning for water resources and the implementation of the plan require a much broader data base than in the past. Social and environmental indicators have to be an integral part of the data bank. Since much of this data is already available, it will not be necessary to duplicate the services, but only to direct requestors to the appropriate agencies. The central data bank serves as an up-to-date referral system.

V. PLANNING FOR EFFICIENT USE OF WATER

A. Reduction in water losses

1. Domestic water supply

Water losses in a domestic water supply system can be defined as the difference between the measured amount of water pumped or otherwise fed into the system, and the total amount supplied to consumers. This difference is often called unaccounted-for water, to denote that part of it may be physically lost and part unmetered or inaccurately metered.

Water losses are a major problem for domestic water supply authorities, mainly in developing countries, where losses less than 10 per cent are rare, and figures in excess of 50 per cent can be found in many poorly operated and maintained systems.

Lost water incurs a waste of money spent on pumping, treating and distributing the water; it entails investments in developing new sources of water which could be postponed or avoided if all the water were supplied to consumers; and it creates environmental nuisances around points of leakage.

Statistical data on water losses in developing countries should be treated with considerable reservation, since in many water supply systems no adequate measuring devices exist, at either the intake or the abstraction points(s) of the supply systems, or at the connecting points of consumers. Water quantities abstracted and distributed by the system or supplied to the consumers are at times estimated by indirect measures such as measurement of electricity supply, pump rating curves or average consumption. Full-scale water metering at both the abstraction and supply ends of the system is nonetheless essential for proper evaluation of water losses and planning possible water savings.

Water losses exist in two major domains of supply systems: the main transmission and distribution network operated by the water supply agency or organization; and, consumer compounds, beyond the (metered) connection to the main supply system.

(a) Elements of physical losses

The main elements of physical losses in domestic water supply system are:

(i) Leakage in the main supply system, from rusted, broken, burst or loosely jointed pipes, and from leaking air valves, drainage taps or pump glands;

(ii) Uncontrolled spills from reservoirs;

(iii) Excessive discharges by consumer taps due to excessive pressures in the system;

(iv) Leaking taps and flush basins in consumer premises.

Unauthorized and uncontrolled water tapping in domestic water supply systems constitutes a substantial element of the total unaccounted-for water in piped water supply systems in developing countries. Inaccurate or estimated metering contributes another major portion. These amounts of water are actually consumed but not paid for, and should therefore not be considered as physical losses. In developing countries it is often difficult to locate and bring under control unauthorized water tapping, mainly because of organizational shortcomings. Since part of the actual consumption is not paid for, it creates an additional burden on the water supply authority and on metered and billed consumers.

Since physical losses constitute just a portion of the amounts of unaccounted-for water, measures to control those losses will often have a seemingly marginal effect on the over-all efficiency of water supply systems in developing countries. A possible range of savings for most domestic water supply systems could be from 2 per cent in well-constructed, operated and maintained water supply systems, up to 10 per cent savings in less well-executed, and poorly operated and maintained, systems.

Reduction of water losses and the introduction of water-saving devices is relatively expensive, and the marginal cost to save one cubic metre of water is high. It requires careful planning and a proper organizational framework as an indispensable prerequisite. Yet despite the high cost and organizational effort needed to reduce water losses in the system and achieve water savings by the consumers, such measures are still often pursued by local or regional authorities. The cost of saving a cubic metre of water is usually still cheaper than the marginal cost to produce a cubic metre of water from alternative sources, especially if local sources have been exhaustively exploited and water has to be carried over long distances.

(b) Reductions in water losses

The following are the principal steps that should be taken by local water supply authorities toward reduction of water losses in domestic water supply systems:

(i) Organization: An adequate organization of properly trained and motivated manpower, together with the necessary workshops and spare parts is a first step toward improved conditions. Checking unauthorized abstraction of water from the public network can only be achieved by a strong and dedicated organization.

(ii) Operation: Modifications in system operation which can reduce losses include, for example, reduction of excessive pressures in certain parts of the network, or creation of additional pressure zones, in order to reduce leakages and burst pipes, and to reduce the discharge of opened taps; modification or addition of storage facilities to provide better distribution of flows and pressures; addition of gate valves to facilitate control over the system and enable isolation of leaking pipes due for repair.

(iii) Metering: Accurate and reliable water measuring devices should be installed at all critical points in the network, including headworks and pumping stations, in order to facilitate the detection of critical sections, with above-normal water losses. It should be kept in mind, however, that reliable water metering is only possible if the organizational infrastructure to maintain and periodically read water meters exists. Since complete consumer metering throughout the system may be initially prohibitively expensive, interim solutions, such as neighbourhood metering, or sample metering, should be considered.

(iv) Repair and maintenance: Replacement and repair of leaking pipes should be done as a matter of routine, based on systemic leakage surveys.

(c) Reduction in water consumption levels

Water consumption levels can be maintained at a reasonable minimum by a combination of the following measures:

(i) Water saving devices: These include flow and pressure control facilities, pressure-reducing valves, double-quantity flush basins and self-closing taps. About 40 per cent of water in domestic supply systems is used in flushing toilets. Therefore, the installation of saving devices in this sector such as the recently developed double-quantity flushing basin, can bring about a considerable water saving.

(ii) Metering: It has often been shown that the very existence of water meters on consumer connections encourages water saving habits.

(iii) Water rates: The imposition of higher water rates for higher consumption discourages waste on consumer premises. The effect of tariff increases has been shown to be mostly temporary, however; water consumption returns after a few months to its previous levels. In addition, higher per capita consumption levels prevail mostly in higher income residential areas, where the effect of increasing water rates is very limited or insignificant due to the low expenditure on water, compared to a family's income. It has been shown that the price of water does not become a significant motivation for saving until a family's expenditure on water exceeds 2.5 to 3.0 per cent of its net income. Water tariff systems are discussed further in chapter VI.

(iv) Publicity campaign and education: The highest and most lasting effect can be achieved by publicity campaigns and education. When people become aware of the shortage of water, sometimes stressed in drought periods or by system breakdowns, they develop water saving habits, choose lower water consuming plants for their gardens, and report leaks and burst pipes to the authorities.

(v) Irrigation efficiency: A relatively large amount of water in urban areas is consumed by public parks and gardens. The introduction of sprinkler or drip irrigation, combined with automatic control devices, can save considerable amounts of water.

2. Irrigation

There is in general more land available for agriculture than there are water resources to irrigate it. This is especially true in countries located in arid or semi-arid areas. Proper planning of irrigation systems and facilities, and increased efficiency, are therefore a major factor in determining the extent to which the available land can be irrigated, and how the limited water resources can best be utilized. The water resources planner should be aware of various factors affecting the efficiency of different irrigation methods, and should consider their likely impact on future water requirements, as discussed below. No attempt has been made here to cover all aspects of irrigation technology. The purpose was merely to highlight some of the long-term planning implications.

(a) Open Irrigation

(i) Efficiencies

At present about 250 million hectares are irrigated throughout the world. The majority of this area is open irrigated (basins, furrows), with over-all efficiencies in the range of 15 to 30 per cent. Some projects have efficiencies as low as 10 per cent, but even projects with higher efficiencies rarely surpass 40 per cent. Although in large river basins part of the wasted water returns to the lower reaches of the river or its tributaries, or reaches the ground water in the project area itself or somewhere downstream, the quality of such return flows quite frequently becomes unsuitable for reuse, owing to contamination by fertilizers and other chemicals applied to the fields, or due to leaching of salts from the soil.

Because of the large amounts of water required in irrigation projects, even a marginal increase in efficiency can enable an increase in irrigated areas. This will be economically justified as long as the marginal cost of increasing the efficiency will not exceed the marginal benefit of increased crop production. Alternatively, the saved amounts of water can be utilized for other purposes, again depending on economic justification.

An increase in the efficiency of existing irrigation systems depends not only on cost and technology, however, but also on good organization, which in turn depends on social and traditional factors. Therefore, care must be taken in considering savings from increased efficiency as an additional source of water for long-term planning. It is also quite difficult to estimate efficiencies for newly planned irrigation projects, and accurate predictions are difficult to obtain. On the other hand, engineers tend to assume too low efficiency values, and unnecessarily increase the dimensions of canals and structures to cope with design uncertainties.

The over-all efficiency of an open irrigation project is a product of three efficiency parameters, as follows:

Water conveyance efficiency: This is the efficiency in the main canal system, i.e., the ratio of the volume of water delivered to all farms to the total amount of water supplied to the main intake or supply point of the entire project.

Farm ditch efficiency: This is the efficiency in the farm ditches, i.e., the ratio between the volume of water applied to the cropped area and the volume of water delivered to all the farm units.

Field application efficiency: This is the efficiency of water applied directly to the cropped area, and is the ratio between the rainfall deficit (the difference between the consumptive use of the plants and the effective rainfall over the cropped area) and the amount of water applied to the cropped area.

Water conveyance efficiency

The following elements have significant influence on water conveyance efficiencies:

Size of irrigated area: Maximum conveyance efficiencies of up to 88 per cent can be obtained for command areas between 3,000 and 5,000 ha. Efficiencies decrease for smaller areas mainly due to the increased difficulty for system operators to make frequent adjustments in regulating flow rates in secondary and tertiary canals, according to demands.

Size of rotational unit (i.e., a land unit with an independent internal supply rotation to the individual plots). The optimum unit size has been found to be between 70 and 300 ha, though in areas where the average farm plot is small (between 1 to 3 ha), the tendency is toward smaller areas (70 ha and even less, according to recent experience) to facilitate internal rotation.

Operation. The conveyance efficiency depends above all on the amount of operational losses, i.e., spills due to excessive deliveries into the main canals and from these into secondary and tertiary canals. Whether these losses are small or great will largely depend on how effective the management and organization for operation and distribution of water are.

Leakage. This will depend on whether canals are lined or unlined, on the texture of the soil traversed by canals, on the quality of canal construction work and on intensity and quality of canal maintenance. Savings of 30 per cent or more in water utilization can be achieved by leakage prevention, by lining canals (see below) or by converting to closed conduits (pipes).

Farm ditch efficiency

To obtain a reasonable farm ditch efficiency the network of farm ditches has to be well designed and operated by skilled farmers. The farm ditch efficiency is mainly affected by seepage losses, water distribution methods and farm size. Data from a study by the International Commission on Irrigation and Drainage (ICID) indicate that small plots of less than about 3 ha on a rotational supply have lower efficiency values than plots of 10 ha and more. The reason for this is that on small plots the relatively high losses at the beginning and end of each irrigation, due to rapidly changing rates of absorption by the soil and overflows resulting from the short time needed to fill the basin or the furrow, cannot be completely avoided. These losses are relatively small in larger farm plots receiving water at a fairly constant rate.

Field application efficiency

The more uniformly water is distributed over the field, at an application depth which matches the water deficit in the root zone, the better is the field application efficiency. The following factors influence field application efficiency.

Irrigation method: High efficiency can be attained in basin irrigation with intermittent application, provided that topographical conditions are favourable. Good efficiencies, although somewhat lower than for basin irrigation with intermittent flow, can be obtained by border strips and furrows. The traditional continuous basin irrigation of rice has low application efficiency because of over-saturation of the soil profile, resulting in deep percolatioin losses, and also because the supply is usually not adjusted to occurrence of rainfall.

Depth of irrigation: To achieve a proper water application, at least 60 mm of water have to be applied, in order to ensure uniform water distribution over the basin or furrow. At least some of this minimum depth of water is lost by deep percolation, since in some parts of the flooded area a much deeper water layer would be required in order to maintain that minimum in other parts of the area.

(ii) Increasing Irrigation Efficiency

Canal Lining

Water losses from unlined canals vary considerably according to soil type and canal design. Losses of up to 30 per cent are quite likely. In addition to the direct implications of losses on the economic viability of existing irrigation projects, leaking canals often cause water logging problems, deterioration of soil fertility, proliferation of weeds and pests, as well as leaching of contaminants into the ground water. Usually, however, the investment in the lining of existing canals is economically justified simply in terms of the capital and current expenditures saved because of reduced losses of water. In any case, the economic attractiveness of canal lining in existing systems should be viewed in light of the value of the saved amounts of water, either as a source for irrigating more land or for alternative uses. Other measures of waste reduction, such as improved control and automation should be similarly analyzed.

The same rationale applies to planning of new irrigation schemes, when a decision on whether to construct lined or unlined canals should be made. The key issue is the value of water, which in turn is a function of the gap between available sources and forecast demand. To this main issue must be added the above-mentioned detrimental side effects of leakage from irrigation canals, as well as the organizational capacity required to run and maintain a system of lined canals efficiently.

Improved control

A significant portion of water wasted in open irrigation systems can be saved by tightening the control over the distribution of flows in the system, from headworks to the farm outlet. This requires good organization and co-ordination both at the farmer's level, where the rotation of irrigation turns should be planned ahead in accordance with individual farmer's cropping patterns and crop requirements, as well as between the farmers and the system operators, who should regulate the flows in the tertiary, secondary and main canals according to the demand.

Apart from the need to provide the necessary staff and introduce operation routines, certain physical facilities are important to assure effective control: regulative gates which are easy to operate and maintain; service roads and vehicles (motorcycles or bicycles for ditch riders; cars for supervisors, mechanics and engineers); and wireless communication instruments. Regulative gates and flow control devices, which are activated by floats, installed either downstream or upstream of the gate, are advantageous, but should not be introduced unless proper maintenance can be assured. Where adequately skilled operation and maintenance staff are available, it may be profitable to install remote-controlled gate regulation devices and even a computerized control centre.

Water tariffs

The possibility of using water tariffs as a means of encouraging efficient utilization of water is hampered in irrigation systems in developing countries, and in open irrigation systems in particular, by the absence of water metering devices. Installation of cumulative water meters, such as are commonly in use in piped systems, is usually impractical in open channel systems, due to the extra head required to activate the meters, which is normally not available in such networks, and also because of the additional costs of installation and maintenance. Only in certain cases have farmers converted from simple traditional unmetered farm outlets to a type of outlet which incorporates a short length of pipe, on which a cumulative water meter is mounted.

The usual method of charging for water in open irrigation systems, however, is based on a fixed payment, usually relative to the size of the irrigated plot and/or the crop. It may be said that higher water rates are paid, and better control can be exercised over the irrigation system, in those cases where farm productivity is higher and system management is more efficient. Seldom in the poorer developing countries do farmers in government-constructed or government-supported projects pay the full cost of water, including capital recovery. This is another reason why water tariffs cannot generally be considered as an incentive for farmers in developing countries to economize in water consumption. Water prices are discussed further in section VI.B.

(b) Sprinkler and drip irrigation (pressure irrigation)

The use of sprinkler irrigation, though still relatively limited as far as the total global irrigated area is concerned, is steadily increasing in importance for irrigated agriculture. Sprinkler irrigation has a number of advantages from the agricultural point of view, such as the possibility to irrigate steep or rolling land and soils of limited depth, suitability to porous and light soils, and ability to apply small amounts of water. The main disadvantages of sprinkler irrigation are its high initial cost and operating expenditures. The most important advantage of sprinkler irrigation, especially in arid and semi-arid areas, is its higher irrigation efficiency. Field application efficiency, can be 10 to 15 per cent higher than in surface irrigation. The conveyance system for sprinkler irrigation is usually made of pipes, mainly for distribution to farms but also for the main conveyance from the source of supply. The over-all efficiency for the entire system is therefore higher than any surface irrigation method, usually in the range of 50 to 200 per cent increased total efficiency. Being a pressure system, fluctuations in water consumption result in changes in pressures and discharges in the pipelines, rather than spills, as inevitably occurs in open systems. Regulation of flow rates and discharges to the planted areas is easier and can be readily automated and remote-controlled.

In many parts of the world, including in developing countries, private farmers as well as the more innovative farmers in government-supported development projects, convert their lands to sprinkler irrigation, especially for cash crops and orchards. Although it cannot be expected that massive conversion from surface to sprinkler irrigation will take place in most of the developing countries in the near future, the possible gradual change to sprinkler irrigation in certain areas and crops should be considered in forecasting irrigation water requirements for future water resources development.

The same can be said about drip irrigation, which is also spreading rapidly in many parts of the world, including developing countries, mainly on private farms with cash crops or orchards. Application efficiency is up to 20 per cent higher than for sprinkler systems; crop yields can be 10 to 30 per cent higher; and better quality is obtained, which is chiefly the result of the ability to maintain a nearly constant soil moisture in the root zone.

(c) Planning implications

The total amount of water to be supplied for irrigation will depend on quantities of various crops grown and on the water consumption per unit of produce, which in turn is a function of irrigation efficiency. In planning water resources development to meet long-term demand, future water requirements by the agricultural sector should be forecast with due consideration of possible changes in irrigation methods and efficiencies. To be realistic, such forecasts must be made within the general context of economic factors affecting the agricultural sector.

As discussed above, there are numerous factors affecting irrigation efficiency, and there is a cost involved in any measure introduced to increase irrigation efficiency. Thus, the economic viability of investments in newly irrigated areas or in raising the efficiency of existing projects would determine the consumption levels which the planner should assume as a basis for long-term water resources planning. Economic studies are therefore an integral part of long-term water resources planning, mainly where irrigation constitutes a significant component of a water resources system. Such studies address the issues of local and international market conditions, demand for farm products, cost of agricultural production inputs (labour, seeds, fertilizers and equipment), and availability of budgets for investment capital and recurrent expenditures to the agricultural sector.

Based on economic studies, the profitability of raising agricultural production by new or improved irrigation can be determined and expressed in terms of cost per unit of land area. The economic analysis should of course be based on cost estimates per unit of area for various irrigation methods. Thus when a level of economically viable investment in irrigation has been determined, it implies a certain irrigation method and water demand per unit area. Consequently, the total irrigation water demand of a project with a given irrigable area, can be calculated.

Typical costs per hectare of various irrigation systems are roughly as follows: open irrigation, US$500-$700 (mostly land levelling); sprinkler irrigaton, $900; drip irrigation, $1300-$1500. These costs include just the on-farm irrigation system, not the headworks, main, secondary and tertiary canal network. In the analysis of investments per unit area of land irrigated by alternative methods, the total cost per hectare should be taken into account. Therefore the profitability analysis of per-hectare investment in irrigation must be done in parallel with planning of the water resources development project, to compare the total cost per hectare of the supplied water with the justified level of investment per hectare. The same rationale applies to improvements in existing irrigation projects, not only to new projects. On the one hand is the profitability of investment in raising the efficiency of the existing system, which implies a certain saving in amounts of water supplied, and, on the other hand, is the cost of the systems and facilities required to bring about this improvement.

In a study done by Nepal's Water and Energy Commission in 1981, a typical breakdown of unit irrigation development costs was found from an analysis of government developed on-going and proposed surface irrigation projects of between 5,000 ha and 50,000 ha (mainly for rice), located in the Terai (the plains along Nepal's border with India), as shown in table 1.

Table 1. Unit Irrigation Development Costs in Nepal, 1981

	Intensive Coverage[a/] (US$/ha)	Minimum Coverage[b/] (US$/ha)
Provision of Water		
River diversion works	600	600
Head reach canal, 5 km	75	75
Irrigation System		
Main canal (with cross regulators, drop structures, escapes and branch and secondary head regulators)	350	350
Secondaries and branch secondaries (with drop, cross and head regulators, turnouts to 50 to 100 ha)	260	260
Tertiaries (with elementary division boxes, turnouts to 5 to 10 ha)	375	0
On-farm development (field channels)	40	0
Drainage	115	75
Other Costs		
Technical services, consultants	240	180
Roads	350	0
Training and fellowships	170	0
Project infrastructure (buildings etc.)	150	90
Agricultural infrastructure	125	70
Land consolidation	750	0

Notes:

a/ Down to 5 - 10 ha, where a perennial water source allows irrigated cropping intensities up to 250 per cent.

b/ Minimum effective development of command area, where available water only allows irrigated cropping intensities up to 150 per cent.

3. Industrial water use

Water is utilized in industrial plants in one of two ways: as a production input or as an aid to the industrial process. In the first case, water is actually consumed, by being introduced into the final product in various forms, e.g., as a diluting or a mixing agent, a solvent or a preservation agent in products such as frozen foods. In the second case, water is primarily used for, say, water-borne conveyance of materials, parts or products (e.g., fruit), or for cleaning, boiling, cooling and heating, and is disposed of at the end of the process, although part of it is inevitably consumed in the course of the production process, mainly through evaporation.

Economies in industrial water utilization can be achieved mainly with the second type of uses. Water which is discharged at the end of the production process can often be recycled and used a second or sometimes a third and a fourth time. Usually the water has to be treated to a certain degree prior to recycling, depending on the type of production process. Additional water-saving measures in industries include, for instance, pressure and flow regulation devices, recycling of heated water, compressed air injection into rinsing water and substitution of water cooling by air cooling.

Obviously, the possibility of attaining a high level of efficiency in industrial water utilization will depend on the cost of water saving devices, and the ability of the industry to pay these costs. As in other water sectors, the achievable level of efficient water use will depend on a combination of factors, including the real cost of water, or its worth to the economy, the water rates charged to the consumer, the effectiveness of legislative measures and public awareness of the need to save water.

In Israel, water-saving methods were introduced by enforcing water allocations, charging high and progressive water tariffs and supporting (by loans) installation of water saving facilities; these policies have resulted in significant reductions in water consumption. For example, the dairy industry reduced its unit consumption of water per litre of processed milk from 3.5 litres in 1964 to 1.2 litres in 1980; the fruit and vegetable canning industry reduced consumption of water per unit of production value from 9.0 m^3 in 1964 to 5.5 m^3 in 1977; and the plastic industry reduced consumption of water per unit of production value from 2.5 m^3 in 1964 to 1.0 m^3 in 1977.

In addition, industry should be encouraged or compelled to use lower-quality water, such as brackish ground water or treated sewage, for purposes such as cooling. This would save higher-quality fresh water for higher purposes such as drinking, particularly under conditions of scarcity. One way to encourage use of lower quality water is to charge a lower price for it.

B. Improvements in water quality

It may be expected that over the next decade, the management of water quality will be one of the major means of conserving the national stock of water in each country. The rapid increase in population in major urban centres, industrialization and the heavy dependence on chemical products in the agricultural sector are leading to a serious deterioration of water quality in developing countries.

Today there is widespread realization that water quality management is an economic imperative for nations as they face growing and competitive demands on the use of an increasingly scarce supply of clean water.

1. Sources of water pollution

Untreated industrial wastes can have serious impacts on receiving water bodies. The specific effects are dependent on the assimilative capacity of the water body and the characteristics of the waste. The major industries in the traditional sector which are causing widespread pollution problems in developing countries are those which process primary products (often for export), such as sugar and oilseed mills, mineral extraction and processing facilities, coffee factories and tanneries. Modern industries, such as petrochemicals and pharmaceuticals, produce effluents laden with toxic substances, which are dangerous and difficult to treat.

Wastes from urban centres and urban fringe areas, in many cases lacking adequate sanitation facilities, result in run-off highly polluted with pathogens and organic materials that can have a serious impact on the water quality of nearby surface and ground water.

Even in rural areas, both surface and ground water are becoming contaminated from run-off containing residues from agricultural fertilizers and pesticides, as well as domestic wastes. The latter are among the major sources of disease transmission. Moreover, overcutting of forests has caused erosion and increased run-off, carrying sediments and nutrients to water courses.

Indiscriminate disposal of such wastes may render water bodies unusable for agriculture, fishing, water supply, and even navigation and industrial use in severe cases. Its net effect is to severely reduce the quantity of water available for use.

The economic consequences of a development policy that does not consider environmental protection may be dire. Degradation of water resources can adversely affect major economic sectors of a developing country, such as agriculture and fisheries. Governments must develop effective policies and institutions to correct current detrimental effects of pollution and to protect water resources for future generations.

2. Technical approaches to water quality management

Some technical options in the field of water quality management are briefly outlined below. Policy instruments will be discussed in chapter VI.

(a) Interception of fresh water prior to salt pick-up

In many semi-humid to arid countries many springs yielding brackish water arise from carbonate aquifers. Hydrogeological investigations have shown that the brackish nature of the spring is often due to a mixing of fresh ground water with ascending brines, which occurs in fault zones, close to the springs. In this case boreholes drilled to ground water upstream from the springs can intercept the stream of fresh ground water directed toward the spring, prior to its mixing with brine. As a result of exploitation of such boreholes, fresh water becomes available, instead of the natural brackish outflow of the springs. Pumping from the boreholes affects the discharge of the springs, even to the extent of their drying up, but the deficiency in natural seasonal spring outflow is compensated by pumping according to the seasonal distribution of demands.

(b) Improving irrigation efficiency for the preservation of ground-water quality

The correlation between the contamination of ground water by nitrates and prolonged irrigated farming is evident in many major agricultural regions. Improved irrigation efficiency reduces return flow to ground water and should halt the rise of nitrate content. At the same time, the use of chemical fertilizers and pesticides should also be restrained.

(c) Reuse of urban effluents

The discharge of urban effluents directly or via rivers into the sea or to the sub-surface, has become in many parts of the world not only a major environmental problem but also a threat to important ground-water sources. A plan for the reuse of urban effluents, after appropriate treatment, for the purpose of irrigation, can be formulated to include treated waste water as a major component in a regional or national water balance. Agriculture would thus receive the treated effluents in lieu of the previous natural fresh water needed for urban supplies.

(d) Small-scale treatment of effluent wastes

Various methods for treatment of effluent wastes on the level of the small to medium-sized rural community are available today for a variety of climatic and other conditions. A modular approach permits a staged amplification of such systems in accordance with growing needs.

(e) Multi-quality water utilization schemes

Where water sources of different qualities exist in proximity to areas of urban, industrial and agricultural development, an integrated multi-quality water resources development and water utilization scheme can be planned, so as to make maximum use of all existing sources in one co-ordinated system, in order to meet long-term demands for waters of different qualities. The range of alternatives which can be integrated into one such multi-quality scheme, subject to engineering and economic evaluation, includes the uses of water listed in table 2 (roughly arranged in order of source quality level).

Table 2. Utilization of different qualities of water

Source/quality of water	Uses
Raw sea	Cooling of thermal plants; street cleaning; toilet flushing
Desalinated sea	Unlimited usage
Raw brackish	Certain crops (depending on soil type); certain industrial processes (cooling); street cleaning, toilet flushing
Mixture of brackish and fresh	Irrigation of selected crops (depending on mixing ratios); domestic supply; cooling and other uses of low-quality water
Desalinated brackish	Unlimited
Urban run-off	Irrigation; all uses of low quality water
Raw sewage	Irrigation of non-edible crops
Treated sewage (depending on treatment level)	Irrigation of a wider range of crops and soils; some industrial processes; cooling and other uses of lower quality waters
Rainfall collected from roofs and man-made catchments	After cleaning, unlimited usage
Fresh water	Treatment for drinking and industrial purposes is usually required when surface sources are used

C. Conjunctive use and artificial recharge

The primary objective of water resource planning is to ensure that there is sufficient water when and where needed. In many regions the total quantity of water may be fairly abundant, but it may not be a reliable supply over time without intervention. When rainfall and streamflows are highly seasonal, the use of storage is required to ensure availability during the dry season. Where storage reservoirs are not economically or environmentally feasible, underground aquifers can play an important role in long-term storage.

Ground-water storage can be one of the most efficient mechanisms for safe long-term storage of water to meet drought requirements. The storage capacity of the ground water basin may be comparable to a surface reservoir, without comparable losses to evaporation.

Using ground-water basins along with surface facilities as part of a network for water supply is called "conjunctive use". Use of this term refers to an orderly plan of development considering all available sources of water, timing requirements and other constraints to maximize the yield capability of both the sources (Paudyal and Das Gupta, 1987).

Conjunctive use of ground and surface water sources may be practised in order to attain one or some of the following objectives:

(1) A higher total amount of supply;

(2) Better regulation of the combined system, thanks to the added storage volume of the aquifer;

(3) A staged development of a water supply or irrigation project, by utilizing ground water first, at small increments of growth, well by well, and later diverting streamflows;

(4) Savings in evaporation losses from surface reservoirs, by using instead the aquifer as a storage reservoir;

(5) Higher flexibility in supply according to the demand curve, by evening-out peaks in streamflow and pumping ground water as and when needed;

(6) Mixing of different quality water, either in the supply system or in the aquifer, to reduce salinity or concentration of other water quality indicators;

(7) Reduction of capital investments and operational expenditures by shortening conveyance distances for surface water;

(8) Inducing ground-water replenishment from streams by extending the duration of flows in the stream by means of dams, or retarding the flow by means of groynes or levees;

(9) Augmenting low flows in rivers which act as the drainage basins for aquifers, by artificially recharging the aquifer with streamflows during months of high flow, thus inducing ground-water drainage into the stream during low-flow months.

A central technique for attaining most of these objectives is artificial ground-water recharge. Artificial recharge is effected either through spreading grounds (or recharge basins) or injection boreholes or shafts. The most suitable method would depend on: the hydrogeological properties of the aquifer; the absorption capacity of boreholes vs. recharge basins; the geological profile and hydraulic properties of the unsaturated zone above the aquifer; the quality of the recharged water and its suspended solid content and the ensuing long-term cumulative effect of the recharged water on the permeability of the unsaturated zone; and on the location of suitable recharge sites relative to the source of water.

Because of the detrimental effect of suspended solids in streamflows on the absorption capacity of recharge basins, as well as on injection boreholes, properly-designed recharge projects contain a surface storage reservoir. This reservoir reduces riverflow fluctuations, enables diversion of larger quantities from the river to the recharge site and impounds the water for a certain period, to allow suspended solids to settle before recharge. Under certain circumstances, the water may have to be given additional treatment, such as flocculation, prior to recharge.

Careful studies of the aquifer and planning of a recharge and pumping regime should precede the selection of recharge sites and the determination of the amounts of water that can be recharged and subsequently pumped. An aquifer simulation model is an indispensable computational tool for predicting the response of the aquifer to planned recharge and pumping regimes. In addition, thorough field investigations, including recharge tests, should be performed in order to locate the most suitable recharge sites and design their dimensions and operational modes. Even then, artificial recharge schemes should preferably be implemented gradually and accompanied by detailed monitoring and observations.

Artificial ground-water recharge can also be used as a means of augmenting aquifer yields, by recharging treated waste water, thus also adding soil treatment to the process of purifying waste water. The Dan Region Sewage Reclamation Project in Israel is one of the largest existing schemes of this type, where some 90 million m^3 of tertiary treated sewage is recharged into a sandy coastal aquifer and subsequently pumped and supplied for irrigation. Besides adding a substantial amount of water to the national water balance, this project adds a final touch to the treatment process, which renders the water suitable for irrigation, with no health risk in case of incidental drinking.

D. The use of non-conventional sources of water

In water-short areas a variety of water resource development techniques can be considered in developing a long-term water resource strategy that is feasible from a financial, social and political point of view. Among the non-conventional techniques that can be examined by a given locality are waste-water reuse, desalination of brackish and sea water, transport of water by tankers and weather modification (cloud seeding).

In areas of the world that are inherently short of available fresh water that can be readily developed to provide an adequate, dependable water supply, there is a definite potential for the use of non-conventional water resource techniques. Some of the areas are located in the Middle East, North Africa, North America and the Caribbean, Australia, Asia and various oceanic islands.

Non-conventional water resources generally do not create new water, but only expand the potential for treating and using water sources that were previously considered unusable or unavailable. This means that sea and brackish water, waste water, and water located in distant places can now be considered as potential sources of fresh water for an area.

There is no single non-conventional solution that is universally appropriate. Each locality must carefully examine its own situation to determine which, if any, non-conventional method would be applicable. This should be part of the water resources development plan, which should examine needs and resources and formulate a strategy that is feasible from a long-term financial, social and political point of view. A study of this type may lead to the conclusion that the use of non-conventional water resource is appropriate for all or part of a supply system or that it is not appropriate at all.

1. Development of brackish and sea-water sources

The use of brackish and sea water as sources of fresh water has been made possible through the development of efficient methods to separate dissolved salts from water. These improved desalination techniques have been developed since the early 1950s. Some minor desalination installations using distillation had been constructed earlier in locations such as the Netherlands Antilles and Egypt, but the cost of distilling sea or brackish water to produce fresh water was very high when compared to conventional water sources.

The experience that has been gained over the last 30 years, however, and improvements in technology, have now made desalination a widely accepted technology, supplying high quality water to water-short areas around the world. The costs of water are still relatively high and can generally be justified only under very site-specific conditions.

Despite predictions made in the 1960s, the costs of desalted water have not decreased, although costs in the 1980s had stabilized to some extent. The 10-fold rise in oil prices since 1970, combined with high interest rates and inflation of materials prices, have made most desalting projects beyond the means of most communities in developing countries.

In developing countries desalinated water should mainly be considered for high-value purposes, such as domestic consumption, tourism and industrial usage where water with a low salt content is required. It is seldom cost-effective to desalt water for agricultural irrigation.

The major application for large desalination plants will probably continue to be in the arid, oil-exporting countries, which have little choice if they want to promote development. Large desalination plants are generally planned in conjunction with power plants, using the waste heat for distillation of sea water.

Planners could also consider relatively small desalination plants (below 1,000 m^3/d) for water-short areas in developing countries and oceanic islands, to meet the needs of tourist hotels, construction sites, military units and isolated small communities. Although their economic conditions vary widely, they share a need for simple plants, capable of operation with minimal maintenance and attendance, yet having over-all reliability.

The desalination of water is an excellent means to enable an area to use water sources that in the past were too saline for human consumption. However, a substantial capital investment is required, and the operation of the system will continue to require funds for energy, chemicals, labour, repairs and replacements. The potential initial and continuing costs must be included in water resources planning exercises, because they can affect consumption and the local economy.

Rough costs (including capital recovery changes) of \$0.25 to \$0.50/m^3 for brackish water and \$1.30 to 3.30/m^3 for sea-water will generally bracket the unit costs of desalination in the United States. Costs per unit for small units in developing countries could be three times as much.

Despite considerable efforts to reduce costs, desalinated water is still expensive. The process is inherently energy-intensive and improvements in equipment and efficiency have been offset by rapid increases in energy costs. Nevertheless, the availability of desalted water can be an economic boon to an area. The economic conditions to support a limited amount of desalination already exist in many water-short areas of developing countries.

2. Transport of water by sea-going tanker

Water is commonly transported from source to end-user by pipeline, or in a variety of discrete containers such as buckets and tanks. Another alternative method for the transport of water has been the use of tankers or barges to transport water from a place with a surplus of water to places with a shortage. Depending on the tanker or barge selected, up to about 250,000 m^3 (60 million gallons) can be hauled in a single trip.

Efficient water transport requires specialized port facilities at both the source and receiving ends which can deliver and/or store large quantities of water. This usually means modern deep-draft docking or mooring facilities, large pumping stations and storage tanks. This requires advance planning for contracts with suppliers and construction of facilities.

The possibility of transporting large quantities of water by tanker has recently become much more attractive for several reasons. With economies of scale resulting from the construction of very large crude carriers (VLCCs) and ultra large crude carriers (ULCCs) from the late 1960s to the early 1970s, the unit costs of transport by tanker have declined. Moreover, with the current glut in the oil market, more than half of the tanker fleet was laid up and transport costs were barely enough to cover costs of operation in 1986 and 1987. Shippers have been willing to consider transporting water as long as they were compensated for any additional costs involved.

The main buyers of transported water tend to be water-short areas which derive their income from such sources as petroleum exports and tourism. Obviously, many countries in the Middle East are along the main tanker routes. Vessels discharging at ports in the United States and the Caribbean area are in a good position to transport fresh water either within the Caribbean or from Caribbean or South American ports to the Persian Gulf on their ballast voyage.

Studies of large-scale backhaul of transport of water indicate costs of from \$1.45 to \$2.50/m^3 of fresh water, depending on distance and ship size. Large-scale fresh water shuttle service could deliver water for an estimated

$1.80 to $5.50/m^3 depending on distance, ship size and freight rate (Meyer, 1988).

The future of tanker transport of water is less a matter of technology, and more a matter of economics under actual market conditions for tankers. The current excess capacity of very large tankers cannot be expected to continue forever, as surplus vessels are being sold for scrap and as the world's need for oil, and thus oil tankers, increases. The removal of the extra vessels from the market may have a negative effect on the economics of this mode of water transport, or transport of water may develop into a satisfactory market for the tanker fleet.

3. Reuse of waste water

Waste water, or sewage, is a potential source of water for a number of non-potable applications such as cooling, sanitary flushing, irrigation and industrial processing.

When water is scarce and expensive, it can be cost-effective to provide treatment to waste water and reuse the water for some appropriate application. This reclaimed water can sometimes be used as a substitute for higher grade water, thus reducing the over-all demand for potable water in an area. However, the greater the percentage of waste materials (contaminants) that are removed from the waste water, the more difficult and expensive the treatment process becomes. If a community collects its waste water in a sewerage system, then it has an opportunity to treat and reuse it for some beneficial purpose. A primary problem in reusing waste water in developing countries, however, is the lack of a central waste-water collection system.

Although waste-water reuse is practiced in many areas of the world, it is often done for two distinct reasons. The first, which is common in highly industrialized countries, is to dispose of treated waste-water effluent without discharging it into an open water body and creating a pollution problem. In these cases the waste water is treated so as to remove a major portion of its dissolved and suspended materials before being reused. The most common reuse practices are for agricultural irrigation of fodder crops or ground-water recharge. The cost of the effluent used in these cases may be considerably higher than water that is locally available, but the costs are considered justified as a part of environmental protection. Recycling and reuse may be built into water resources plans, particularly where deterioration in water quality is a problem.

In the second type of waste-water reuse, the emphasis is on the use of the water rather than on protecting the environmental quality of receiving water bodies. This type of application usually occurs in areas where fresh water is in short supply and expensive to obtain. In this case the effluent is considered as a potential resource rather than an environmental problem.

In the case of real economic necessity, public health considerations in using reclaimed waste water for agricultural irrigation should be the prime consideration in its treatment before usage. It would be unwise at this time for developing countries to reuse waste water for domestic consumption.

As water becomes more scarce and developing countries become more concerned about water conservation, the reuse of treated waste water in agriculture and industry is likely to become considerably more important.

The future prospects for the widespread application of water reuse depend on a number of important factors. The first is the installation and use of waste-water collection systems (sewers and pump stations) to provide a source of waste water. The second will be further research into the long-term public health implications of various levels of water reuse. The final factors will be the cultural acceptance of the reuse of water for various beneficial uses and the desire to treat waste-water discharges so as to minimize their effect on the environment and on public health.

Many of the countries in the Middle East have embarked on reuse projects in conjunction with the construction and operation of centralized waste-water treatment facilities in their major cities. In most cases the waste water is, or will be, given treatment in standard biological secondary plants and its use generally restricted to irrigation of landscape, fodder crops and forests. This will reduce the amount of potable grade water required for such purposes.

Estimating costs of treatment for reuse is difficult in general because they vary according to a multitude of factors, such as: the degree of treatment desired; costs and availability of land, labour, energy and equipment; and the proximity of the reuse application. Generally, the estimated costs for various waste-water treatment processes in the United States (1983 prices) ranged from \$0.10 to \$1.00/m^3. Costs of ground-water recharge depend on the degree of pretreatment and the recharge method. For surface spreading and recharge by rapid infiltration, the pretreatment is usually a primary or secondary process.

Industrial reuse can include cooling water, boiler feed and process water. The lowest treatment requirements and greatest volume needs are usually for cooling water, and this is the industrial reuse application with the highest potential. Costs of reclaimed waste water can be kept low by using more land-intensive facultative ponds rather than conventional activated sludge systems. The feasibility of any water reuse scheme ultimately depends on the costs of alternative supplies, protection of the public health and user acceptance.

4. Enhancing water supplies through weather modification

One way to enhance the water supplies or sources that are already available in an area is to increase the rainfall through weather modification by cloud seeding. The prime ingredients necessary are clouds of the appropriate type and in a suitable location to produce beneficial rainfall. Once suitable clouds are naturally available, they are seeded with materials, such as dry ice or silver iodide, in an attempt to promote rainfall.

Cloud seeding is not an exact science and it appears to work better in some places than in others. Despite the fact that today's techniques aimed at precipitation enhancement rest upon sound physical principles, the progress made in this field has been fairly slow. Carefully controlled application of such principles is made difficult by the overwhelming complexity and variability of atmospheric phenomena.

Over the last 35 years, research in weather modification techniques has indicated that artificial precipitation may be an economically beneficial method of producing rain in certain areas. Efforts have been made to modify the weather in such countries as Australia, India, Israel, Spain and the United States. The most successful experiments so far seem to have been in Israel, where it is postulated that the right kinds of clouds are common.

Because of the high risks involved, many communities depending on rain would probably not want to invest in weather modification. During a dry or drought period, there are generally not enough clouds suitable for seeding. The technology works better during wetter periods and is most useful for supplementing light rainfalls or rainy conditions rather than creating rain where there was none. This additional rainfall is then used to add water to reservoirs, ground-water aquifers or for additional crop irrigation (by rain). Thus, the infrastructure has to be available to catch the water or otherwise use it efficiently. This means that careful regional planning and investment are probably needed before weather modification is attempted and a backup plan formulated, in case it fails.

Agriculture and water supply systems are generally the primary candidates for potential benefit. The yield and value of most crops will increase with increased precipitation. Water also has a value when collected and used in a supply system. Among the industries that may be affected negatively by precipitation enhancement are tourism, construction and other outdoor work activities, such as lumbering. Some agricultural activities and crops can be hindered by inopportune or excessive rain. In addition, consideration must be given to possible negative effects, real or imagined, on targeted or adjacent lands.

Koenig (1985) from the World Meteorological Organization has recently estimated the potential costs for a cloud seeding operation. This included setting up and operating a cloud seeding operation in a fashion that would enable the project to reasonably verify, after five or more years, the project's effectiveness. By purchasing some of the equipment used and keeping the number of planes to only two, he estimated a total capital cost of about $1.3 million, excluding financing costs. Operation and maintenance could add another $1.3 million per year. Although these are crude estimates, they give an idea of the potential costs involved. Projects have been financed and operated for considerably less monies but the data collected was generally insufficient to tell if they really worked.

5. Conclusions

With the exception of weather modification, the other non-conventional methods of increasing water supply discussed above are basically intended to assist countries with water resource problems in specific small geographical areas. It may be appropriate to plan for the use of non-conventional resurces in local areas predicted to have a serious water shortage in the near future.

Desalination, water reuse and transport of water are usually designed and built to supply water to a specific city, town or other limited area, although by repeating the installations or extending pipelines, the water could be distributed over a relatively large region.

The common characteristics of non-conventional water resources are that they are more complex in development and operation than conventional sources, and the cost of the water produced is generally high. Where it is possible to develop conventional water resources, that should almost always be the preferred solution. However, if this is not possible, planners should give consideration to the non-conventional water resource techniques discussed. In several water-short areas of the world, such solutions have in many cases provided the key to economic development.

For developing countries with shortages of fresh water, use of non-conventional sources could expand their supply of fresh water to meet long-term demand, provided that the locality can afford the costs. The capital and operating costs associated with desalination and tanker transport, for example, are high, and the high operating costs continue as long as water is produced.

On the other hand, the use of a non-conventional water resource may offer the possibility of improving the standard of living. A small reverse osmosis desalination plant, for example, could provide a reliable source of fresh water for areas that in the past have relied on the uncertainties of nature for water. It can also reduce the distance over which water is transported from the source to the user, as desalination can make closer, previously unpalatable, sources usable. Since this tranportation is often by truck, barge, animal cart and/or carried manually, desalination can often produce savings in fuel, money or time. Current experiments using desalination units coupled with solar or wind energy systems may eventually provide a viable technology for remote communities.

Barging water or reusing waste water might provide lower-quality water for industrial or agricultural uses, making limited supplies of higher quality water available for domestic use.

While the best course of action for any area is to develop its low-cost conventional water resources first, the prospects for wider application of non-conventional water resource techniques are promising, mainly as the result of two factors. The first is that the reliability, and possibly the cost, of many of the techniques should improve with further investigation and use. The second factor is that the continued increase in population and per capita water use will stress existing supplies and increase the cost of developing sources and supplies by conventional means. This will provide opportunities for the economic application of non-conventional water resource techniques.

The key to cost-effective long-term development of water resources in an area is planning. In any country, no matter what the level of development, the best water resources plan is one that is more than just economically reasonable in the paper study stage. It is one that results in a system that works when it is implemented and continues to work and produce the desired service at the expected quality, quantity, and cost for the planned life of the project.

A good review of non-conventional water resource techniques is contained in other publications produced by the United Nations. These are The Use of Non-Conventional Water Resources in Developing Countries (United Nations, 1985), which is available in English and Arabic (Sales No. E.84.II.A.14) and the Proceedings of the United Nations Interregional Seminar on the Use of Non-conventional Water Resources in Developing Countries (United Nations, 1987, Sales No. E.87.II.A.20). The seminar was held in Curaçao, the Netherlands Antilles in April 1985 and the Proceedings contain about 50 papers.

VI. APPLICATION OF INSTITUTIONAL AND LEGAL MEASURES

The process of attaining a higher water use efficiency is rather complex and difficult. Countries with an abundance of water often fail to execute any plans toward higher water use efficiencies, with the result that water is wasted and over-irrigation threatens many productive areas. On the other hand, countries with acute water shortages, or which will experience them in the near future, often do not have either the legal or the administrative facilities to achieve higher water use efficiencies.

A. Water legislation

The preparation and promulgation of a water law or its modification as a basis for efficient water use can take several years. Countries in great need of efficient water management and utilization should therefore commence planning for efficient use, especially in areas of water shortages, in parallel with legislation.

To encourage efficiency in water use, water resource planners should recognize the alternative technological options and incorporate them in the planning process, but in parallel an entire process of legislative and administrative measures should be set in motion. The major steps in this complex process are as follows:

(1) Enactment of water laws and regulations;

(2) Definition of legal, financial and professional responsibilities in the water sector;

(3) Establishment of organizational bodies to undertake these responsibilities;

(4) Introduction of a comprehensive measurement system on which to base water use standards and norms and allow their enforcement;

(5) Allocation of water to regions, water authorities or individual user entities;

(6) Introduction of a progressive water tariff structure;

(7) Introduction of a public awareness campaign.

The following discussion briefly covers the main legal aspects of this process.

1. The need for water laws

Factors such as the enormous growth of population, with a rising standard of living in many countries, the need for increased food production, the development of high technology industries, the increasing need for water for recreation and other requirements have resulted in a rapid expansion in exploitation of water resources, at times approaching their maximum availability, and often creating contradictory and competing demands from present and potential users. Uncontrolled exploitation, return flows from irrigated lands and disposal of contaminated waste waters have resulted in deterioration, sometimes irreversible, of limited water resources.

A water law is essential to secure proper utilization and distribution, to establish, maintain and regulate water users' rights under prevailing socio-economic and environmental conditions, and to preserve water resources from depletion and deterioration. Engineers should be consulted and should contribute to the formulation of water-related laws and regulations by helping lawmakers solve problems of a technological nature with respect to the prevailing conditions as well as expected changes and developments.

In many parts of the world, customary laws and riparian water rights are still dominant. Yet it is important to have water laws which take into consideration earlier and recent developments in water abstraction and utilization as well as any foreseeable further development, so as to allow for changes and innovations in water utilization. In many countries, water laws are limited; many do not cover the full range of requirements and are not flexible enough to suit changing conditions.

Large scale projects, in particular, require a water law to provide an adequate legal and administrative framework for transfering water from one area to another with possible alterations in water allocations, for intensive exploitation of ground water and proper control of exploitation rights, for safeguarding resources from over-exploitation and contamination, and for the control of waste-water disposal.

The introduction of a water law can follow one of two different approaches. One would be to prepare special laws for regions for which water exploitation has become a critical issue. The other would be to draw up a fundamental water law for the entire country, in which provisions would be made to enable the authorities to execute the law by regions, in accordance with development needs and local hydrological, geological, climatological and other conditions. The second solution, i.e., a fundamental water law, is obviously preferable, but under critical circumstances the first approach should be adopted, as it is easier and faster to apply.

A fundamental water law should empower the authorities to promulgate subsidiary legislation (regulations, orders, bylaws, rules) that would facilitate the application of the law to any region in the manner most suitable to its specific conditions. Since the compilation of a comprehensive law and its enactment can take several years, however, it may be necessary, under certain circumstances, for the authorities to consider the promulgation of temporary emergency regulations to give legal sanction to the measures required for a specific region.

2. Principles of water legislation

Any water law to be drafted or amended, should be based on a number of principles, which are in particular relevant to areas deficient in water resources, but also applicable, with certain modifications, to other areas.

(a) Control of water resources

Adequate powers must be vested in the authorities to control the utilization of all water resources in the country or in a specific area, to prevent their depletion or pollution, and to enable their development and exploitation for the benefit of the area as a whole.

(b) Existing and new water rights

Existing rights to agricultural water should in general not be changed, provided they are beneficially utilized. However, such rights should be limited to the actual quantities needed by the holders of such rights for efficient and economic use on the land directly irrigated by them. Any increase by a present consumer, over and above the amount withdrawn in the past, should be considered as a new allocation, which requires approval by the authorities. The law should eventually be enacted in such a way that the water right is limited to allocated quantities which would be determined from time to time by the authorities.

(c) Severence of water rights from a source

In the over-all interest of the area, the right of any water consumer should not be linked to a specific source or to a definite category of water. The law should only protect the consumer's rights to a given quantity of water over a certain time span, and this only subject to its efficient, non-wasteful use. The law should not permit any landowner or farmer to hinder the implementation of a development programme on the strength of specific rights to a definite source. The water supply authority should be empowered to supply the consumer with water from whatever source it deems fit, including reallocation of a water source.

(d) Registration of water rights

A clear and detailed procedure must be introduced for the accurate registration of water rights in the authority's water register. Such registration must be based on a provision in the law which would vest the authority with the exclusive powers to determine the water rights of claimants in the region, in keeping with existing customs and past use. The decisions of the authority should, however, be subject to control by the courts. No appeal of water rights should be allowed after their registration, unless exceptional circumstances, such as error or arbitrariness, can be demonstrated.

(e) Water rights linked to land holding and use

Water rights should generally be related to identified water uses and land holdings, and should be enjoyed by their beneficiary only as long as he makes efficient use of them. Allocations should be flexible to allow adjustment to changing demands.

(f) Licensing of water exploitation

A system of licensing the withdrawal or use of water, whether from sources already exploited or with respect to new water, should be introduced at least in those regions where a shortage of water exists or is envisaged, so that all legally recognized water rights will be covered by a license. Licenses should be subject to conditions such as efficient use, etc. Though licenses should be of permanent nature, authorities should have the right to modify them.

(g) Regulation of water consumption

The consumption of water for all purposes, including consumption by agriculture, industry, domestic use (not by individuals, but by local authorities) should be regulated by licenses.

(h) Periodic re-examination of schemes

The authority should examine periodically local and regional development schemes, in order to ascertain their adequacy and to verify whether the local authorities conduct the licensing and the allocation of water in compliance with adopted development plans.

(i) Water authorities

A chapter related to water administraton and water authorities should be included in the law, so that these may derive their powers from the law rather than from administrative decisions or directives. It is recommended that a national water authority be set up at ministerial level, to decide on all matters of national policy connected with water development plans, to approve priorities in the execution of large-scale water development projects, and to settle any legal problems arising in connection with major water development schemes.

(j) Miscellaneous provisions

Further provisions to be embodied in the water law, should include powers vested in the authorities to:

(i) Enforce the conservation and control of water resources and the prevention of their waste, deterioration or pollution;

(ii) Control the cost of water through powers which would permit the establishment of water tariffs for different categories and volumes of consumption;

(iii) Impose water tariffs and other taxes (i.e., on water-use permits) aimed at obtaining revenue for financing water development schemes;

(iv) Penalize persons for unauthorized use of water;

(v) Establish principles for assessing compensation to a consumer disconnected from a source of supply, or for other damages resulting from implementation of a water development scheme, including the settlement of any dispute arising therefrom;

(vi) Settle water disputes between individuals or between an individual and the authorities, through the establishment of water courts or joint committees;

(vii) Define engineering and economic principles for the design of water supply, irrigation, hydropower generation, drainage and sewerage schemes;

(viii) Issue directives concerning the introduction of water metering.

The implementation of a water law or the modification of an existing law is highly complex, and may take a long time. However it is not considered advisable to embark on the execution of any long-term project of basic importance before the principles specified above have been secured by a law capable of practical application. Therefore, in order to provide a legal basis for the implementation of development projects in the interim period until the law is enacted or modified, temporary regulations should be enacted to cover the most important aspects of the matter. Such regulations should be annulled immediately after enactment of the law.

B. Economic incentives

1. Preconditions for the use of water pricing as a tool of management

There are a number of preconditions which must be met for water pricing to be a practical tool for water resource management. These preconditions imply a fairly sophisticated general level of management. There must be a good level of competence in costing, budgeting and bookkeeping procedures in order to make realistic cost estimates and check performance. There must be the technical and administrative ability to operate a pricing system efficiently. This requires:

(a) Reasonably accurate metering of the water supply to each consumer who is to be billed separately for his water use. This means that initial installation of meters must be backed up by an adequate system of maintenance and repair (including recalibration of meters at appropriate intervals).

(b) Orderly reading of meters at clearly defined intervals (e.g., monthly or bi-monthly).

(c) Preparation of water accounts and delivery of bills to consumers with the least possible delay after meter reading.

(d) Payment of accounts within a reasonable time and genuine penalties for late payment (in the form of fines or interest on the outstanding debt) and a final sanction of cutting off water supply.

In the absence of the above technical and administrative infrastructure, the attempt to charge for water by volume of consumption will almost certainly prove to be a waste of scarce and valuable resources. Under such circumstances, simpler solutions should be sought for levying some or all of the costs of water supply.

2. Cost calculations

The objective of water cost calculations should be to calculate the real cost of supplying water. In the case of a private firm, this may seem obvious, but widespread experience shows that, in the case of many publicly-financed projects, the process of subsidizing water prices begins with the understatement of costs.

The actual calculation of costs is not a uniquely defined process even when the above principle is accepted. The following is a very brief review of some of the problems, and the factors which have to be taken into consideration.

(a) The discount rate: The capital costs charged to any investment are very sensitive to the rate of interest used in the calculation. There is a very considerable body of economic literature on this subject and it is important to use a realistic interest rate. The calculations may have to be revised if the interest rate changes dramatically.

(b) Project life: The physical life of water resource projects tends to be very long and there may be justification for basing annual capital costs on a shorter "economic life". Clearly the shorter the life of a project the higher the annual capital costs.

(c) Investments in social overhead or infrastructure: The definition of some investments as investment in infrastructure is often used as an argument for charging these investments to the national budget rather than to a particular project. Although this is a highly controversial subject, it would seem that any investment which imposes a continuing charge on the economy should be charged to the specific purpose it serves and not to some general item of social overhead.

(d) Inflation: Under inflationary conditions, nominal capital costs soon lag far behind real costs so that it is of the greatest importance to update costs (by some method of indexing) if they are not to be eroded over a fairly short period.

3. Agricultural water prices

In many countries agriculture is not regarded as a purely economic sector. The Government may have a wide variety of reasons for deciding to maintain an agricultural sector of a size which is not justified in terms of narrow benefit-cost analysis. It may, for instance, wish to achieve self-sufficiency, to bring new regions under cultivation, to raise rural incomes, or to slow down rapid rates of urbanization. Whatever the reason, the maintenance of an agricultural sector which does not completely pay its way on the return from the crops it grows means subsidization of farmers. Subsidized prices for irrigation water are an administratively convenient and popular way of providing subsidies to the agriculture sector. There are, however, negative aspects to subsidization, particularly of a scarce factor of production, which cannot be ignored.

Beneficiaries of the water price subsidy, acting rationally, will plan their water use according to the price they pay, without regard to the real cost to the national economy. This will tend to generate excess demand and pressure for the construction of more and bigger irrigation projects, beyond what is economically justified or what is needed to fulfil non-economic policy objectives. The response to this excess demand may take two forms. The first is the attempt to control water use by administrative means, such as licensing of consumption and the use of fines and other penalties for excess use. This in itself places a burden on limited resources, such as trained administrative personnel, and carries the danger of bureaucratic delays and confusion. The second response is to expand investment in irrigation projects beyond what is justified, thus diverting scarce capital resources from higher priority uses.

There are ways of combining water subsidies with pricing systems which maintain some level of economic incentive for efficient water use, thus mitigating the severity of the problems described above. There are systems which operate on some normative allocation of water for specified crops and regions. Only the allocated quantity of water is supplied at the subsidized price, with a sharp rise in price for any additional water use. The logic behind such a system is that any farmer will receive a given, planned subsidy for water provided he uses it efficiently (in terms of the cost to the national economy, not the price he pays), while beyond that he will be charged some approximation of the real economic cost of the water.

Another element which may find expression in the pricing system, whether or not total payments cover total costs, is a higher charge for water supplied at peak periods. Depending on the sophistication of the system, peak demand may be defined seasonally, monthly or even for peak hours during the day. Meeting peak supply may impose heavy capital costs on the system where projects are constructed to meet a very uneven temporal distribution of demand, e.g., summer irrigation of crops, or heavy energy costs where a given project is overextended to meet peak demand. The alternative measure would be to charge a lower rate to consumers who irrigate during off-peak periods, such as at night or during the off season.

Another pricing measure which encourages conservation is to charge a lower rate for low quality water, such as partially-treated waste water for irrigating non-edible crops, such as fibre crops or ornamental crops, watering lawns and fighting fires. This frees high quality water for domestic consumption, which can be charged for at a higher rate.

C. Water Quality Management Programme

Problems related to the pollution of water supplied for human, industrial and agricultural use always stem from processes that can be traced to some human interference in the natural hydrological cycle. There are, however, notable differences between industrialized and developing countries in the attention these processes and their effects receive. As an example, in industrialized countries, the necessary investments to restore the purity of a polluted river--huge as they may be--will ultimately be made because of necessity and pressure of public opinion. In developing countries, the solution to river pollution problems is often postponed because public awareness and pressure is less effective and the scarce capital available is needed for seemingly more pressing tasks. With respect to ground-water pollution, the attitude is liable to be even more negligent, because the pace of deterioration of the ground-water quality is often slow, the cause-effect relationship more difficult to prove, and legal instruments that can compel polluters to introduce improvements may be less effective than in the more clear-cut cases of surface water.

The innumerable case histories of water resources pollution should, indeed, be sufficient to create an attitude of foresight wherever population is increasing, urban and rural centres are growing, industries are being created and intensive irrigated agriculture is expanding. Despite the valid argument that, on the basis of existing experience, it would be more economic to prevent pollution than to resort to remedial measures once the source has been polluted, realities show that pollution that could have been prevented is permitted to occur, and staving-off action is only taken belatedly.

1. Planning for prevention of pollution

Planning the prevention of pollution should be an integral element in the over-all water resources development plan. The reuse of waste waters for various purposes renders the economic aspects of the preventive measures more attractive. Early planning of reuse of effluents has a double effect on the over-all availability of water: on the one hand, it protects the natural source from pollution and thus assures its greatest possible longevity, and on the other hand, it increases the over-all availability of water for use, mainly in irrigation and industry.

The institutional requirements necessary to manage the water resources quality of a nation must be carefully planned and developed. An incentive system must be planned, institutions strengthened or created and a water quality management plan formulated. Good planning and institution-building will result in the efficient use of human and financial resources to achieve desired water quality objectives.

In conjunction with the over-all water master plan, planning for water quality management begins with the identification of desired water uses in light of social, political and economic demands. Having determined the desired uses of a water body, the commensurate water quality objectives are then defined. The water body must be tested to see whether its quality meets the desired objectives. Actual water quality would be determined through a programme of sample collection and testing and data analysis. When considering new actions, such as the siting of a new industrial facility, the actual water quality resulting from the change would be predicted through a mathematical model or other analytical means.

When existing conditions do not meet desired objectives, or when analysis of proposed actions indicates resultant violations, a need for intervention is established. A water quality management plan is a rational and orderly procedure for identifying and evaluating alternative control plans and arriving at a preferred alternative. A water quality management plan comprises several components: inventory of pollution sources; determination of cause/effect relationships; identification and assessment of alternative control plans; and ranking of alternatives.

Requirements for sampling, data collection and use of mathematical models should be integrated into the over-all water resources data bank and the master plan for water resources development.

2. Policy instruments

Where deficiencies in water quality are identified, improvements must be made to the legal basis for pollution control activities and to the institutions responsible for those activities. A comprehensive water quality management programme might include the following types of policy instruments:

(a) Direct charges on effluents as an incentive to polluting entities to reduce waste loads;

(b) Subsidies to promote pollution control, using tax rebates or payments to offset costs of water treatment;

(c) Government standards on effluents from production processes, limiting discharge levels of certain substances into water courses;

(d) Government licenses under which permits would only be issued to entities using "clean" processes;

(e) Requirements of environmental impact statements from potential investors in new projects.

More details on such pollution control programmes can be found in Fano, Brewster and Thompson (1986).

To accompany the introduction of such a programme, education of environmental specialists will be necessary for most developing countries to fulfil the functions required. Educating the public and the polluting entities will greatly enhance the acceptance of a comprehensive water quality management programme and will contribute to its success. The value of saving our water resources from contamination is greater than the cost of developing new sources, because of the far-reaching environmental side effects.

VII. CONCLUSIONS AND RECOMMENDATIONS

Water resources planning in developing countries is generally a formidable challenge because of the lack of good, reliable data and experienced planners. Anyone who attempts a comprehensive water plan in a developing country must have both a thorough knowledge of the engineering and economic context and an intimate insight into the possible social, political and cultural factors which could influence the choice of specific projects.

While non-engineering and non-economic considerations may ultimately determine the fate of a proposed water project, the planner should none the less be able to offer the decision maker the best advice based on data available of the advantages and disadvantages of the proposed project. Of great assistance to both planner and decision maker would be to build the following into the early stages of a plan: a comprehensive assessment of existing water supply and demand, and projections into the future; and an information system and data bank. While these are being developed, computer models can play an important role in planning under conditions of unreliable and scarce data. The planning process itself sets in motion important activities crucial to water resources development, such as: data collection; hydrological investigations; projections and economic studies; and building up a cadre of professional engineers and planners.

It is particularly important in developing countries that the planning process be flexible, so that it can adapt to changing conditions. It is desirable to have a centralized planning group responsible for defining overall goals and developing policy recommendations, while implementation agencies retain responsibility for carrying out projects in their specific areas of expertise.

A water resources master plan is needed to define water requirements for all types of uses and establish an order of priorities for optimal allocation of water resources and funds within general guidelines and policies. The master plan should reflect prevailing constraints on physical, financial and human resources and the need to allocate critically sparse resources to projects wich promise to be cost-effective and which correspond to socio-political objectives.

More efficient use of existing water resources is likely to become the major thrust of planning in the future. More efficient use implies the use of water-saving technologies in agriculture, industry and domestic appliances, as well as leak detection and repair. It may also involve the use of non-conventional water resources, including reused waste water, and the conjunctive use of surface and ground water, including artificial recharge of ground water. It also implies a strengthening of government policy related to pollution control and prevention of waste, in order to enhance existing supplies. The imposition of water tariffs at realistic levels reflecting the real costs of delivering clean water should have the effect of dampening demand and reducing waste. Differential tariffs may be introduced to encourage large consumers to use lower-quality water in low-priority uses.

Government policies implemented in the present can have a significant effect on the availability of water in the future. In the first place, training programmes and facilities are crucial to long-term sustainability of water resources programmes.

Moreover, a government's economic policies will to a great extent determine how many projects get implemented and how many people get served. In the 1980s it has become beyond the means of almost all governments to provide irrigation and water supply projects to meet the needs of their people at public expense. Therefore, in many countries government is relinquishing its centralized control over water resources systems in favour of community and private sector management or ownership. Communities are taking responsibility for much of the burden of recurrent expenditures, while the private sector is in many cases filling the gap in meeting local demand for wells, pumps and repairs.

It is also important for a government to ensure that realistic and enforceable water legislation guides the development of the sector. Legislation should cover proper utilization and distribution of waters, the regulation and maintenance of water users' rights and the preservation of water from depletion and deterioration.

Finally, water pollution control should be an integral element of government policies and plans. Comprehensive water quality management programmes, including effluent changes, requirements for waste-water treatment and government standards on effluents, will be necessary to preserve our global water resources for future generations.

Annex I

METHODOLOGY FOR DEMAND ASSESSMENT

This section contains a very brief summary of a subject dealt with in considerable detail in the United Nations publication, The Demand for Water: Procedures and Methodologies for Projecting Water Demands in the Context of Regional and National Planning (1976).

A. Estimation of withdrawal uses

The most reasonable sequence of steps for the water resource forecaster to take is the following:

(1) Establish the regions into which the country is divided. Allocate all water-related elements of the economic data base to these regions, maintaining consistency with national totals. The regions should be selected so that water supply can be compared with the measure of "demand" (if expressed as a function of price) or "requirement" (if expressed as a function of production with stipulated unit coefficients). Since supplies are easiest to measure if the region is defined by hydrology, whereas demands or requirements are easiest to measure if the region conforms to economic and demographic census boundaries, some adjustments of data and boundaries may be required. Ideally, census or data units should be small enough to allow coding the aggregation into political or hydrologic units, as desired.

(2) Adopt the population projections (with estimates using two or three different growth rates) as made by the responsible agency for demographic studies or other central agency or agencies responsible for multisectoral investment decisions. Derive projections of labour force and urban and rural populations. Distribute urban and rural population among regions;

(3) From projected labour force and estimated productivity per worker, estimate gross national (or domestic) product. Use estimated labour force and GNP as a control over estimated outputs of individual producing sectors either intuitively or by mathematical relationships;

(4) Project outputs of agriculture, mining, electric power and major manufacturing sectors for the nation as a whole, assuming reasonable consistency with populations, labour force and GNP projections. Determine the regional distribution of activities and the mix of products within each major industrial class to the extent that the mix affects water use. For agriculture, this means the cropping patterns under irrigation. Industrial mixes are more complex. For example, in pulp and paper milling or beet sugar refining, both the product mix and the process applied should be specified; for electric power, the type of fuel used should be specified;

(5) Ascertain the current rates of unit water use and project them into the future. Water-use coefficients should be computed on a gross as well as net or consumption basis. Gross water use is itself an ambiguous concept since it may refer to "flow-through" or "withdrawals", the two diverging if there is in-plant recirculation. Net use - i.e., consumption or loss of fresh

water - is a reasonably straight-forward idea but frequently less well known than flow-through or withdrawals. Estimates of water use as measured by withdrawals must be accompanied by explicit recognition, of in-plant rates of recirculation;

(6) Municipal water use is itself a mix of uses: household, public, commercial and industrial. Where possible, these uses should be projected separately and then aggregated, adjusting the total to avoid double counting of manufacturing water use. In the absence of information about the separate classes of municipal water users, but with some knowledge of how the mix will change, changes in prospective per capita water use may be made intuitively and combined with the projection of urban population to yield aggregate municipal use. Water usage should be projected on a gross and net basis, although the latter may be no more than an educated guess;

(7) Water users - cities, irrigation projects and industries - that are located on tidewater but have their sources up-stream should be segregated, since all of their withdrawal is lost from the basin's fresh-water supply as a result of discharge into tidewater. There are, however, exceptions such as the use by industry or agriculture of treated effluent;

(8) Aggregate water use for each of the foregoing activities is projected by combining the estimates of changes in per unit water use with the estimated changes in output. Some technological changes will take place with a relatively high degree of certainty - e.g., gradual adoption of today's best practices - whereas others are only a gleam in a science fiction writer's eye. The water resource planner can either project several alternatives based on different paths of technological change or can intuitively select a single technological path but make explicit the nature of his choice. Withdrawals are more sensitive to probable changes in technology than are losses. Perhaps the changes of greatest consequence over the next few decades will be in the amount and character of waste discharged per unit of product.

B. On-site uses

The importance of on-site uses relative to withdrawal and in-stream uses will vary widely from region to region and country to country. On-site uses of water consist of those activities that reduce run-off rather than appear as an exhaustion of or charge against the water that is measured by run-off. Two on-site uses can be distinguished: land-use practices and structures designed to conserve soil and ground moisture; and swamp and wetland habitat.

If the land-use practices and structures that now exist have remained unchanged for the period of stream-flow records, these records implicitly account for the evapotranspiration attributable to these practices and structures. But if additional land area is treated by reseeding, contour ploughing and construction of water-spreading and infiltration devices (check dams and farm stock-goods), the amount of precipitation that appears as stream run-off is reduced. Rather than consider these practices as contributing to a change in "supply" it is suggested that they be treated as a "demand". However, whereas withdrawal uses are aggregated to yield a measure of gross or net water use, in the case of on-site uses the amount that figures into the measure of demand is the increase in use that is expected to occur beyond the base period for which streamflow data are recorded. The same reasoning applies to a projected change in the area of swamps and wetlands. Additional evapotranspiration per unit increase in the area covered by soil, and moisture conservation practices or swamp and wetland habitat, will depend upon local conditions and, in any event, will likely be difficult to measure.

The projection of increased evapotranspiration from on-site uses is a two-step process: (i) estimation of the additional land that is to be subjected to treatment; and (ii) multiplication by the increase in evapotranspiration (and irrecoverable soil moisture) per unit of land attributable to the programme. A similar process is followed for any increase in swamps and wetlands.

Soil and moisture conservation programmes are designed mainly to maintain or increase agricultural productivity, reduce flood threats and reduce sediment loads and their accompanying effects on stream run-off. Practices that reduce erosion of agricultural land also reduce the contribution of fertilizers and pesticides to steam pollution. Projections of the amounts of land to be given soil and moisture conservation treatment or converted into swamps and wetlands will depend upon the ultimate objectives of governmental agencies responsible for such programmes and the annual rate at which these objectives are being reached. Many countries, of course, are engaged in neither type of land-use programme.

C. In-stream uses

In-stream uses of water consist of hydroelectric power, navigation, recreation, waste disposal, fish and wildlife habitat and flows to maintain salt balance in estuarine habitat. Certain of these uses compete with each other; all of them compete with withdrawal uses. Depending upon the distribution of economic activity along a river, and according to the seasons, certain flow uses may be complementary with each other and with withdrawal uses. The most troublesome pre-emption of water in industrialized areas or areas of dense population is waste disposal. In arid regions, the main pre-emptive use is likely to be irrigation.

Projecting flow requirements for most flow uses is made difficult because of the possibility of various technical arrangements and because critical elements of information are still lacking. An example of a technical arrangement is the possibility of maintaining navigation by converting a live stream into a series of slack-water lakes, the flow requirements for the latter being a fraction of that for the former. An example of a lack of critical information is the required flow of fresh water into estuaries, bays and other coastal waters that serve as habitat or nurseries for commercial and sport fisheries. While the effects of pollution on estuarine waters are widely known, the effects of up-stream changes in river regimen are not, nor are the effects of reduced flows if accompanied by steps to regularize them and also reduce waste discharges. Also not fully known are the effects of increased regulation on the ability of and need for a river to scour its bed, on the location and number of sand-bars important for fish productivity and on deltaic formation.

For coastal regions in which fisheries are important - shell and fin - significant economic effects may be entailed by up-stream uses. In many developing countries, artificial lagoons, in which salinity can be regulated, are being used to maintain fishery production. Where such methods are commercially feasible on a large enough scale, dependence on streamflow is of course drastically reduced. The water resource planner, in collaboration with fishery experts, can probably estimate a minimum safe flow that is consistent with expected productivity.

D. Aggregation of the demands

The underlying assumptions for projections of water resource requirements will depend upon the policies that guide land use and investment and development programmes in general. Projections of water use are needed for two purposes: to assure optimum use of a given water supply; and to guide investment in new water resource facilities.

In most countries, water use is a right protected by law. While changes in use will respond to changes in technology, population growth and movement, tastes and economic activity, the response tends to be slow. Moreover, government policies designed to subsidize particular activities, notably agriculture, may conceal the fact that, in the face of shortage, water is being uneconomically used. Identification of uneconomic uses of water is facilitated by projecting all expected uses of water and comparing the results with implied marginal costs of water. In this way, the decision to subsidize can be made explicit and on grounds that are persuasive, or the uses of water can be rearranged. The ultimate strategy for water resource development should be tested against the benefits and costs of various uses at the margin of each use, in order to be certain that projections do not imply improper or unplanned subsidies.

If usually accepted economic criteria are used, the allocation of water among alternative uses will proceed to the point where the marginal value of the product of water is the same proportion of the marginal cost of water in all uses. Such uses as domestic water supply, for which a marginal value cannot be established, except arbitrarily, may be handled in an intuitive fashion.

The precise way in which a benefit cost (marginal value versus marginal cost) analysis is used to supplement extrapolation techniques will be, of course, itself an intuitive judgement of those responsible for water resource planning and the budgeting of investments in general. Moreover, before a solution is adopted, the full range of possible adaptations to water shortage (or high marginal costs) must be examined. These include:

(1) Adopting water-economizing techniques. In some cases these are already known and commonly available. These were discussed in more detail in chapter V. On occasion, these techniques may be costless as, for example, if water is being over-used in irrigation. In other circumstances, savings of water may require other inputs. The water resource planner must, moreover, distinguish between changes in water resource use that reduce withdrawals and losses from those that reduce withdrawals but leave losses unchanged or even increased as, for example, may be the case with increased in-plant

recirculation of cooling water. He must also distinguish between a change that reduces the water intake of a particular user and has a corresponding effect on the basin aggregate from those that have little or no effect on the aggregate for a basin. An example is the elimination of leakage from a municipal system when the escaping water adds to ground-water reservoirs. An important class of technical changes are those that deal with the amounts and forms of industrial wastes and the techniques of waste treatment;

(2) Changing the regional distribution of population and production so that a better balance between supplies and demands is achieved. The degree to which government policy can affect the location of population and industry may be relatively weak, but in the absence of public discussion of alternatives, one can scarcely reach a conclusion. Debate over major trans-basin diversions should help throw light on whether it is easier to move people than water or vice versa;

(3) Modifying the national bill of goods to reduce the use of water-related (and water-polluting) goods and services;

(4) Transferring water from surplus to deficit regions;

(5) Augmenting water supplies by some other method.

Presumably, the end product of all possible adjustments will reflect the marginal intensities of consumer preferences and other national objectives as compared with the relative marginal costs of their satisfaction, whether the economy is based mainly on market transactions or is centrally planned.

Adding to the complexity of the analysis is the fact that certain forms of investment in water resource facilities provide two or more services, some of which may be complementary and some competitive. Joint costs must be allocated among participating uses and, in ascertaining the merits of expenditure, both average and marginal costs must be considered. (Average costs are especially important where marginal costs are below average costs.)

Annex II

CASE HISTORIES

A. The National Water System of Israel: A review of some planning issues

Planning of water resources development in Israel has evolved over a period of more than 40 years, and is still an on-going activity. Development of water resources has been part and parcel of the process of resettlement of the country, and a precondition for its success.

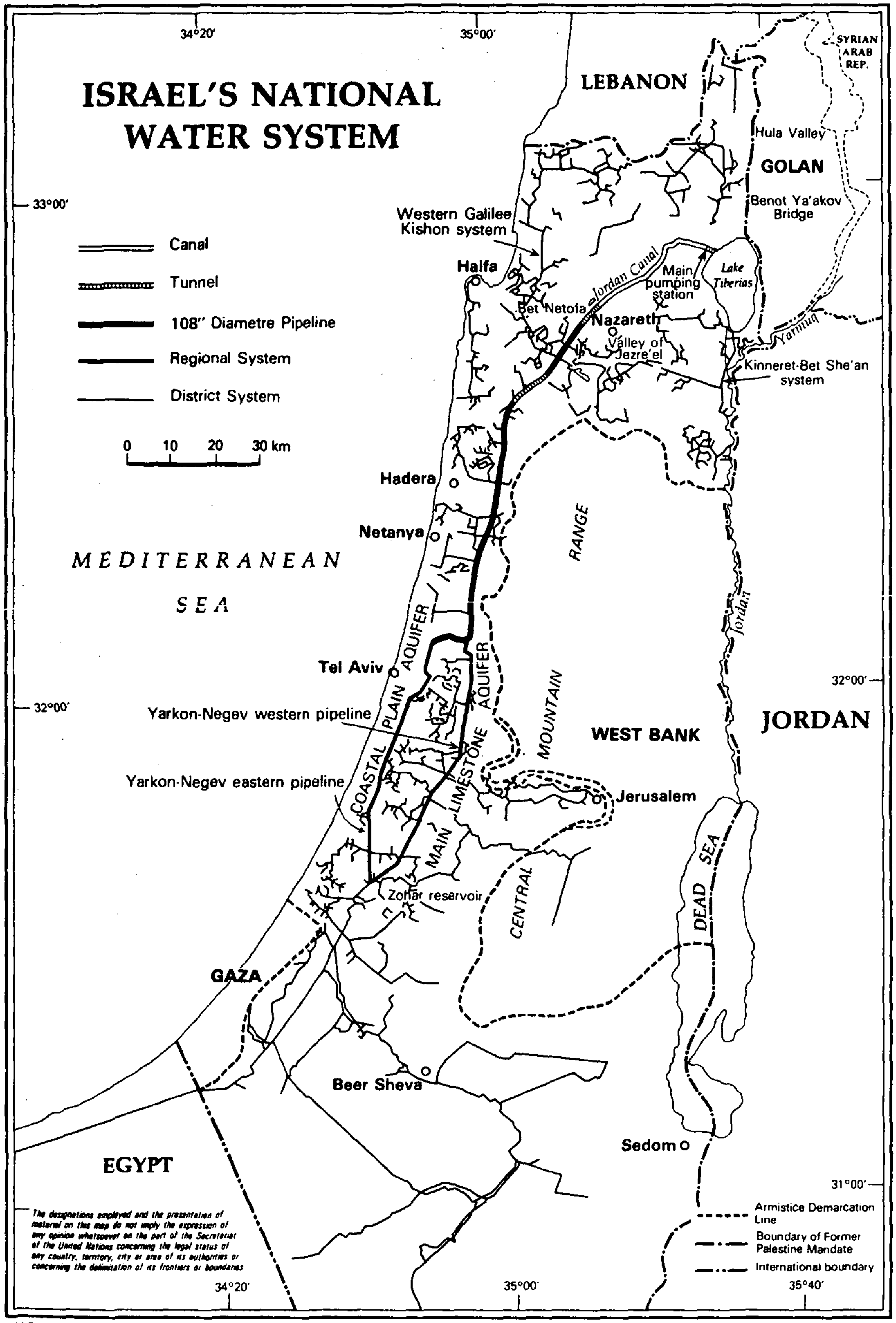
The main problem was one of dislocation of water and land resources. The country has abundant water in the north, the Upper Galilee, where the River Jordan starts its 90 km southward flow into the land-locked Dead Sea. On the other hand, the largest reserves of cultivable land lie some 130 km south-west of the Upper Galilee and on the other side of the Galilee-Judea-Samaria range of mountains, which run north-south between the Mediterranean Sea and the River Jordan (see Fig. 5).

Overcoming this geographical hurdle and conveying large amounts of water from the north to the south of Israel, and doing this in a minimum amount of time, was the main engineering challenge for the planners during the early years of Israel's independence. There were, however, other problems, as described below, some still challenging engineers, planners and politicians in Israel's water sector today.

1. Water balance of the Dead Sea

The Dead Sea is a terminal lake, forming the drainage basin for the entire River Jordan catchment, which contributes 70 per cent of the water flowing into the lake. The total catchment area of the Dead Sea is 42,000 km^2. Until the early 1950s, its water level and salt concentration were fluctuating around an equilibrium point which reflected the balance between evaporation from its surface and the inflow of fresh water. The historical steady state level of the Dead Sea was approximately -390 m (below sea level). Since the 1950s, increasing diversions of water from the Jordan and its tributaries have been causing a continuous decline in water levels and increase in salt concentration, with slight annual fluctuations caused by the variability of precipitation and temperatures. In 1987 the water level was -405 m.

Planners of the Israeli National Water System have recognized from the outset that, by substantially increasing the utilization of water from the River Jordan and its tributaries, the Dead Sea water level would fall several metres below its historic elevation, creating problems for the Dead Sea mineral industries which utilize large evaporation ponds situated at the southern end of the lake, and also seriously damaging beaches and spa resorts, as well as degrading the scenic beauty of the lake. Therefore, a proposal was made to divert River Jordan waters from Lake Kinneret to the south, and to convey sea water from the Mediterranean Sea to refill the Dead Sea. This plan also proposed to utilize the 400 m difference of elevation between the two seas to generate much-needed hydroelectric power, and utilize the sea water along the inter-seas conduit. However, the economic feasibility of this



MAP NO. 3490 UNITED NATIONS
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Figure 5. Israel's National Water System

scheme was questionable, as a result of lower oil prices, and the project has been shelved indefinitely. Meanwhile, Dead Sea levels continue to decline.

2. The National Water Balance

Israel's Water Carrier (see Fig. 5) extends over a distance of some 130 km and has lateral distribution branches extending further south as well as in all other directions along its route, leaving just a small portion of the country, the Arava in the South, outside its reach. Nearly 70 per cent of the water is currently supplied to the agricultural sector.

The numerous branches of the system, together with the National Carrier, enable nearly all of the country's water sources to be connected in one way or another. The notion of a national water balance has, under these conditions, a very practical meaning, since it is possible to develop additional water in one part of the country, for the benefit of agriculture or towns at the other end of the country. At first, the more readily exploitable sources of water were harnessed. At present, when virtually all of the natural water resources have been developed, water of lower quality and higher development costs are put into use, including purified sewage, desalinated brackish water and flash floods, in order to balance annual supply and demand. Considering that there always is an option of desalinating sea water, this trend can go on as long as there is an economic justification for developing more and more costly water. However, the cost of desalinated sea water is still far greater than that of any of the other types of water in use in the national system. Efforts to balance the increasing demand with the sum of natural and reclaimed water resources are therefore directed at maximizing the efficiency of water utilization, and developing every conceivable source of water other than sea-water desalination. The cost of desalinating a cubic metre of sea water can thus be viewed as the ultimate worth of agricultural production per cubic metre of irrigation water which, if ever attained, would economically justify adding this unlimited source to the national water balance. The same economic reasoning applies to further development of other so-called marginal sources of water anywhere in the national system.

For practical purposes, however, the national water balance does not at present include any desalinated sea water, because there is no likelihood that agricultural production would attain in the foreseeable future such a level of benefit per additional cubic metre of water that would balance the unit cost of desalinated sea water. In Israel the marginal productivity value of water in agriculture is currently estimated at $0.35/m^3, while the cost of sea-water desalination is estimated at $0.60/m^3. Consequently, to balance the projected growth in urban and industrial water demand, the agricultural sector, in addition to investing in increasing water utilization efficiency, would have to manage with gradually decreasing amounts of water, supplied at higher price and lower quality.

3. Water quality preservation

Severe dfficulties in preserving the quality of Israel's water resources have resulted from the rapid increase in exploitation of natural sources over the last 40 years, and additional problems are created by the growing utilization of treated effluents.

Prior to the construction of the National Water Carrier, the main source of water for the rapidly growing population and irrigated agriculture had been the limestone and sandstone aquifers situated relatively close to the demand centres. The National Carrier was built to increase the irrigated area, mainly in the South, as well as to alleviate the exploitation of ground water. Until massive quantities of Jordan River waters could be conveyed by the Carrier and recharged into the aquifers, however, a huge overdraft on the aquifers had already accumulated. Furthermore, the construction of conveyance systems and artificial recharge facilities needed to relieve the pumping stress on the aquifers did not progress as planned, mainly because of budgetary constraints, so that even today the rate at which the overdraft on the aquifers is being replenished by artificial recharge is too slow.

The consequences of this situation are mainly evident in the coastal sandstone aquifer, which extends along some 120 km of the country, beneath the most densely populated and cultivated region of Israel. Water levels in this aquifer have dropped so low that in several places the sea-water front has penetrated inland so far that numerous production boreholes have been salinated and had to be taken out of use. To exacerbate this situation, experience with artificial recharge of water transferred from Lake Kinneret by the National Carrier into recharge boreholes in the sandstone aquifer has shown that the presence of microscopic algae in the water gradually clogs the aquifer around the boreholes. Recharge boreholes in the limestone aquifer can absorb much higher discharges and are not affected by algae. Therefore most of the water transferred at present from the National Carrier for recharge in the coastal aquifer is first recharged into the limestone aquifer, and subsequently pumped from it and transferred by a number of transmission pipelines to recharge boreholes in the coastal aquifer, which lies close to the limestone aquifer. In addition, the coastal aquifer is artificially recharged with flood water, intercepted and spread in recharge basins at suitable places.

As mentioned above, a substantial increase in artificial recharge capacity is required in order to gradually recover the coastal aquifer from its present state of over-exploitation, and check the encroachment of sea water. This activity is part of a comprehensive programme required to preserve the quality of water in the coastal aquifer. In contrast with the deeper limestone aquifer, most of the area of the coastal aquifer is exposed to direct percolation of rain water from the surface. Therefore, sources of pollution in the area above the aquifer, such as sewage, industrial effluents, sanitary landfills, and chemical fertilizers applied to cultivated lands, eventually find their way into the ground water. And while in the past, water levels in the aquifer were high enough to maintain a gradient of flow towards the Mediterranean Sea all along the coast, at present in many areas there are troughs in the water table which have stopped this outflow, thus also halting the leaching of pollutants out of the aquifer. As a result, several water supply boreholes have already been polluted and alternative sources of water had to be found.

The future of the coastal aquifer of Israel hinges on a carefully planned regime of pumping and artificial recharge, and on implementation of conveyance and artificial recharge facilities that would enable such a regime to be maintained under varying climatic conditions, growing demand and intensified rural and urban development.

B. Water resources planning in Ghana

The Republic of Ghana, in West Africa, has a population of some 13 million and an area of 240,000 sq km. Ghana's water resources, mainly surface water, exceed the identifiable long-term needs, although their spatial and temporal distribution is not always in line with consumption patterns. Problems arising from this spatial and temporal mismatch have existed in the past and are increasing, but have so far not become a major issue among the other difficulties faced by the water sector of Ghana, as can be seen from the following brief review.

In Ghana, as in most developing countries, water resource planning, if at all, is done independently by different authorities, within as well as outside the water sector, with almost no co-ordination. Domestic water supply and hydropower generation are the dominant water sub-sectors. Irrigation has been introduced only sporadically and is still not significant in the agricultural sector. Agricultural policy is mostly concerned with the stabilization and restoration of traditional staple food production, for crops such as maize, cassava and yam, and with the recovery of Ghana's lost leading role as a cocoa-exporting country.

The first comprehensive study to analyze Ghana's available water resources, identify long-term needs and water requirements of the entire water sector, and ways to match them under the prevailing critical conditions, was carried out in 1970. Long-term requirements have, however, always been eclipsed by urgent needs, mostly those of the domestic water supply sector. This situation, combined with organizational shortcomings within Ghana's planning framework, has resulted in a very limited use ever being made of that study. In December 1980, a committee was established under the National Development Commission to assist in the preparation and formulation of planning policies, targets and strategies for the the entire water resources sector, to be used as guidelines for preparation of the 1981-1985 Development Plan for Ghana. The committee studied the past performance of the sector, identified major problems and constraints, drew up goals and objectives to be pursued during the Development Plan period, and recommended policy measures, priorities and strategies to be adopted, as well as a list of programmes and projects to be implemented. Over-optimistic assumptions and forecasts, on the one hand, and the realities of an ailing economy with limited financial and organizational resources, on the other, had not been adequately considered, and the programme became quickly obsolete. The implications of planning shortcomings, at both intrasectoral and intersectoral levels, can be depicted by the following overview of the performance of two water utilization sectors: domestic water supply, and Volta River hydropower and regional development.

1. The water supply sector

Comprehensive planning for water supply schemes was first done in 1964, in the Master Plan for Water Supply and Sewerage for the Accra-Tema

Metropolitan Area, serving at present a population of about 1.3 million inhabitants. Other comprehensive studies for water supply systems were also conducted in the period 1964 to 1970. A first nation-wide approach to planning was adopted in the 1976-1980 Five-Year Development Plan, a programme oriented to a large extent to increasing the percentage of the total population served with potable water from 38 to about 50 per cent. The programme focussed mainly on the urban sector. In 1978, the United Nations Development Programme (UNDP) and the World Health Organization (WHO) provided assistance to prepare a Rural Water Supply Master Plan, with the aim of correcting the imbalance between the urban and rural sector. Thousands of hand-pumped wells were subsequently installed across the country. In 1980, the Planning and Research Department of the Ghana Water and Sewerage Corporation (GWSC) prepared a 10-year (1980-1990) water supply development programme to expand domestic and industrial water supply in line with the plannning policies, targets and strategies for the water resources sector, postulated in 1980 by the National Development Commission.

In 1984, following an economic crisis in Ghana, the Government embarked on a three-year (1984-1986) Economic Recovery Programme with a view to removing some of the country's economic ills. This recovery programme also included a plan to rehabilitate the water supply sector, prepared with support from the World Bank. A comprehensive Five Year Rehabilitation and Development Plan was drawn up by GWSC in 1986. Certain progress in rehabilitation and development of some of the 200 water supply systems of Ghana has been made since the beginning of the 1980s, with assistance from several countries and international lending and donor organizations. Yet in 1987 less than half of Ghana's population were enjoying safe drinking water supply.

None of the above-mentioned long-term, and increasingly ambitious, programmes could be implemented to any substantial degree, nor act as a guide to development staging. Existing water supply systems deteriorated continuously and had to be rehabilitated; most of the newly-started water supply systems could not be completed. This growing gap between long-term planning and implementation reflects some basic shortcomings in water resources planning, typical of many developing countries:

(a) Acute shortage of professionals, especially persons trained in water supply planning in general and long-term planning in particular.

(b) Limited and unrealistic analysis of present conditions of existing and on-going water supply systems, as a starting point for future development.

(c) Lack of analysis of the existing and future organizational capabilities necessary to construct, operate and maintain water supply systems proposed in development plans.

(d) Underestimation of financial requirements and availability of funds from internal and international sources.

2. Volta River hydroelectric and regional development project

In 1964 the world's largest man-made lake (8,500 sq km) was created on the River Volta in Ghana by the Akosombo dam and hydroelectric power plant.

This scheme has a very long history of engineering and economic studies, culminating in a financing arrangement unprecedented in complexity and involving funds from several countries and international agencies. This complexity reflected the fact that at the time of planning the principal economic justification for the scheme, electricity supply to aluminium smelters, was not adequately clear, and additional planned benefits could not decisively tip the economic balance in favour of the project. Therefore, considerable political goodwill had to be solicited by Ghana's leader at that time, President K. Nkrumah, to mobilize the necessary capital, amounting to £UK 60 million (in 1960 prices).

Now, more than 20 years after its inauguration in 1966, the Volta Lake Project appears to have attained just some of its objectives, while problems emerged which were not sufficiently foreseen and are as yet unresolved. The main objective of power generation has been largely attained, although the original hydrologic forecasts prepared for the long-term operation of the scheme were recently shown to have been over-rated. In 1983, Volta Lake levels fell to an unforeseen low level, which necessitated imposing restrictions on electricity supply. A side effect of this situation, caused by a sequence of years of below average precipitation, was that several pump intakes constructed on the lake's shores for rural and urban water supply purposes, remained above water for a period of 2-3 years.

An important component of the Volta scheme was the irrigation of the large expanses of fertile lands of the Accra Plains, utilizing the regulated flow of the Volta River downstream of Akosombo Dam. This plan has not yet been implemented despite a series of studies which have shown the scheme to be economically viable. A massive development of irrigated agriculture might solve Ghana's problems in production of export crops such as cocoa, much needed for foreign exchange, and in provision of basic food crops to feed the growing population.

It appears that the main reason that the scheme has not been implemented, as with other irrigation schemes, was that the necessity and the capability to create the infrastructure required to operate irrigation schemes of this magnitude were overlooked. As in other African countries, Ghana has so far had a relatively short exposure to intensive land cultivation practices and has not yet developed the technical and organizational skills required in enterprises of this type. Most analysts now believe that a policy of small-scale financial support and technical assistance to the traditional small landowners, combined with field level training programmes, promise better results in improving the lot of the rural people, than capital-intensive development projects. After a tradition of intensive farming methods gradually evolves, the suitable technological environment and the ability of farmers to absorb advanced irrigation practices, based on efficient agricultural technologies, can be created. At the same time, the necessary physical and institutional infrastructure has to be developed.

Had the investments in the Accra Plains scheme been made as planned, their fate would have been the same as that of a much smaller irrigation scheme - Weija, constructed in 1979 - as well as other irrigation projects in Ghana and elsewhere, which have been prematurely implemented.

Other human factors related to the Volta Lake scheme appear to have been under-estimated, even though they were given adequate attention in the plans. A total of some 80,000 people had to be resettled by the time the lake started filling in the year 1964. The resettlement operation had been carefully planned, including construction of houses, roads and public amenities, land was cleared and compensation monies were allocated. Nonetheless, the execution of this very complicated programme encountered such organizational and financial difficulties that until today villagers who lost their homes in the inundated area have not been adequately compensated, and the matter continues to be a drain on the budget of the Volta River Authority.

The creation of Volta Lake also had a negative effect on the propagation of water-borne diseases. This subject had been thoroughly investigated in the planning stages, and steps were taken to counter the detrimental effects of a drastic expansion of favourable habitats for harmful insects and aquatic fauna as a result of formation of the lake. Nonetheless, the magnitude and complexity of the problem appears to have been beyond the capacity of the authorities to cope with, and the consequence is that an entire population around the lake is afflicted with a variety of water-borne diseases, and the problem absorbs substantial human and financial resources of the Volta River Authority.

C. Republic of El Salvador Water Resources Development Master Plan

This master plan provides an example of a project-oriented study for the development and management of water resources on a national scale. The purpose was to identify development requirements in five water-utilization sectors:

(1) Urban and rural water supply;

(2) Sewage systems;

(3) Irrigation;

(4) Hydroelectric power;

(5) Water quality protection, i.e., reduction of surface water pollution.

The result of the study was a proposal for a development and investment plan for those sectors, that would take into account the implementation capacity of the Government. The proposed plan would concentrate on specific and concrete projects rather than on a full and exhaustive resource-demand evaluation.

A special methodology was devised to carry out the study to the required level, in four phases:

(1) Preparation and evaluation of single-purpose projects;

(2) Evaluation of multipurpose projects;

(3) Assignment of intrasectoral priorities;

(4) Intersectoral analysis.

Phase 1. The preparation and evaluation of single-purpose projects included three levels: (i) preparation of preliminary designs; (ii) adaptation of existing plans; and (iii) parametric analysis. Preliminary designs and cost estimates were prepared for a number of sample projects. Parametric analyses were carried out by identifying the main cost-affecting parameter, such as flow rate, population served or population density. Projects were generally split into main project components, e.g., headworks, main conduits, treatment plants and distribution or collection systems. Parametric analyses were then carried out for those components. The parametric analysis was justified for the large number of water supply, sewerage and irrigation projects permitting statistical inference. It was less suitable for hydroelectric schemes, where the entire scope of relevant projects is covered by preliminary designs.

Phase 2. The evaluation of multipurpose projects comprised two categories of projects:

(a) Projects that are individually single-purpose, but use a common water source and may compete with each other for this source, e.g., an upstream irrigation scheme and a downstream hydroelectric plant; such projects were termed multipurpose users of water.

(b) Projects which by themselves serve more than one purpose, such as dams for hydroelectric power generation and downstream flow regulation (to make available more water during the dry season), were referred to as multipurpose projects. Multipurpose projects were first treated as single-purpose projects. Their main purpose was identified and they were subsequently dimensioned and costs were estimated. When two projects were mutually exclusive because of their competition for the same source of water, the project which was ranked higher by a single criterion or by multi-criteria analysis was accepted.

The evaluation of the multipurpose use of water therefore determined:

(a) Indirect costs and benefits;

(b) Basin-wide water balances of uses and sources for the peak demand month (for run-of-the-river projects) or annual flows (for surface water storage and ground water projects). From these water balances, the gap between water demand and supply was assessed. If demands exceeded available water, projects with low cost effectiveness were eliminated.

Phase 3. The intrasectoral priority assignment refers to projects within the same water-using sector, e.g., irrigation, urban water supply, hydroelectric power and water quality control, that may be mutually exclusive, complementary or independent. Ranking of independent projects was based on a number of criteria referring to economic benefits and to other benefits such as equity, public health, environmental protection, certainty and reliability of supplies and conservation of water resources. To these criteria, non-monetary yardsticks were applied such as population served, existing unsatisfied water demands and geographic priorities. When more than one criterion was applicable, a multi-criteria analysis was performed.

Phase 4. Intersectoral analysis was treated in this study as a problem of allocating a limited development budget, which represents the implementation capacity of the Government, among the five water utilization sectors. Allocations were determined in four steps:

(a) Division of the total budget between the production sector (irrigation, hydropower) and the service sector (water supply, sewerage);

(b) Division of the resulting budget for the production sector between irrigation and hydroelectric projects;

(c) Division of the resulting budget for the service sector between water supply and sanitation projects, i.e., sewerage and industrial waste treatment;

(d) Division of the resulting budget between urban sewerage and industrial waste treatment projects.

The recommended concept of development was based on "development nuclei", that is, concentration of efforts and resources on integrated development of a small number of scattered centres. Primary agricultural production and agro-industry were recommended for rapid development, as well as industries to enhance advanced farm production, such as textiles. Development of all the required technical infrastructure and direct services was incorporated in the plan, together with the development of public services to support higher standards of living for the population. Reasonable assumptions were made as to the geographic location of each nuclei, in accordance with the general development strategy of the Government.

The study identified and dealt with over a thousand projects in the fields of water supply, sewage, irrigation, industrial waste-water treatment and hydroelectric development. From this basket of projects, using the methodology developed, a comprehensive multisectoral development plan was formulated for the short, medium and long term, allocating an order of priority for the implementation of the selected projects not only separately for each sector, but also intersectorally. National development strategy was, for the purpose of this study, deduced from current development plans and trends. It was recommended that future planning be undertaken in an interactive manner through dialogue between decision makers and planners, a process for which the methodology developed is especially suitable.

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