Chapter 9

Water Resources Planning

The objectives of this chapter are:

- To introduce the concepts of water resources planning,
- to explain the various stages of planning, and
- to explain the use of system analysis tools in water resources planning.

River basin planning for water resources development and management has been practiced in many parts of Asia and Africa for at least nine thousand years. The oldest recorded practice of irrigated agriculture has been traced in Jericho in 7000 BC (Saha and Barrow, 1981). There are also recorded histories of sophisticated engineering works for water regulation in China, Egypt and Iraq, which date back to several thousand years. An intricate system of basin irrigation involving longitudinal dykes parallel to the main channel of the Nile to regulate flood waters and a network of cross dykes and canals to conduct flood waters into pre-designated basins was evolved in Egypt as early as 3400 BC (Hamdan, 1961). About 250 BC, the Chinese had built a sophisticated system, called Duijiangyang Irrigation Project, which is still in use. This system uses dykes and spurs to divert river water but has no dams. By the 7th century AD, the Chinese had developed a highly sophisticated network of structures for irrigation, making a balanced use of ground and surface water resources. They had organised a system of administrative authority to ensure a high state of maintenance of these structures and perfected a land-use pattern that maximised the use of available irrigation facilities. Detailed accounts of canal irrigation systems in Iraq dating as far back as 4000 BC are also available. An important milestone of the modern form of river basin planning was initiation of developments in the Tennessee Valley through the Tennessee Valley Authority (TVA) in the 1930s in U.S.A.

A water resource can be defined as any aspect of water that has value or which is exploited by the user to get a certain benefit. A benefit is any tangible or intangible output that is valued or desired by producers or individuals. The different aspects of a water resource of interest are its quantity and quality, potential energy, flow depth, surface area, aesthetic value, waste assimilating capacity, its biological productivity, etc. Typical bulk users of water are: municipalities and industries, irrigated agriculture, hydroelectric power plants, thermal power plants, commercial navigators, recreational water users, and fish and wild life. Integrated water resources management is a way to manage an area's water resources taking into account the fact that the aspects such as quantity and quality are facets of the same physical water system. It recognizes the physical interconnections among components of ecosystems and the relationship among the users.

Different water users need different amounts and types of water. The principal categories of water uses are shown in Table 9.1.On the average, the total consumption of water by all users should not exceed the rate of its replenishment by the hydrologic system in a region. Hence, the availability of water in a region and the amount and nature of requirements determine how many water users can be supported. Since the rate of resource replenishment is finite and limited, the water users may be in competition with each other.

Table 9.1 Principal categories of water use [adapted from UN (1976)].

Infrastructure	F	Drinking	W	W	Withdrawal
F	F	Domestic uses	W	N	In-stream use
	F	Public uses in settlements	W	O	On-site
Agriculture, Forestry and	A	Rain-fed agriculture	O		
Aquaculture	A	Livestock	W	(a)	Highly consumptive use
A	A	Fish and Wildlife	N		
	A	Forestry	O	(b)	Heavy impact on water quality
Industry	A	Irrigation (a)	W		
I	F	Navigation	N		
	I	Hydropower	N		
	I	Thermal power	W		
	I	Mining (b)	W		
	A	Swamp and wetland habitat	O		
	I	Cooling	W		
	I	Manufacturing (b)	W		
	I, F	Waste disposal (b)	N		
	F	Recreation	N		
	F	Aesthetic enjoyment	N		
	A	Utilization of estuaries	N, O		

A water resources (WR) development project is a set of structural or nonstructural activities to develop or improve water resources for the benefit of society. A physical WR system is a collection of various elements (for example, reservoirs, canals, pipelines, etc.) which interact in a logical manner and are designed in response to social needs. The ultimate goal of WR planning and management is to serve the public by ensuring that water of required quantity and quality is available at the right location and at the right time. The aim is also to protect society from the harmful effects of water. All this must be achieved within accepted levels of assurance.

Planning was defined by Weiss and Beard (1971) as *the process by which the society directs its activities to achieve goals it regards as important.* According to UN (1972), "Planning aims at optimal use of available resources. WR planning involves estimation of short term and long term needs and ways to meet these needs. It involves a comparative evaluation of alternative solutions with respect to their technical, economic and social merits. Planning needs looking into the future and looking from a broad spectrum of disciplines." The US Water Resources Council (WRC) issued a set of 'Principles and standards for planning water and related land resources' in 1973. These were revised in 1979 and 1980 and specified that the overall purpose of planning should be to improve the quality of life through contributions to:

a. National economic development,
b. Environmental quality,
c. Regional economic development, and
d. Other social effects.

WR planning is a logical course of actions leading to the selection of the best acceptable project in response to an identified need. Because of wide variations in distribution of surface water and groundwater resources over a region, WR planning is always broad in scope. Such a planning is needed at different levels and for different purposes of water management. It, therefore, requires that many different uses of water are considered and evaluated, leading to the articulation of trade-offs among conflicting and competing objectives. It requires that decisions are made at many different levels, ranging from national or even international water plans to regional or local projects and involving experts and decision-makers who have varied backgrounds and who are often not water-cognizant: politicians, lawyers, and social scientists. The spectrum of objectives that are considered important for a particular water resources project by such a motley group may differ very widely.

WR planning requires a well-coordinated team of qualified professionals with clear objectives and scope of the project, who can draw a plan which is acceptable to those who are impacted by the project and to the decision-maker. This is an involved task because water resources are subject to natural variations, and future changes in demography and economy are difficult to predict. Consequently, elements of uncertainty enter the process. The other noteworthy aspect is that many WR decisions are more or less irreversible. For instance, a dam that has been built in a river valley exists practically forever, regardless of whether there is a need for it or not. It will never be possible to restore the site to its original condition, even if a dam that is no longer needed is carefully decommissioned.

To appreciate the scope of water resources planning process, the following characteristics may be noted:

(1) WR systems most often have multiple objectives and functions.
(2) While technical aspects of the problem provide the foundations, institutional, social and other considerations are also important.
(3) Multiple decision-makers, representing various constituencies, needs, and aspirations, are commonly involved in the planning process.
(4) The projects have a significant influence on society and regional economy.
(5) Elements of risk and uncertainty characterize almost all WR systems.
(6) The planning and the decision-making processes are hierarchical in nature.
(7) The activities, such as problem definition and formulation, data collection, processing, and analysis, constitute the dominant effort in the planning process, at least in initial stages.
(8) The wide scope of WR planning requires experts from many different disciplines, such as hydrology, engineering, agriculture, economics, and social sciences.

9.1 INTEGRATED PLANNING

With the best project sites already utilized in many countries, multi-purpose goals must be adopted to make the best use of remaining limited sites. Due to ever increasing demand of water for agricultural, domestic, industrial, and other purposes, a great deal of emphasis needs to be laid on optimum utilization of water resources. A wise exploitation of WR calls for integrated planning which is the planning of water, land and other associated resources with coordination among geographical, functional, and procedural aspects.

It is important to note that uncoordinated planning activities are likely to lead to an imbalance in the resource use because the availability of one resource in natural ecology is closely related to the use of another. In absence of coordinated planning and sustainable development, the natural balance existing among different resources will be disturbed leading to harmful results. The two basic requirements that must be met in basin-wide integrated planning are: improved coordination of a diverse variety of human activities, and integration and utilization of large amounts of information. An integrated plan must explicitly identify the factors and interrelationships that form the basis to plan and implement activities for use of resources to achieve desired goals. The planning should be organized in such a way that all decisions are optimum and the relationship between resource use and outcome is foreseen.

The concept of integrated planning has its roots in regional and comprehensive planning. In regional planning, the activities are project-oriented and concerned with economic development in a region. Of late, the environmental and social issues have also become important. As the awareness of the significance of inter-relationships among diverse projects has increased, it is recognized that planning should more explicitly take into account a large number of variables and functions. This led to the concept of comprehensive planning. In the late 1960s, it was felt that planning activities must become more closely coordinated and interrelated. Additional efforts for interfacing different planning activities and their close coordination led to the concept of integrated planning. These days, it is essential to examine environmental protection schemes, afforestation, catchment area treatment, soil conservation, conjunctive use, and command area development, etc. while preparing project feasibility reports. These measures orient the project toward an overall development.

9.2 STAGES IN WATER RESOURCES PLANNING

The scope of WR planning process can vary from broad-based preliminary planning of a new project to detailed evaluation of a selected physical project (a feasibility study). The broad flow of activities of WR planning activities is shown in Fig. 9.1. The project may be a large (and sometimes) internationally financed activity to small project that is financed by a small city or a private party.

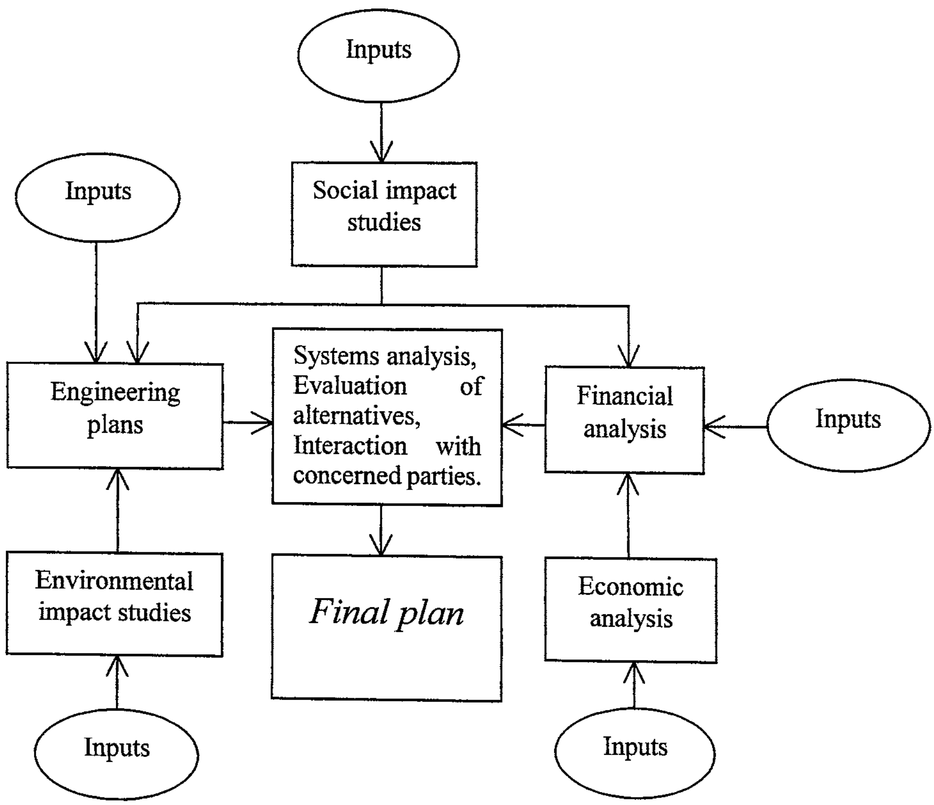

Fig. 9.1 Flow of activities in the planning process [adapted from Grigg (1985)].

Stephenson and Peterson (1991) identified three levels of planning, associated with three areas of different geographic extent: national, regional or river basin, and local areas. Based on the time sequence of the planning process, the entire life cycle of a project can be divided into three phases (Haimes et al., 1987): (1) Planning, (2) construction/ implementation, and (3) operation.

Phase 1, which is relevant for this chapter, can be categorized into five stages:

Stage 1. The project initiation stage: It begins with the statement of needs and includes preliminary planning, feasibility, and field investigations.
Stage 2. The data collection stage: Detailed data are gathered for analysis and decision-making.
Stage 3. Project configuration stage: A large number of alternatives are investigated and a small number of promising alternatives are selected for detailed analysis.
Stage 4. Detailed planning stage: The design parameters, operation rules, costs, benefits etc., of the alternatives selected in stage 3 are determined, and the final project configuration is selected. Actually, this phase represents a detailed form of stages 2 and 3.
Stage 5. The design stage: The final configuration is translated into detailed structural design.

The fifth stage is not a direct part of WR planning, since it mostly involves structural design and financial aspects of a project. This stage is beyond the scope of this book.

The above classification into five stages is only one of many similar classifications. The UN (1970) has outlined a four-phase programme for integrated river basin development consisting of: (a) preliminary investigation and organization; (b) general reconnaissance of existing conditions; (c) initial phase of implementation, including and actual start of small-scale projects; and (d) construction and operation of major structures. Simonovic (1989) outlined a four-step planning process being followed in Yugoslavia: (a) inventory, forecast and analysis of available water resources; (b) inventory, forecast and analysis of water demand; (c) formulation of alternative solutions for satisfying water demands from available water resources; and (d) comparison and ranking of alternative plans. According to the US WRC guidelines, the planning process consists of six major steps:

a. Specification of the water and related land resources problems and opportunities associated with the federal objective and specific state and local concerns.
b. Inventory, forecast and analysis of water and related land resource conditions within the planning area relevant to the identified problems and opportunities.
c. Formulation of alternative plans.
d. Evaluation of the effects of alternative plans.
e. Comparison of alternative plans.
f. Selection of recommended plan based on the comparison of alternative plans.

It can be seen that the steps/stages given by the various agencies are more or less identical. In the following discussion, the above 5-stage classification will be elaborated. The sub-division into five stages is convenient, since each stage is a logical precursor of the previous stage. However, the situation may be significantly different in some countries. Also, not all the proposed projects clear all stages. Unfortunately, one may find water resources projects that are stalled at various stages, including the construction stage. There are also instances where the project configuration was finalized in a court based on legal rather than technical considerations.

The definition of the five stages of planning yields a conceptual model of the planning process which is shown in Fig. 9.2. Here, the stages are a part of a sequential decision process, in which the tasks to be executed in each stage are represented by boxes and the connecting lines denote decisions to be taken. Arrows indicate the direction of the information flow from one stage to the next. Of course, there will always be many formal and informal linkages which cannot be shown in such a diagram. The planner must, therefore, allow enough flexibility for later adjustments, because most operation procedures are developed on the basis of some assumptions, and it is very likely that the real world will not behave as predicted during planning.

9.2.1 Relationship among Stages

The process of planning of a WR project can also be visualized as a hierarchical structure of subsystems and decisions. A considerable overlap is bound to be present when dividing a complex process, such as WR planning in stages. In fact, this is nothing but a logical continuum between them. For example, stages 2 and 3 may be combined to form a preliminary feasibility stage. Some aspects of stages 2 and 4 may be combined into a feasibility study that provides the basis for the final financial decisions that are made before the project is designed and executed. Stages 2 and 4 may also be coupled in terms of data development and improvement. Furthermore, planners at stage 4 itself may need design of components that is normally carried out at stage 5 to have more accurate cost estimates. In certain cases, only one plan may be selected, and a detailed analysis is made for that plan alone. Sometimes, construction activities, such as excavation for the dam or building a coffer dam, may begin before the design of certain components, e.g., spillway gates is being finalized.

Stage 3 is basically a preliminary screening, while stage 4 brings the project very close to its final configuration. Thus, stage 4 requires more resources and the use of sophisticated techniques. Depending on the circumstances, there may be a need for detailed analysis of some portions of stage 3, with perhaps the generation of a few additional alternatives.

During stage 4, the project is analyzed in detail, including the generation of one or more suitable integrated models. This will require the following steps:

a. quantitative definition of all variables and terms;
b. quantification (to the extent possible) of final objectives, constraints, input-output relationships and measures (structural and nonstructural);
c. identification and evaluation of available candidate models;
d. evaluation of the database needed for step c;

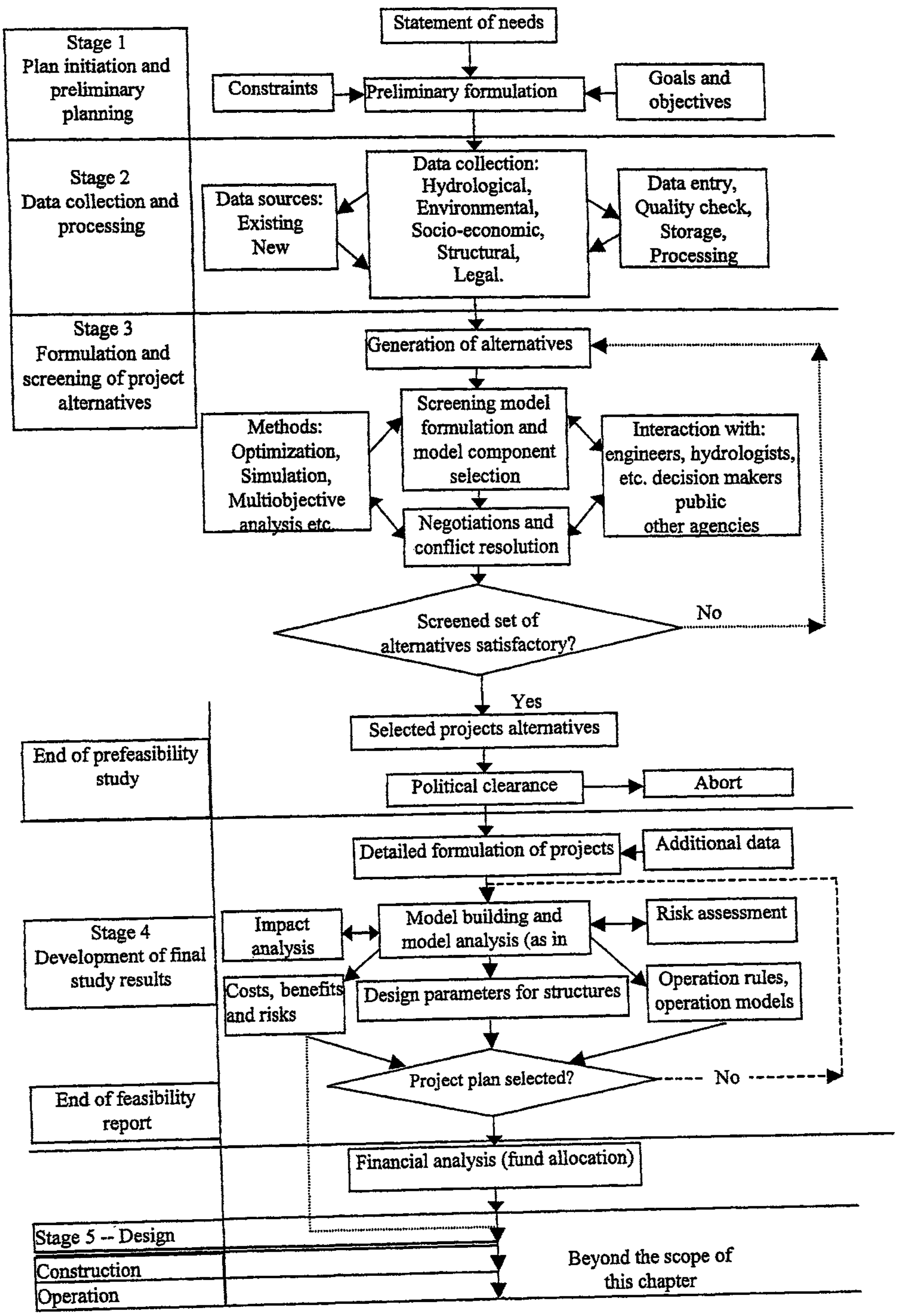

Fig. 9.2 Stages in the water resources planning process [Source: Haimes et al. (1987).

e. construction of new models;
f. integration of newly developed models with existing models, as appropriate; and
g. model calibration, validation, and application.

The planning and policy options developed through the use of models and their associated trade-offs and impacts are discussed in detail at this stage. Ideally, this requires participation of all concerned decision-makers, stake-holders, constituencies, and agencies. The final result of this stage should be an optimal plan.

A brief discussion of data collection and processing is given next. Since this topic has been discussed in Chapter 2, here the attention is focused on those aspects that are related to planning only.

9.3 DATA COLLECTION AND PROCESSING

Data collection and processing constitutes stage 2 of the planning process although this activity may continue till the final design is prepared. In stage 2, the data needed for the project should be collected and their quality and quantity evaluated. Depending on the availability of data, decisions need to be made about the collection of additional hydrometeorological data, water demand and quality data as well as demographic, economic, and ecological information.

The data collection process requires identifying the sources of data, exploration of these sources, inquiries about other possible data sources, evaluation of data quality, and computerization of data for processing. This process involves a lot of fieldwork and planning because the data collected must be purpose - oriented. The purpose must govern the type, the accuracy, and the time horizon of the data. The acquisition and processing of water resources data have been discussed in Chapter 2. The purpose of this section is to explain main aspects related to planning.

9.3.1 Specifications and Sources of Data

When the results of preliminary planning exercise indicate that the project will come into being, a detailed analysis is initiated. By now, some data are already available from the preliminary analyses but in most cases these are insufficient for a detailed investigation. At this stage, a broader database is needed. The first effort should be to compile whatever data are already available and pertinent to the project. This may require visits to many offices scattered all over the project area. In many instances, the data may have to be manually copied and then entered in computer. If the available data are limited and further observations and measurements are required, additional field sampling and investigation programs are initiated. It is common to set up additional rain gages and stream gaging stations specifically to collect data for project planning.

Due to the high level of automation and modern means of information dissemination, the data collection is a simpler exercise in developed countries. But in many countries, much of the data are still in the manuscript form and are scattered in various branches of a data collection agency. Usually no data inventory is available in a central office and it may be necessary to visit each branch office and copy and computerize the data. Also, there may not be a common format for storing the data and the quality and reliability may widely vary from agency to agency and sometimes across the same agency. Therefore, sufficient time and funds should be allocated for the purpose of data collection. The problem may be slightly simpler due to the fact that many times the planning agency may also be involved in observation of a few variables. The accessibility of data banks through the Internet is becoming a common practice now in many countries. One should also inquire about the other data sources as sometimes non-traditional departments may also be observing pertinent data.

In many organizations, the data collection is just one of the responsibilities, sometimes the least important. Therefore, the personnel assigned to data collection works are frequently moved to more urgent tasks. The maintenance of equipment may also not be as prompt as it should be. The observer might not have sufficient training and may not be adequately motivated and aware of the importance of the data that he is producing.

9.3.2 Data Adequacy

The adequacy of data is defined with respect to the purpose for which the data are to be used and the consequences of using inadequate data. Virtually any hydrologic database can be considered to be inadequate in some respects. Therefore, the assessment of data sufficiency should be based on sampling and parameter uncertainties and on an evaluation of how sensitive the key project parameters are to changes in the data accuracy. From an economic standpoint, the data can be considered adequate when the marginal cost of obtaining the additional data is equal to the marginal benefits from this data. However, this concept is difficult to apply because of uncertainties in the evaluation of future benefits.

The analytical methods that can be used in a specific situation should be commensurate with the quality and coverage of the database. There is no point in subjecting unreliable data to intensive processing. The reliability and representativeness of the data must be evaluated before choosing analytical tools. A common feeling is that the experts always press for more and more detailed data while even the available data are not fully used. But the mathematical models cannot be effective without adequate data for model calibration, validation, and application. This is why the data-gathering process should be directly related to the needs of analysis and tools. The analysts must remember that their methods can hardly be used to give appropriate results if they are not based on an adequate and realistic description of the system.

In many instances, particularly in developing countries, WR projects are planned based on hydrologic and non-hydrologic database, which are far smaller than that desired for an effective analysis. But the planning activities can't be suspended until detailed data are available. Of course, in some instances special stations are installed during early stages of planning to collect more data and the analysis is refined after desired data are available. Sometimes, the plans are hurriedly prepared because a project is to be pushed through due to political pressure or the existence of problems requiring immediate action. In such situations, it is worth considering the possibilities of implementing the project in stages, if this is technically feasible, although this always entails additional costs. The other possibility is to design the project in such a way that eventual losses due to the use of imperfect data are minimized. The strategy of "wait and watch", hoping that uncertainty about some of the crucial factors influencing the project will be reduced, is not generally helpful. Waiting does not always improve things and in fact new uncertainties may crop up with time.

9.3.3 Data Quality Control

The term data quality control denotes preliminary checking that is undertaken to weed out obvious errors and inconsistencies from the raw data. The methods include preliminary checking, plotting, and removal of errors by spatial and temporal consistency checks. The preliminary checking must ensure the overall correctness of the indicative information; simple spatial and statistical checks should be applied to see if the data provide a reasonable long-term picture of water availability and use in the region under consideration. Preliminary processing may also include identification of data gaps as well as filling such gaps by suitable techniques. These days, all analyses are performed on computers.

It is also important that the data are representative of the current hydrological conditions in the basin. This is especially important for streamflow series in a basin subject to large-scale man-made changes, e.g., deforestation or upstream withdrawals. Although relatively long records may be available, these may no longer be representative unless man-made changes in the basin are appropriately accounted for.

9.3.4 Data Systems

Database systems include data stored on computer media and collection of software for operations such as data input, search, retrieval, updating, and deletion. Of late, many organizations have started calling their data files as databases without giving attention to properties, such as exclusion of data redundancy, provision for data independence and protection, and precise definition of mutual relations among different data. The importance of these aspects has grown considerably with the expansion of databases and development of better software for data processing and management.

WR planning requires handling a large amount of data and the task of data processing, compiling results and report writing cannot be coped with by conventional methods. Adequate attention to develop a database in the initial stages will save considerable time, effort, and headaches in the long run. The type of information system that is advisable for a given plan depends very much on the level of effort, availability of computer facilities, data management experts, etc.

Depending on the purpose, data requirements vary considerably. For long-range planning, monthly or annual data are needed. For operational purposes, short-time data are necessary. Therefore, a data series which serves one function may not necessarily be able to serve another. With the expansion of Internet, the common system configuration consists of a database server and on-line users who access the database from remote hosts. With the development of software for management and analysis of geographical data, the task of planners has become relatively simple. The GIS tool has been described in Chapter 3.

9.4 ESTIMATION OF FUTURE WATER DEMANDS

The use of water can be divided into two categories: consumptive use, in which water is an end to itself, and non-consumptive use, in which water is a means to an end. The first category includes the use for municipal, agricultural, industrial and mining purposes. The non-consumptive uses are in-stream uses, such as hydropower, transportation, and recreation. Consumptive uses are modeled using consumptive functions and non-consumptive uses, using production functions. The water use refers to the amount of water applied to achieve various ends so that it is a descriptive concept. Water demand is the scheduling of quantities that consumers use per unit of time for a particular price of water, which is an analytical concept. Modern water resources projects are mostly multipurpose, catering for flood-damage reduction, irrigation, hydro-electric power generation, domestic and industrial water supply, navigation, recharging of groundwater, conservation and improvement of soil and sediment abatement, low flow augmentation and water quality control, etc. The sequence of these uses is shown in Fig. 9.3.

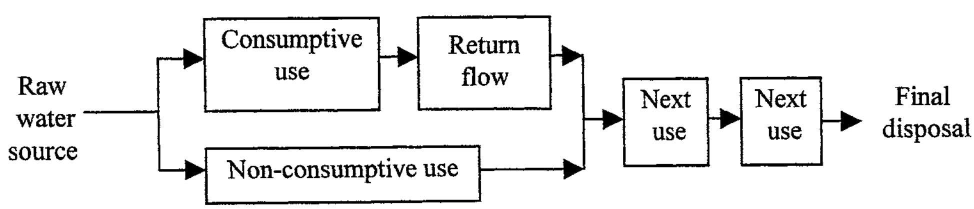

Fig. 9.3 Steps in use of water resources.

The ability to plan and design new water resources facilities is directly linked to the ability to predict future water requirements. In the context of planning, future could refer to years, or decades depending on the particular problem. Demand forecasting is estimation of water use in the future based on the previous water use, socioeconomic and climate parameters of the past and present water use, and projections of population and economic growth. Because of the size and capital intensiveness of most water resources projects, the time scale in water demand forecasting generally is 15-25 years for medium-range forecasting and about 50 years for long-range forecasting. According to UN (1976), the time horizon must be fixed in relation to periods which are characterized by the adoption of new technical means and methods by far-reaching social and economic changes or by a radical substitution of raw material resources. This will lead to the elaboration of a number of water resources development scenarios. It will be possible to select from these the most probable scenario, or that which is preferable by elimination.

The projections of future population are important inputs in planning because the quantities, such as the demand of water, energy, etc. crucially depend on these. Most countries have specialized agencies to provide these projections. International organizations, such as the UN, also make these projections from time to time. Sometimes, estimates are made for different scenarios of population growth. For example, the population of India by the year 2050 is projected to be 1581 million in high growth scenario and 1346 million in low growth scenario (NCIWRD, 1999).

A forecast is an estimate of the future state of a variable that has four dimensions: quantity, quality, time, and space. In planning, the major factors determining the project cost are the quantity of water that must be stored, treated, supplied, and the quality of waste water to be collected, treated, and disposed. Water demand and use exhibit hourly, daily, monthly, seasonal and annual variations. The type, size, and timing of engineering facilities largely depend on these quantities. Forecasts of water demand should also reflect technological changes in production processes, product outputs, raw materials, and waste treatment methods, and public policies with respect to water use and development. An explicit inclusion of these factors is important in medium and long-range forecasts. Otherwise, forecasts would be of limited value to decision-makers. Therefore, simplistic methods, such as a linear extrapolation of past water demand (called projection), are generally not appropriate for long-term forecasting. Besides the magnitude, the variation of demands is also equally important to examine how far the various uses are compatible to each other.

A broad database is needed for forecasting and this should include gross and per capita demands, water use, effluents discharged with and without treatment, and the quality of sources of water. Additional data include water charges and effluent treatment cost. This information would be most suitable if it is available for each planning unit, say basin or sub-basin.

In what follows, water requirements for municipal and irrigation are described in detail. The water use for hydroelectric power is discussed in Chapter 10. Some industries, such as petroleum refining, chemicals and steel manufacturing, textiles, food processing, and pulp and paper mills, are such intensive water users that they must be identified and studied separately, the basic procedure remaining the same.

9.4.1 Water Requirements for Irrigation

Almost every plant process is directly or indirectly affected by the supply of water. Water constitutes about 80 to 90% of most plant cells and tissues in which there is active metabolism. Crop water requirements are defined as "the depth of water needed to meet the water loss through evapotranspiration (ET) of a disease free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment" (Doorenbos and Pruitt, 1977).

The three important factors for estimating irrigation requirements are: evaporation, transpiration and consumptive use. Transpiration is the process by which water vapor leaves the plant life and enters the atmosphere. The term consumptive use includes transpiration, evaporation, or the water evaporating from the adjacent soil surface, the surface of plant leaves and the water used by the plant for its metabolic activities. Since the water used in the metabolic process is very small (less than 1% of the ET requirements), the terms consumptive use and ET are interchangeably used.

The three major factors which determine the amount and timings of the irrigation water are: (a) the crop water requirements, (b) availability of water, and (c) capacity of the soil root zone to store water. The water requirement of a crop is *the quantity of water required by a crop in a given period of time for its normal growth under field conditions*. It can be calculated by

$$WR = ET + AL + SR \tag{9.1}$$

where WR is the crop water requirements, ET is the evapotranspiration of the crop, and AL is the application losses which include losses during conveyance and application in the field, and SR is the special requirements. Since rainfall and moisture present in the root zone of soil may meet a part of the water requirement, the irrigation requirement (IR) can be calculated as:

$$IR = WR - (ER + S) \tag{9.2}$$

where ER the effective rainfall, and S is the contribution of soil profile.

Potential evapotranspiration (PET) is an atmospheric-determined quantity which assumes that the ET flux will not exceed the available energy from both radiant and convection sources. Doorenbos and Pruitt (1977) defined the reference crop evapotranspiration (ET_0) as "the rate of ET from an extensive surface of 8-15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". A number of methods are available for its determination. These include pan evaporation method, energy budget method, temperature based methods, aerodynamic profile methods, and the combination method.

Actual ET can be obtained by multiplying PET with the appropriate crop coefficients which account for crop characteristics. The crop coefficient relates PET to ET of a disease free crop grown in large fields under optimum soil water and fertility conditions and achieving full production potential under the given growing environment. The crop coefficients vary seasonally but an average value can be used for rough calculations. Doorenbos and Pruitt (1977) have given procedures for selection of appropriate values which take into account crop characteristics, time of sowing, stage of crop development, and general climatic conditions. They have also discussed various aspects of crop water requirements in detail and have provided typical values of ETcrop and crop coefficients for various climatic conditions. However, this methodology has been revised recently since it was found to yield over estimates under certain conditions. The Food and Agriculture Organization (FAO) of United Nations has programmed the new methodology to estimate crop water requirements in the software named CROPWAT. Its details are available at their ftp site ftp://ftp.fao.org.

9.4.2 Municipal Water Use

The municipal water use can be divided into categories of residential (houses and apartments), commercial (businesses and stores), institutional (schools and hospitals), industrial, and other water use (park watering, swimming pools, fire-fighting). Unlike the water use in agriculture, where water is an input into a production system, municipal water use is mostly for meeting human needs. To the water delivered for these uses (or consumption) must be added the loss due to leakage from the distribution system to determine the amount of treated water. Now, adding the amount consumed by the treatment processes, the water required for the city is obtained.

Forecasting the municipal water demand is an important task for water utility agencies, involving three interrelated activities. The first activity is supply management which refers to forecasting the water demand so that new supply facilities can be designed, sequenced, and timed. A second interrelated activity is the demand management to determine the impact of water price changes, conservation measures, and rationing. The third activity is the collection of waste water, its treatment and disposal.

The total annual water use is a result of the combined effect of many factors. The per capita approach is commonly used to examine the relation between the total annual water use and population. Naturally, the annual water use would increase as the population grows. If such a relationship can be established, planners can predict the amount of water use for the anticipated population growth. Regression analysis is one of the most frequently used statistical techniques to estimate future water requirements. Here, the first task is to identify the factors that might affect the water use and include the population size, price of water, average income, and annual precipitation.

The first step to establish such a relationship is to plot the population size (on the horizontal axis) versus the corresponding water use (on the vertical axis) in the form of a scatter diagram. The next step is to develop a mathematical function to describe this upward trend of water use with respect to the population size. It may be assumed that the water use, Q is linearly related to population, POP, which can be approximated by the following equation:

$$Q = b_0 + b_1 \, POP + e \tag{9.3}$$

in which b_0 is the intercept, b_1 is the slope of the line, and e is the error term denoting the discrepancy between the observed water use and that estimated by the straight line equation. As data points will not exactly fall on a straight line, the error (e) accounts for the failure of the proposed model to exactly fit the observed data. If e is zero, eq. (9.3) is a deterministic model in which the water use (Q) is uniquely determined by population (POP). This is a simple linear regression model containing only one independent variable. A general extension of eq. (9.3) involving more than one independent variable yields a multiple linear regression model which can be expressed as

$$Q = b_0 + b_1 x_1 + \ldots + b_k x_k + e \tag{9.4}$$

Once the form of the model is finalized, the next phase of analysis is to estimate the regression coefficients. Regression analysis is an iterative process; the success in developing a reasonable model depends largely on the analyst's ability to interpret the resulting model and to correlate the model behavior with the process under investigation. The regression analysis has been discussed in Chapter 4.

Due to the ever-changing nature of social, economic, and political environments in a region, there are numerous uncertainties in any forecast. Errors in water use forecasts may arise from inappropriate assumptions made in determining the model parameters. If the population projections are too high, naturally the demand estimates will be high. An unreasonably high estimate of economic growth or too high an emphasis on past trends without a basic understanding of the reasons behind this trend and their sustainability will also produce a high estimate. Planners, due to their over-enthusiasm in promoting the projects, may also adopt unreasonable values. Whatever the cause, errors in forecasting produce excess economic costs which may be avoided through the use of improved approaches. Additionally, improved methodologies for forecasting water demands are needed to account for: (1) growing number of conflicts among water uses and water users; (2) increasing realization of interrelationships among different outputs from WR systems; and (3) increasing scope and scale of WR development.

9.5 PLAN INITIATION AND PRELIMINARY PLANNING

This is the first stage of the water resources planning process. Usually, the plan for a water resources project is initiated to meet existing needs or those that are likely to arise in the future and this is followed by formulation of a plan. Sometimes these needs are clearly identifiable and sometimes not. For example, a project may be built to provide irrigation water in an area which is drought prone or economically backward. Utmost care and efforts are required to analyze, in the broadest possible terms, their real nature since this is a very important phase of the planning process. There are no golden rules for successful identification of needs. A beginning should be made with broad thinking. Extensive ground work and contact with local people is necessary to clearly understand the aspirations and expectations of the society. The planning team should strive hard to clearly understand the problem in the beginning rather than redefining it at later stages of the project planning. According to Grigg (1985), problem identification is one of the most important parts of any management process, especially problem solving.

One of the biggest difficulties in WR planning is that the needs are sometimes not clearly identified in the initial stages. In some cases, one may have to proceed even though the needs have not been defined as well as they should be. This issue also poses a problem while the formulation of objectives, because the aims may not be clear, and the project boundaries and the data needed to even initiate the work may not be available or non-existent. There may be various groups with divergent interests lobbying to orient the development for their benefit. In a democratic set-up, elections to various bodies are the time when people commonly raise demands for various projects. At that time, the politicians are forced to look into them; they usually agree and make commitments. Obviously, many of these projects are not well thought of and only a few pass the initial screening. The screened projects are included in the list of appropriate bodies, depending on the scope and extent.

The levels of planning differ in character and scope from one country to another, but all of them require that water problems be formulated in the context of the overall economic and social aspirations of a given region or nation. The level at which decisions are taken at the first stage also varies. In some cases, there may not be any regional representation in identification of plans and the local people may not be enthusiastic about the project. Hence, it is always good and necessary to have some representation of regional and subregional levels with its extent depending on the disaggregation of problems. In a federal set-up, the decision making level depends on the project size. Smaller projects are approved at a local level while bigger projects or those that involve inter-state basins need clearance from progressively higher and usually some federal authority.

The main tasks under the problem formulation are determining the goals or objectives, deciding the investigations to be carried out, and chalking out the approach for analysis. The clarity of the problem formulation decreases as the scope increases. For example, a nationwide water resources plan will be less specific than a regional irrigation project.

At the first stage, the problem should not be viewed only from the perspective of water, but a broad view should be taken. For example, an area may have a shortage of electric power but this should not immediately mean that a hydroelectric power project needs to be constructed. A better solution might be a thermal power plant. The solution also depends on the attitudes and stage of development of the society. A society, which is affluent, nature-loving, and conservation-oriented, may not be willing to construct a dam to meet water requirements. However, such concerns will not be prominent in another situation, e.g., when a dam contributes to water supply to a drought prone area or the production of badly needed food and fiber. But local concerns are not always the deciding factors. At times, vocal and influential outsiders are able to stall or even thwart a project, may be out of conviction or due to other interests.

Translation of needs into problem formulation is an iterative process. It undergoes changes in time and becomes more and more focused and pin-pointed with time. The problem formulation depends on the nature and scope of the problem, the planning level, various constraints (technical, economic, political, etc.) that must be taken into account, and above all, the project objectives. The problem formulation is also subject to several constraints. Administrative and hydrologic boundaries rarely intersect, time and funds allocation for the problem are often limited, and various regulations narrow the range of planning options. Moreover, skilled professional personnel may not be available. These are some of the constraints that influence the problem formulation. The appropriate consideration and resolution of these constraints is necessary to search and implement a viable solution.

Once the preliminary formulation of a plan nears completion, a clear statement of the project objectives should emerge. Such a statement cannot be prepared without the detailed data about the cost of achieving each of these objectives. Various alternatives to meet each objective should be considered and the adverse or beneficial impacts of each decision on other objectives should also be considered. It is necessary to have realistic information about the cost of meeting each objective and the benefits likely to arise. For example, in many projects, faced with the opposition, the promoters began quoting those objectives also which were not initially part of the project or highlighted those objectives which were a minor part of the project but had higher emotional value. This was done to buttress the justification for the project but caused confusion and problems later on.

9.5.1 Dependency of Water Sector Plan on Other Sectors

For this discussion, 'other' implies non-water sectors, e.g., energy, transportation, rural development, poverty alleviation, etc. Every development scheme that has a component concerned with water should not be considered to be a WR project. Unless the solution has substantial control and management of water, the project need not be in water domain. Therefore, all competing proposals of other non-water sectors of the economy should be considered before formulation of a water plan. The issues that may arise at this stage typically are hydropower versus other sources of power development, navigation vs. rail/road transportation. This also requires studying substitution and trade-offs. The interface and interdependence of water and related land resources with other sectors of the economy should be recognized in a preliminary project formulation. Water resources planners may have inadequate information concerning other sectors of the economy. For example, the assumptions about the future cropping patterns are frequently not realistic because farmers follow that particular cropping schedule which is the best from their point of view rather than from the project view point.

The extent to which water resources development is treated as an individual sector of the national economy depends on the major income generating sectors of the economy. For example, in India, where agriculture was the main occupation till 3 to 4 decades ago, the resource allocation for water sector was made under the broad heading of irrigation. In fact, the nodal ministry in the water sector was known as the Ministry of Irrigation. Recently, this Ministry has been named as Ministry of Water Resources but the allocations under the national plan continue to be under the heading of irrigation. The responsibility for the management of water resources is shared among a number of ministries, e.g., Ministry of Agriculture, Ministry of Energy, and Ministry of Rural Development. Many times, there is considerable overlap in the responsibilities of these ministries resulting in confusion and sub-optimal WR management.

9.5.2 Articulation of Project Objectives

The goals and objectives are stated differently at various planning levels. The ones at the national level tend to be global (e.g., to enhance national economic development, social well-being, regional economic development). Moreover, they do not detail the conflicting issues. They are intentionally as encompassing and as comprehensive as possible to ensure broad support by various constituencies and stakeholders. After an agreement about the general project objectives is reached, more focus should be centered on specific objectives and their translation into design criteria. These criteria require definition of the measures that will be used to assess the degree to which individual objectives have been met.

One of the most important parts of preliminary plan formulation is a clear statement of project objectives. In most practical situations, objectives cannot be taken as given. A difficulty may arise because the objectives may be conflicting and the alternative means of satisfying any one objective may produce substantial adverse effects on another. It is usually impossible to appropriately define objectives without having detailed information about the feasibility and cost of achieving them. Only a rigorous quantitative analysis can indicate whether a particular objective is feasible or not and how much it will cost to achieve it. Such analysis and ultimate choice of socially relevant project objectives requires judgment on the part of the water resources planner as well as other participants in the planning process, e.g., the politician. The perception of project objectives by the public at large and other constituencies is also equally important.

The specific project objectives usually coincide with some water management aspect, such as water supply, protection against floods, hydropower production, and development of navigation. An analysis of project objectives shows that depending on the character and the scope, objectives can be stated in very different ways. While formulating objectives, many assumptions are also to be made. This is a difficult task and many times the planners make such assumptions that help justify the project. An important and crucial assumption in irrigation projects is about the cropping pattern in the command area. An analysis of the existing projects shows that in many cases, the actual cropping pattern is completely different from the one assumed in the planning stage. Prior to the project, the farmers were growing the crops which were best suited as per the water availability at that time. However, when adequate water became available, they switched to the crops which gave them the best returns.

9.5.3 Project Constraints

The enumeration of project objectives and constraints go together. The constraints are helpful in the sense that they restrict the feasible alternatives and reduce their number. However, from an evaluation point of view, constraints often have a function similar to objectives. Reasons like topography, dense population, etc. make some projects so narrowly constrained that only a few feasible options are left.

All constraints on the projects should be clearly identified and listed at the initial stage. At this stage, the constraints should not be viewed as an absolute restriction and these need not be treated as inviolable. Of course, some constraints depend on physical factors, e.g., water available at a particular site and these cannot be violated. A problem may arise when there are differing views of the experts on the subject particularly if adequate data are not available. For example, different experts may arrive at different yields at the given site and the planner will be at loss while choosing the right number. Such types of problems, however, can be minimized if detailed data are available. Although the constraints considered in water resources planning vary widely, most attention is paid to technical and economic constraints. Also important and often overlooked or underestimated are the institutional and cultural constraints which rule out certain project alternatives. In general, all constraints should be explicitly specified and open to debate in the plan initiation phase to avoid controversies that may surface at later stages. Often the planners may also be constrained to use only the existing data, irrespective of how inadequate and unreliable the database is.

The availability of funds clearly imposes a constraint on the magnitude of development. However, such constraints can be overcome to various degrees and should not be viewed as sacrosanct. There are instances when the political decision-makers decided to take up a project even though the full funding was not arranged. The perception of funding agencies also changes with time due to developments in global economy, the progress of the project, and views of influential groups.

The above discussion suggests that the constraints must be scrutinized from many points of view as the analysis proceeds and technical possibilities emerge, and their roles may be subject to change. Some constraints are permanent and can never be violated, while others are binding in the short run and may be changed with the passage of time or removed by invention or technological improvement. But irrespective of the nature of particular constraints, the systems analyst should examine their influence on the marginal cost and project outcomes. The analyses should also bring out the consequences of violating or relaxing a constraint.

9.5.4 Planning for Operation

Planning for operation, which generally leads to the generation of operational rules for the project, is an important step in the planning process. It is also the most intensive systems analysis step. Although the operation policies are developed for the entire planning horizon at this stage, they are not followed in reality. These policies considerably change when the real-life operation commences. However, they serve the following important objectives in the planning process:

(a) Provide an analytical mechanism with which to develop design criteria and thus optimize the project design.

(b) Enable the planner to better understand the couplings among the various subsystems (reservoirs, rivers, groundwater systems, etc.) and consequently account for the system constraints and attributes.

(c) Enable the agencies responsible for operating the project to initiate contractual agreements with, for example, electric power or water supply utilities.

(d) They lead to identification of major gaps in data, if any. If needed, a new data collection program can be started.

(e) Help to uncover early signs of conflicts with other agencies and/or water resources operating entities. In this case, a process of negotiation may be initiated and/or some of the project design may be altered to accommodate these newly discovered institutional or organizational constraints.

(f) Provide a useful training medium for those who will be responsible to operate and manage the project when it is completed.

(g) Assist in the development of an appropriate cost-sharing formula for the project.

These and other objectives associated with operational rules dictate that the planning team should develop a reasonable planning-for-operation policy as a part of the planning process.

9.5.5 Conjunctive Use Planning

Integrated WR planning must deal with the availability of water from all sources, the use to which water is to be put in the best possible manner (including the amount and timing), the various impacts of the uses on its quality and on environment, constraints in water development and management, and socio-economic needs. One option to solve water resources problems is the conjunctive use of water which is the coordinated management of surface water and groundwater. It should be attempted whenever possible.

Various advantages of conjunctive use are worth mentioning here. Operation of both surface and ground water reservoirs provides for larger water storage and hence greater water conservation. Greater utilization of ground water leads to smaller surface distribution systems. Since pumping well would act as a vertical drainage and aid in controlling the water table, a basin where conjunctive use is practiced would require a small drainage system. In conjunctive use planning, canal lining can be reduced, as seepage from canals provides recharge to ground water. Surface reservoirs can store water during the period of excess flows to control floods. This water can be released later for artificial recharge. The conjunctive use leads to lesser evapotranspiration loss. Surface water is a source of electric energy and this energy can be transmitted to a far away place and used to withdraw groundwater.

The problem of selecting the best strategy for conjunctive use of surface and ground water in a complex system where conflicting interests compete for limited natural and financial resources can be solved by the systems approach. Therefore, the systems approach is being increasingly used to solve various problems associated with conjunctive use planning more so with the advent of digital computers. Basically the problems have been solved in two frameworks: optimization and simulation. The topic of conjunctive use planning has been the theme of innumerable technical papers starting with the classic work of Buras (1963), Buras (1972), and Rogers and Smith (1970). Willis and Yeh (1987) also provide a detailed discussion on this topic.

9.6 INSTITUTIONAL SET-UP

An administrative structure which guarantees careful operation and maintenance of completed systems and which has sufficient flexibility to adjust to changing needs is necessary for efficient water resources planning and operation. Establishment of a well-functioning water administration with strong powers of regulation and a well-trained maintenance staff hardly requires emphasis. Countries, that have a well-developed WR administration that has evolved with time and experience, have been able to reap large benefits. The organizations that are involved in water management commonly belong to federal government, state government, and local/municipal authorities. In addition, there are river basin authorities, private utilities (for water, sanitation, and energy), non-governmental organizations (NGOs) and water user societies.

The organization that is commonly assigned the responsibility to initiate planning for a new WR project is often an existing institution or group. Most commonly, an existing structure fits the objectives of the project; in rare cases a new planning entity may be created. If a national agency charged with water resources planning is already in existence, it may, in all probabilities, take the lead and prepare the plan. There will be a local set-up for a small-scale project.

To ensure a sufficiently comprehensive plan and to evaluate several project options, a mix of agencies is preferable. This is because government agencies in many countries have developed a specific mission over the years. One of them, usually the biggest, is entrusted with the leadership and coordination responsibilities. Typically this will be a water resources or an irrigation department. There might be a federal organization with a clear mandate to technically examine and approve all the projects before they are included in the national plans. Sometimes, more than one such organization examines the project from specific angles, say water resources, environment, pollution, etc. The involvement of external experts from academic or research institutes in the planning process is quite common; specific research projects to study important aspects may also be occasionally funded.

9.6.1 Involvement of Experts

The multidisciplinary nature of water resources planning necessitates that interdisciplinary interaction should take place at each stage. The contributions by experts from different fields are necessary to ensure the best results. Usually the results are more multidisciplinary than interdisciplinary, meaning that although there is interaction, it tends to take the shape of a presentation of results by the individual experts as seen in the light of their own expertise.

The major group of experts involved in the plan initiation and preliminary planning phase consists of systems analysts. They must interact with other groups who have expertise in municipal and industrial water supply, irrigation, hydropower production, forestry, etc. It is crucial that the systems analysts and disciplinary experts fully understand project purposes and objectives. This is especially important when the disciplinary experts identify constraints that reduce the modeling freedom of the systems analyst. It is also important to consult experts from other fields, such as lawyers, biologists who investigate rare species, archaeologists, etc. to ensure that these issues are also suitably addressed.

The locally available expertise and the scope of the project influence the selection of experts. Since water projects are closely linked to social and economic life, the consultants should be familiar with these facets of the society and do not impose alien practices.

9.6.2 Decision Making Levels

Many water resource projects are large, and huge sums of public money are invested. The allocation of money for them depends upon the needs of the other sectors of economy. Therefore, decision making chains are long and final decisions are made at political levels. The natural disasters, like floods or droughts, often provide push for initiation, formulation, approval, and implementation of water resources projects.

The basis for a decision on a WR project is a detailed report in which the project objectives of are outlined as well as the means by which they are to be accomplished and associated costs. The consequences of the project in terms of benefits and adverse impacts are also detailed. WR planning is the sum of all activities which lead to such a detailed project report. The larger the project and the more intensive the use of WR, the broader becomes the scope of the planning process. It is, therefore, necessary to evolve a hierarchy of levels for water resources planning, beginning at a level where all possible projects are considered in the context of a general national master plan. A national water plan must spawn sub-plans, which cover more details for a smaller area.

Typical of such a planning cascade is a division into various levels. Different countries have different planning levels, but in general one can identify three levels, and these are often associated with different planning authorities.

(i) Level A is a reconnaissance study or a general framework study. The temporal horizon is about 30 to 50 years. The purpose is to identify major current or prospective problems. The geographical coverage is generally very large. This level may involve international agreements on the allocation of water from a river which flows through two or more countries. These agreements are reached on the basis of water resources development as well as many other national interests including strategic aspects. The decisions on a national or international level are of great consequence since they set the strategy for development.

(ii) Level B is a comprehensive planning effort for a smaller region. This level should follow Level A, where problems have already been identified. The time horizon is about 15 years. The purpose of water resources planning on this level is to set priorities for the long-term development of a country. Its decision level is largely political and involves technical inputs only on a limited scale, usually as financial data or constraints. Often this is the levels at which the decision whether to proceed with the planning for a project or not is taken and funds earmarked.

(iii) Level C is implementation planning, where specific project designs are developed. Generally, Level C should follow Level B, because specific plans or recommendations from the Level B effort are implemented here. This level is regional; its results are incorporated into a regional water plan which identifies WR projects within the context of different requirements imposed by alternative development plans of a region. The objective of such a study is to set priorities and to make recommendations for allocation of WR to different users.

9.6.3 Compatibility among Agencies

Even though cooperation with agencies during the planning process is essential, this will not necessarily lead to a coordinated output. All the agencies may not feel the need for cooperation. There may be inter-agency or personal disagreements or dislikes. Usually there is no clearly identified person for coordination and it is common to see that different persons or a person without much interest, background, responsibility, or authority is assigned the duty of coordination. It is also important that a water resources plan does not get 'drowned' by the activities of another agency's project, e.g., a water quality improvement plan poisoned by diversion of polluted flows by another agency. Although these things look very simple and logical but there may be complications. Frequent interaction and coordination is the best way to avoid wastage and save efforts.

The possible ways to enhance cooperation include jointly working on problems, mutual visits and exchange of personnel. With the developments in information technology, it has become much easier to share and exchange data and documents. Although it is important to put in place a proper mechanism, the actual coordination depends on persons – unless the concerned persons are enthusiastic about it, the things just do not work.

9.6.4 Capacity Building

This is not a part of planning process but has its relevance and importance for overall development. The shortage of trained manpower is a major hindrance in applying the improved technology, particularly in developing countries. This shortage can be overcome in two ways. As an immediate solution, some funds can be earmarked to train a few personnel on the techniques that will be used in the analysis. These people may also impart training to their co-workers. The second and a long-term solution is to initiate advance courses in local universities which can be taken by the prospective candidates. At the same time, job positions at an appropriate level with commensurate benefits should be created in the planning department.

A hierarchy of objectives of education programs for water resources engineers, planners, and managers was presented by Dyck (1990). A number of sample course structures of different durations based on the background of the target audience have also been presented in this publication.

9.7 PUBLIC INVOLVEMENT

Evaluations of many past development projects have shown that poor identification of the needs of local communities and inadequate assessment of the social impacts is key reason for project failures. This experience has forced planners to search for ways to improve projects. An important remedy is more rigorous pre-project analysis of social and cultural conditions and more interaction with people and consulting local communities during project design and implementation in 'open' planning. Furthermore, local residents with deep knowledge about the area can sometimes provide better inputs than 'an outsider planner'. At the same time, the local communities may not be able to appreciate the new ideas unless they understand the thought process which has generated these ideas. Thus, there is a necessity of a framework within which all stakeholders can access and analyze information, establish priorities, and develop plans. The United Nations (UN, 1997) has laid special emphasis on public involvement in WR projects. Since WR projects are capital intensive, it is common to approach international financing and donor agencies for funding. The major financing agencies use the term *Public Involvement* to denote the activities through which the concerned stakeholders are integrated into the decision-making process.

Public Involvement (PI), also termed as public participation, is the process through which the views of all interested parties (stakeholders) are integrated into project decision-making. Here *public* refers to persons or groups having an interest in the project. Public participation refers to the involvement of such individuals or groups in decision-making or trying to influence decisions. The basic premise behind such participation is that the officers of a governmental agency or the engineers of a water authority may not know fully well what the public wants and what is best for them. An important implication of this finding is that public participation should not be limited to just ascertaining different views. It should also make the project affected people conversant about the decisions being made and their implications on their life and environment. At the same time, it is important to ensure that expression and consideration of public viewpoints does not improperly impede the decision - making process. While coordinating public participation, the planners should be aware of (a) the limitations inherent in public participation, (b) the requirements that must be met to ensure adequate anticipation, and (c) how that participation should be structured.

The term *stakeholders* includes all individuals and groups with an interest in a project. They can be divided into four categories: government agencies, directly affected parties, indirectly affected parties, and other parties (including NGOs). Some stakeholders are easily identified; to find others, field visits, studies, and discussions are necessary.

In several countries, WR planning and management is the responsibility of specialized agencies which represent the interests of all water users. The public is indirectly represented in the planning process through their political representatives who are members of government administrative agencies. Except through politicians and non-governmental organizations, generally there is no worthwhile public participation in WR planning activities in many countries. In some cases this has led to serious problems during execution of projects. It is necessary to acquire land for reservoirs and canals projects; there may also be displacement of population due to land inundation. A large-scale displacement disturbs the social setting and usually old people have a nostalgic attachment with the land. There might be resentment against the project among the project-affected-people if they feel that they have not been adequately compensated. Public participation in the project planning is helpful largely to overcome such problems, although it does not always work that way. In many countries, public involvement in a project is ensured through public hearings where planners present and discuss their plans to the general public.

The main aim of PI is to create openness and dialogue from the outset of a project so as to improve decision-making. It is important to note that development should be based on a process of sharing knowledge and values, rather than attempting to impose new values.

Also, there are no prescriptive methods for involving the public in decision-making. While the underlying principles of PI are applicable to all countries (and all natural resources projects), the mechanism and degree to which the public is permitted to participate, will vary considerably from one society to another (according to socio-political and cultural context) and from one project to another.

Although PI may appear to be time-consuming and costly at first, the long-term benefits far exceed initial costs. Nevertheless, it is an iterative (repetitive) and flexible process which should, ideally, take place throughout the lifetime of a project. As far as possible, the PI process should be integrated into project planning, and in particular into the environmental assessment process. This process should start at the earliest stage possible in decision-making; better even when the project is being conceived. As things are, it would be wonderful if all stakeholders accept PI as the normal way in which to plan and implement projects.

9.7.1 Advantages of Public Involvement

The concept of PI has evolved over time through learning and experience. The key advantages of public involvement in decision-making are:

- PI reduces the risk of project failure by improving the quality of planning and decision-making.
- By bringing a diverse range of values and opinions to the table, PI can improve problem solving.
- PI helps in development of the feeling of partnership with local communities. It thereby overcomes the local resistance and provides a conducive work environment.
- PI significantly reduces conflicts between individuals, groups and organizations.
- PI helps in improving the project performance by using the technical expertise of the public.
- The poorer the people, or the scarcer the resource, the more important it is that local communities take part in project planning and decision-making because their survival and well-being may critically depend on it. In some cases, the project in question may be the most crucial chance of development for a generation or more.

Specifically, the benefits that PI can bring to all stakeholder groups, including the government, developers, and the affected parties are:

Advantages to the Government

- Increased credibility, legitimacy, and positive image through transparent decision-making, particularly when decisions are controversial.
- Improved coordination between governmental departments as per the needs of the PI process.
- Higher level of commitment of all stakeholders to decisions made.
- Reduced risk of serious confrontation, thereby minimising project costs and delays.
- Development of a sense of belonging and responsibility among local communities toward projects.

Advantages to Financing Agencies

- Realistic information about the needs and preferences of local communities.
- Better project database right from the early planning.
- Improved technical design of projects, thereby reduction in costs.
- Increased market share by virtue of positive image.

Advantages to Affected Parties

- Improved understanding of the project and its impact on their lives.
- A project which meets their actual needs.
- Higher chances of success of the project and thereby improvement in the living standards.
- A platform for local communities to voice their concerns at all levels of government.
- Better targeting of benefits.
- Increased levels of accountability of government and developer to local communities.

9.7.2 Activities in Public Involvement Process

The PI includes a number of activities where each step is a prerequisite and leads to the next. Considerable pre-planning is needed and PI has to be carefully handled to gain the most out of it. For example, one cannot have participation without consultation and consultation cannot occur without information dissemination. Goodman (1984) classified the various public participation and education techniques in five categories. These are: large group meetings, small group meetings, organizational approach, media, and community interaction. He analyzed 23 PI techniques and has discussed advantages and disadvantages of each of these.

The four main activities of PI are enumerated below.

1. *Information gathering:* It is a systematic analysis of existing social, cultural, and economic conditions about directly affected groups of stakeholders (such as farmers or indigenous minorities). Data are obtained through surveys, questionnaires, site visits, and polls. These are analysed to identify key issues, key people and organizations, and their level of interest.

2. *Information dissemination:* It is a process of providing information about a project to the stakeholders. A variety of tools can be used depending on site conditions, level of literacy, infrastructure, and attitudes of the communities: electronic and print media, exhibitions, conferences, and seminars. Trained field staff is useful for this purpose. The public should be kept informed regularly – during active periods as well as during 'quiet times'. To the extent possible, the information should be disseminated in local language without too much technical jargon. Clearly, the stakeholders can participate and be useful only if they are fully informed.

3. *Consultation:* This is the step in which decision-makers listen to the views of other stakeholders in order to improve project design prior to implementation or to make necessary changes during implementation. Consultation should involve government, affected parties, lending agencies, and NGOs through workshops, round table discussions, and seminars, preferably at a project site. It is important to classify stakeholders because not all of them will interact at the same level. Irrespective of the knowledge and skills, all the members of public should be treated with dignity and respect.

4. *Participation:* This is basically an extension of consultation where directly affected groups become joint partners in the design and implementation of projects. They participate in "making" the decisions. It is a good idea to involve district/county level authorities in this effort. Finally, the public should be informed about the decision and reasons thereof.

It is important that all stakeholders, including those who may be affected unknowingly, are involved and given a fair opportunity to influence the design and implementation of a project. Indirectly affected parties (often poor or marginalized communities) are the most difficult to identify and involve in the PI process. Planners should take a pro-active role to facilitate and monitor the PI process from early consultation to the post-decision period. Needles to say, even the best techniques fail unless the agency responsible for overseeing the PI processes has the required sincerity, integrity, and commitment.

In some countries, public hearings and public participation are required by law prior to the final approval of any major WR project that involves public funds. These public hearings have a great advantage because the public concerns, objections, and views (other than those of directly interested agencies) are heard, and subsequent modifications are often incorporated in these plans. There is a need to systematize this participation to the extent possible and integrate it with the entire planning and screening process. The development (and design) of questionnaires that can articulate public preferences in a cogent way is also important. Also, a preliminary education of the public on the issues at stake and the preparatory steps for public hearings and evaluation of these alternative plans should be planned well in advance.

Examples

(i) It was reported by UN (1997) that during the early 1980s, the National Irrigation Administration (NIA) in the Philippines changed its approach from construction of large-scale irrigation systems to assisting in the development of small-scale community systems. A programme of new projects was initiated, building on indigenous methods and improving these methods via participatory projects with local farmers. Additionally, NIA embarked upon an extensive training programme for farmers and its own staff, and assisted farmers in organizing themselves into formal irrigation associations. By the mid-1980s, in participatory irrigation schemes, crop yields were generally 20 per cent higher than in non-participatory schemes, and farmers' satisfaction with the canals and structures was considerably higher. The levels of cost recovery were between 5 and 7 times higher; and water distribution between farmers was more equitable.

(ii) A Brazilian water and sanitation project for low-income communities involved communities and was able to design systems at a cost of US$ 50 per capita, well within the government-stated ceiling of US$ 120 per capita. Both the funding agencies and the government benefited from PI.

(iii) In India, some states are encouraging transfer of responsibilities of management of irrigation systems to Water User's Associations. The state of Maharashtra is one of the leaders in this aspect. The results of case studies have shown that the transfer of rights and responsibilities has led to improved performance in terms of maintenance of structures, equity in water distribution and higher productivity. Simultaneously, adoption of volumetric pricing has resulted in higher water use efficiency. The recovery of water use charges is also better.

9.8 FORMULATION AND SCREENING OF ALTERNATIVES

This is the third stage in the water resources planning process. The main activities at this stage are: classification of project alternatives, the actual generation of project alternatives, and screening the project alternatives. The outcome after this stage is the formulation of selected alternative projects and evaluation of their relative advantages and disadvantages.

9.8.1 Classification of Alternatives

In the planning process, all plausible project alternatives should be considered: feasible and infeasible, structural and nonstructural, and water and non-water. Although some may view the study of infeasible alternatives as wasteful, important and valuable information might be gained from such an effort. For example, a sensible measure or plan that happens to be at the time politically or institutionally infeasible can shed light on the cost associated with existing institutional impediments and might indicate specific ways for removing or alleviating such obstacles. Non-water alternatives often constitute an integral part of a water alternative package; for example, land transportation might be considered as an alternative to navigation. Technical constraints also govern the selection of alternatives. For example, a dam site might have an excellent rock foundation but would require major work in relocating people or rerouting transportation lines, while another location might require extensive foundation work.

Furthermore, it must be realized that there are often different alternatives to accomplish the same objective. For example, flood protection can be achieved by retention structures, flood levees, or zoning to prevent settlements in flood-prone areas. Similarly, alternatives for water supply include the use of ground or surface water or both. Hydropower generation should be considered within a broader economic scale, with nuclear or fossil-fire generating units considered as part of the system. Such considerations commonly lead to the use of pumped storage plants, where excess energy during low-consumption periods is used to pump water into a temporary storage at high elevation, from which it is released through turbines to generate energy during peak hours.

9.8.2 Generation of Alternatives

Stage 3 of the planning process involves formulation and screening of project alternatives. Depending on the number of alternatives to be examined, there are several possibilities for their screening. These are as follows:

(i) If the number of alternatives is small, the screening step can be eliminated.
(ii) If there are many but not too many alternatives, it is helpful to systematically screen them using mathematical models.
(iii) If the number of alternatives is large, some type of hierarchical screening in stages is helpful. An increasing rigidity of selection and/or exclusion criteria can be adopted as the screening proceeds till a small number of alternatives remain.

Stage 3 has a considerable overlap with stage 4 (development of final study results). Therefore, ideally the same personnel should be involved. The planner who is engaged in generation and analysis of alternative projects should carefully select the decision variables and their feasible range. Alternatives are generated by selecting the various possible sites for projects and then various sizes and configuration of the components. The planner and the decision-maker also decide which of the systems objectives should be kept as such and which should be considered as constraints.

9.8.3 Techniques for Screening Alternatives

There are two principal options to deal with the screening problem. In the first option, alternatives are screened using some mathematical technique or judgment based on prior experience; a simplified representation of the system is chosen. Application of LP as a screening tool at this stage is a fairly common practice. In the second option, a set of potential alternatives is developed (often based on experience or experts recommendations), and these are then evaluated and ranked according to some criteria. In both options a single criterion or a multitude of criteria may be employed. Screening of alternative plans is an iterative process. The techniques that are commonly used for screening have been described in Chapter 5.

Screening techniques may range anywhere between the rule of thumb and formal analysis, depending on the type of the problem and the level of screening at which ranking procedures are used. By means of optimization methods, a large number of alternatives can be evaluated, but while using these models, a detailed description of all the alternatives is not possible. By contrast, a simulation model allows for a very detailed description of the system, but only a few alternatives can be investigated due to limitations of time and other logistics. The choice of the right systems analysis tool depends on the individual problem and the preference of the analyst.

9.8.4 Evaluation of Alternatives and Finalization

Since planning deals with future, the planners have to make predictions about the conditions when the project will be operational. The future cannot be predicted with certainty and there is always an element of uncertainty. In addition, decision-makers must analyze the various alternatives that often involve conflicting economic, societal, environmental, and political forces. With ever-increasing public awareness and influence in the decision-making process, the planning task has become even harder. The main steps of the evaluation process are as follows:

To elaborate and quantify:

- The scope and extent of the system,
- The structural and nonstructural components of the system,
- Constraints – topographical, hydrological, structural, financial, institutional, etc.
- Target demands for various purposes, e.g., irrigation, municipal and industrial, hydropower, water quality maintenance, recreation, etc., and
- Flood management aspects, if any.

To analyze:

- Evaluation of alternative plans that have been identified at earlier stages,
- Economic analysis, and
- Assessment of environmental impact of alternative plans.

The pre-feasibility study is considered to be over when the potential alternative plans that are suitable for implementation have been selected. In many countries, public hearing is held at this stage to explain the plans, and elicit public views and comments. The decision-makers at various levels also participate in the discussions. Based on the outcome of these, the plans are suitably modified. The planning agency may also be asked to carry out additional or more elaborate analyses during the scrutiny of the project proposal. This process culminates in the decision to continue or discontinue the planning activity. This decision is usually taken at the political level.

9.9 MODELS FOR WATER RESOURCES PLANNING

Because of the complexity of the issues involved in WR planning and because of the significant impacts of such projects on environment and regional/national economy, appropriate planning methods must be employed which can handle the problems satisfactorily. The systems analysis approach is a set of tools for analysis of water resources projects. In systems analysis, the system and their components are described by means of mathematical models. The objective of the analysis during planning is to find the system design with best possible combination of elements to meet the desired objective.

A model is a simplified representation of the real system and the utility of modeling results depends on how well the modeller is able to perceive actual relationships and capture them in the model. While physical models are mostly used to design various physical components of a project, e.g., spillway, mathematical models are useful in analysis, such as hydrologic, economic, impact assessment, etc. Mathematical models are also very handy in evaluating the consequences of alternative plans. Clearly, one cannot conduct experiments on a prototype project. The use of models is often less expensive and convenient than conducting comprehensive surveys or other conventional approaches.

Mathematical models describe the physical processes, such as the movement of a flood wave in a river channel in a simplified manner through arithmetic and logical statements. These models have assumed a unique role in planning and management of water resources. Models are currently used to investigate virtually every type of WR problems for small- and large-scale studies and projects, and at all levels of decision making. The use of models has made it feasible to quantitatively compare the likely effects of alternative decisions. At the cost of redundancy, it needs to be stressed that systems engineering is not a substitute for the decision-making process. Rather, it is a set of tools that help these tasks.

9.9.1 System Decomposition

A necessary condition for successful use of systems methodologies for WR planning is the ability to develop a model that takes care of various objectives, constraints, and input-output relationships of the system being modeled. Only if this condition is met, the results of the model will be meaningful and implementable.

A real-life WR system possesses most of the following characteristics:

(i) multiple non-commensurable objectives as well as multiple decision-makers;
(ii) a large number of variables and parameters;
(iii) a large spatial and temporal database;
(iv) a large number of subsystems; and
(v) relations among the variables that are nonlinear, space and time-dependent, and stochastic.

Working under such a complex situation, the analyst may be bogged down in the plethora of models, analyses, and results. With this motivation, the concept of the hierarchical approach was presented by Haimes (1977) and is based on the decomposition of large-scale and complex systems and subsequent modeling of the system into "independent" subsystems. This decentralized approach utilizes the concepts of levels and layers, and enables the modeler to analyze the behavior of subsystems at a lower level. The results are then transmitted at higher levels. When applying the hierarchical approach to water resources systems, several combinations of hierarchical structures are possible. The four major decompositions are as follows.

(1) Temporal decomposition

The planning horizon for water resources projects is of the order of 100 years. However, the conditions of the system change with time; the storage capacity of a reservoir changes with time; the development of a command area proceeds with time; the area to be protected from floods undergoes changes; and so on. Hence, an intermediate term of 10-15 years, often referred to as planning-for-operation, is usually embedded in this long-term planning. There may be another short term of 2-5 years further nested into it. All these plans have to be compatible with each other and well coordinated since they relate to the same system.

(2) Physical-hydrological description

A river basin is the natural unit for planning and operation of water resources projects although administrative units are adopted in some cases. A regional water resources development program may cover several river basins. Each basin can be further divided into sub-basins and so on. The topic of river basin modeling has been discussed in Chapter 14.

(3) Political-geographical description

More than 200 river basins in the world are trans-boundary basins, i.e., they fall under the territory of two or more nations. Within the same nation also, the project area may fall under different political or administrative units, e.g., state, district, county. The analyst may consider either political or natural boundary as a criterion for decomposition.

(4) Goal-oriented or functional description

Water resources systems can be analyzed with respect to their economic and functional goals. The models following this pattern typically are demand and supply models, and models for hydroelectric power generation, irrigation, municipal and industrial use, etc.

9.9.2 Selection of Systems Analysis Tools

Although a spectrum of systems analysis tools, varying from very sophisticated to simple, is now available, the choice should be to go for 'appropriate' technology. In other words, the technique chosen should be commensurate with available data, equipment, expertise and site-conditions. According to Miser (1982), analytic tools should be chosen considering six principles:

1. They should be appropriate to the problem and to the prospective solutions that may emerge.
2. They should match appropriately the available data. A method may be very attractive but if it requires data that are not available for the focus system, it cannot yield trustworthy results.
3. They should be internally consistent (the sophisticated analysis of one part should not be bludgeoned by hazy speculation in another).
4. They should be balanced in detail and accuracy (if one enters with order- of-magnitude estimates, one is seldom entitled to five - figure accuracy in the results, or if accurate estimates are combined with very questionable estimates, this fact should be reflected in how the results are presented).
5. They should be appropriately interdisciplinary in the light of an appreciation of the problem with which the work began and is being continued.
6. They should be appropriate, if at all possible, to the process of presenting the findings that will emerge at the end of the planning study (the client will surely not want to poke into details, but some understanding of the analytic tools has a persuasive value for many users of systems analysis results).

Generally, the techniques of analysis for a particular project are not completely chosen in the beginning nor they are finalized in one go. The selection also depends on the preferences of the analyst and the requirements of the funding agency, if any. In the early stages, design may be based on thumb rules and the sophisticated techniques come into picture with the involvement of experts. There are many instances where tools of widely varying complexities have been applied in the same study. It is not uncommon to see that the output of a crude analysis forms the inputs to a sophisticated analysis! Frequently a tool is employed just because it is available or a person trained for that tool is a member of the planning team, although more relevant tools might be available.

It is advisable to use simple models in the earlier stages of planning. The reason being that not much data may be available at these stages, a large number of alternatives may have to be tried, and the available time may be limited. There is a trade-off between accuracy and expediency; the balance often tips toward the later to provide quick and reasonable results. But in later stages, the balance should gradually be moved in favor a greater accuracy and more detail. Actually, the requirements at later stages necessitate the use of the best possible tools to refine the analysis.

An important requisite for the viable use of models in the planning process is the perception (by the planners and the public) of their credibility. The entire study can lose the participatory support of the concerned agencies if the models and procedures used are perceived as lacking in credibility and scientific footing.

The systems analyst has to find the tools that will best meet the planning needs. An approach, which allows the aggregation of several models, can be very helpful. In complex planning efforts, simulation is usually the preferred approach. Jacoby and Loucks (1972) were among the first to demonstrate how the optimization and simulation models can be effectively used together in river basin planning. Often, simulation is coupled with some kind of single-objective or multi-objective optimization, e.g., for optimization of water allocation at each simulation step.

Many times one comes across the debate whether optimization is a better tool or simulation is. This debate is unfortunate at best since the prime objective should always be to solve the problem in the best possible way rather than promote a particular technique. Simulation, when used as a search technique, is often preferred in complex problems. Many analysts prefer to take a number of simulation models by changing the input to get a feel for the behavior of the system or to do 'manual optimization.' In this approach, the analyst can effectively use his experience and judgment.

9.9.3 Use of Multi-objective Analysis

Multi-objective analysis is especially pertinent in river basin planning due to the presence of several conflicting and non-commensurable objectives. For example, the economic efficiency is measured in monetary units while environmental quality may be measured in units of pollutant concentration. However, society is placing an increasing importance on non-pecuniary objectives that are difficult to quantify monetarily. As pointed earlier, Major

(1977) noted that the term "multi-objective" refers to multiple economic, social, environmental, and other objectives of water development, and "multipurpose" refers to multiple functions of water projects like navigation, flood control, etc. These are not synonymous; purposes can vary and still be aimed at the same objective, and one purpose can fulfill more than one objective.

Traditionally, benefit-cost analysis has dominated the planning process. In this, only one objective (economic efficiency) is considered, with the other objectives being included either as constraints or as being somehow commensurate with the primary objective. In fact, that this analysis is a simplified case of multi-objective analysis in which all objectives are expressed in terms of benefits and costs.

Fundamental to multi-objective analysis is the Pareto optimum, also known as the non-inferior solution. The generation of Pareto optimal plans can be invaluable in identifying specific characteristics and attributes of a basin's subarea as well as in quantifying the complex interrelationships among the many components in the planning process. The non-inferior solutions and the associated trade-off values help the decision-maker select an acceptable level of assurance and the corresponding cost. In other words, decision-makers can make known their preferences with respect to the level of assurance against uncertainties in the model prediction at the expense of degradation in the model's optimal solution. While formulating and screening alternative plans, multiple purposes which are often in conflict and competition, must also be given explicit and quantitative consideration to the extent possible. For example, the use of reservoirs for flood control purposes may be achievable at the expense of reducing hydropower generation.

Multi-objective analysis should be viewed not only as a new method but also as a philosophy. Trade-offs are an inherent part of negotiation, of reaching consensus, and of compromise solutions. Thus, the use of multi-objective and trade-off analysis in the development of final plan results can be a natural step in this phase. The role of multi-objective analysis is particularly critical in addressing nonstructural plans, in which the cost, benefits, and risks cannot be easily quantified in monetary terms as is the case in more structured plans. Furthermore, as environmental and other socioeconomic aspects dominate and influence policy decisions, the importance and need of multi-objective analysis become more and more critical and evident.

For most water resources systems, decisions are not made by a single individual but rather by a group of individuals. These may be legislative bodies, the river valley authorities, etc. In every case, each member of the group has a personal view of the significance, importance, and relative value of the various objectives being considered. Each decision-maker may have a different constituency to whom he or she is responsible. This means that the decision-maker must integrate the relative influence and views of the segments of this constituency into the evaluation of the merits of the alternatives. The critical influence of these decision-makers and stakeholders must be recognized throughout the planning process.

Multi-objective planning involves an interaction between planners and decision-makers and requires efficient communication for its success. According to Major (1977), there are four aspects of communication in multi-objective analysis: 1) between planning leaders and those who develop models and techniques for production of alternate plans, 2) between planners and participants in the political process, 3) communication with planners in other sectors, and 4) communication after delivery of a report or the completion of the planning process. In view of this, communication activities must be carefully planned and periodically reviewed to ensure proper flow of information. These days, decision support systems (DSSs) are being employed to help in multi-objective analysis. The North Atlantic Regional Water Resources Study (Major and Schwarz, 1990) was a large-scale application of multi-objective planning.

9.9.4 Object-Oriented Modeling Approach

The object-oriented (o-o) approach is frequently used in software development. An object is a "black box" which receives and sends messages. A black box actually contains code (sequences of computer instructions) and data. Traditionally, code and data have been kept apart. For example, in the C programming language, units of code are called functions, while units of data are called structures. In the C language, functions and structures are not formally connected -- a function can operate on more than one type of structure, and more than one function can operate on the same structure. But in o-o programming, code and data are merged into a single indivisible entity which is an object. This has many advantages. The main characteristics of the o-o approach are the following (Simonovic et al., 1997).

Identity: It implies that data is organized into discrete, recognizable entities called objects. These objects can be real-world things, such as a reservoir, a canal, or a conceptual things, such as an operation policy.
Classification: An object is defined via its class, which determines everything about an object. Objects are individual instances of a class. For example, one may create a class 'river' and then have objects like river1, etc. The choice of class depends on the application.
Polymorphism: It implies that the same operation may behave differently on different classes. It is an action that the object performs or is subject to.
Inheritance: Let there be a class which can respond to a group of different messages and a new similar class is required with a few more messages? All that is needed is create a subclass of the original class which inherits all the behavior of the original class. The original class is called the parent class of the new class. Inheritance also promotes reuse.

Many o-o programming languages are available, such as Java, C++, which permit easy use of this modeling approach. Simonovic et al., (1997) used a language known as Stella II for WR planning in Egypt using the o-o approach.

9.9.5 Model Credibility

The credibility of a model refers to the faith in the model and acceptance of its results by the concerned parties. The lack of model credibility and acceptance constitutes one of the most common reasons for misgivings about models. This lack of faith in the mind of decision-makers and the public is an important, although often neglected, issue and needs to be dealt with at all stages of the planning process. One way out is to have a presentation about the model and its applications in a similar set-up to the decision-makers in the early stages of analysis. One should, however, not rush to conclude that all decision-makers are averse to model use. In fact the reaction of a decision-maker very much depends on his background and exposure; nowadays it is not uncommon to find a decision-maker who is well versed with the modeling terminology and understands and appreciates the analysis.

Models are only as good as the perception of their creators. Because of this, they should be only one part of the decision process. Before the results of a model are accepted, it has to be proved or verified using the data of the same or a nearby system. In many instances, the results of an application of the model to a far away place, may be in a different country, are cited to support the model. Often, such justifications fail to convince the target audience. Therefore, it should be ensured that the model is applicable to the present case and the assumptions are not violated.

9.10 SENSITIVITY ANALYSIS

Sensitivity analysis is an important part of any analysis; the same is true for the planning process too. The aim of this analysis is to understand how sensitive the various plans are to the characteristics of decision variables and input data. For example, if it is found that an irrigation project can cater for 10% more command area and the marginal benefit-cost ratio is more than unity, the decision-maker may like to bring the additional area under the ambit of the project. Furthermore, if it is realized that the project design is not sensitive to a particular input variable, there is no need to put in too much effort in collecting data about that variable.

9.10.1 Risk and Uncertainty Analysis

Planning is concerned with future which is always uncertain. Risk analysis provides an assessment of trade-offs among the beneficial and adverse consequences that result from adopting a particular risk level. The existence of these trade-offs requires that risk management should be an integral part of the decision-making process. The efficacy of risk analysis in WR planning and management can be gauged by the assistance it provides to planners and the decision-makers in the following ways:

a) It identifies the sources of risk and uncertainty associated with exogenous variables and events derived from hydrological, environmental, and social factors.
b) It quantifies the input-output relationships with respect to the randomness of these exogenous variables and events.
c) It quantifies, as far as possible, the probable impacts that risk and uncertainty and their associated trade-offs will have on alternative policy decisions.
d) It enables decision-makers to make the scientific use of information about risk and uncertainty.

A relevant example of risk analysis is the dam-break modeling. This study is carried to understand and quantify the damages that will take place if a dam holding water fails. There have been many instances of dam failures in the past. Different types of dams, e.g., concrete dams, earth and rockfill dams, have different failure behavior and fail due to different reasons. In case of concrete dams, 29% of the cases are due to overtopping, 53% of the cases are due to foundation, and 18% of the cases are due to other reasons, including shortfall in construction/design, material degradation, gate failures, seismic events, etc. The main causes of failure of earth and rockfill dams are overtopping, piping, or earthquake. The list of dams that have failed in the past include the Teton Dam (U.S.A.) due to hydraulic fracture, the Machhu Dam-II (India) due to overtopping, and the Sheffield Dam (U.S.A.) due to liquefaction. The Koyna dam (India) had suffered damages due to an earthquake. Since the failure of dams is associated with huge losses of life and property, it is important that the risks associated with a dam failure are properly examined before constructing a dam. About 2000 people were killed due to the failure of Machhu dam in 1979 (Herschy and Fairbridge, 1998).

A number of mathematical models are available which can be used to delineate the downstream area likely to be submerged and the maximum water level reached in case a dam fails. Many funding agencies and governments have made dam failure analysis a pre-condition before giving clearance for major and medium dam projects. Also, if an important project, such as a nuclear power house, is to be constructed downstream of a dam, a dam break analysis is necessary to evaluate risks. Wurbs (1987) has carried out a comparative evaluation of several dam breach flood wave models. Singh (1996) has discussed the theory and mathematical modelling of dam failure and its applications in detail.

9.10.2 Uncertainties Associated with Objectives and Constraints

After the goals and objectives are adopted by the planning team, they become the dominant force that drives the planning process. Goals are positive attributes or characteristics which individuals or the society tries to attain. Goals of individuals and society are an unbounded set, i.e., any stated goal is included within at least one more-encompassing goal, and there is a set of more narrowly defined goals within it. Two major sources of uncertainty related to planning goals and objectives should be identified and addressed at the appropriate stage of the planning process. These are (i) perceptions of long-term societal goals and objectives and (ii) perceptions of the long-term availability of technological and non-technological means with which the planning goals and objectives can be achieved.

Societal goals and objectives are intrinsically hierarchical. Hence, uncertainty associated with each subgoal and subobjective contributes to the uncertainty of the overall societal goals and objectives. The input data may have errors in it. The model may have errors and the assumptions may not be realistic. Moreover, these errors and uncertainties are associated with all levels of planning. Then there are uncertainties associated with the perception of the availability of long-term technological and non-technological means of achieving the planning goals and objectives. This is particularly true for the assessment of future technology and its cost, reliability, and acceptability. Thus, the planning team should assess and evaluate the uncertainties associated with the goals on which the selected plan(s) are based and with the ways and means of realizing these goals. The approaches to rational decision making discussed in Chapter 8 will be helpful to this end.

9.10.3 Post-evaluation of Projects

Although this is not strictly a part of planning, a study of some recently constructed projects could be a very good learning exercise. The aim should not be to find mistakes in those projects but to learn what methodology was used and why, and how the same can be useful for the project under question. At the same time, the weak points of the analysis should also be noted down so that these could be improved upon. It will also be useful to have interaction and personal rapport with the planners associated with the study of those projects. There are many minor points and experiences which could be very important for people working on similar problems. Many such things may not be available in a formal report; these can only be communicated and appreciated through personal interaction.

9.11 INTERACTION BETWEEN ANALYST AND DECISION-MAKER

In cases where there are different groups of planners and analysts, in initial stages of interaction, the planners develop blue prints of several alternative plans. The analyst then uses mathematical models that incorporate a simplified model of the plans, the various internal relationships, objectives, and constraints to put these alternative plans in a quantitative form. The planners reevaluate the alternatives and modify them as appropriate, using the quantitative information generated by analysts. Following several iterations among planners and the analyst(s), the alternative plans are ready for evaluation by the public and/or policy analysts and decision-makers. In many cases, there may not be distinct groups of planners and analysts or only one team may be working on the problem. Naturally, in these cases the process of zeroing on the alternatives will not be so clear cut, although the final outcome will be the same.

The analyst, while consulting decision-makers, such as politicians and senior bureaucrats, must be aware that they may try to exclude alternatives that compete with those that they favor. Decision-makers can also identify political and institutional constraints that would exclude some alternatives. Detailed outlines of the plans must be presented to politicians, bureaucrats, and affected agencies early enough so that they will not be taken by surprise and react by completely rejecting the plan. Thorough discussions will help make them amenable to accept the plan and to identify themselves with it; this will also increase the probability that they may ultimately become its advocates.

The planners' objectives should be the development and/or formulation of a final plan that can enhance the social well-being of the people in the region, can ultimately be accepted by the public and other policy or decision-makers, and can also be implemented. In the screening process, this objective should guide the planners toward a compromise plan or solution that is viable and that has a good chance of acceptance. It should never appear at any stage that the planners want to impose their decision on the public and it would be very unfortunate if, in the end, the target beneficiaries become the worst critic or opponents of the project.

9.11.1 Presentation of Results

A good study loses its value if the decision-maker is not convinced or satisfied about the utility of the results. Therefore, decision-maker(s) should be involved as much as possible in the study through interim progress reports, discussions, presentations, etc. Sometimes this is difficult because the decision-maker may change during the course of the study and the interaction with a new person will have to be commenced from the scratch.

It is quite possible that people representing a wide spectrum of backgrounds and interests will review the final study reports. A common practice is to present the reports in three segments:

(i) An executive summary that is suitable for politicians and senior bureaucrats.
(ii) The main text suitable for experts and professionals, who may have to scrutinize the work.
(iii) Appendices containing input data, figures, drawings, computers listings etc. The material must be presented so as to enable the technical personnel to check and verify the analysis and results.

There are, of course, different angles from which decisions must be made -- technical, political, etc. The decision-maker will be interested in the extent to which the planner has considered various options. Along with the absolute values of levels of objectives that can be attained by the project (such as the value of hydropower generated, average annual flood damage saved, etc.), it is also useful to include the percentage improvement in various indicators. This will be helpful to the decision-maker to judge and appreciate the contribution of the project. Finally, the use of computer graphics and other tools have made it easier to quickly prepare and present the results in an attractive format.

If funding for a project is being sought from an international financing or donor agency, such as the World Bank, a detailed project report will have to be prepared according to the norms of the concerned agency. In the World Bank, a project is examined from a number of different aspects like technical, economic, environmental, financial, institutional, organizational and managerial aspects. In the past, the development assistance and landing operations focused mainly on construction and infrastructure facilities without giving much attention to water quality, environmental issues, and operation and maintenance. The approach by the World Bank (1993) recognizes that a comprehensive policy framework is needed, management should be decentralized, and water be treated as an economic good. Great emphasis is placed on pricing and participation of stake-holders and the importance of the project for regional or national economy, its impact on improvement of general welfare, and standard of living. Besides, organizational arrangements for construction and operation and management skills are also given weightage and improved methods have been devised to determine social impacts on lower income groups of society. After completion, a report is prepared in which the success of implementation of the project and difficulties that were encountered are included.

Likewise, each major agency has its own guidelines for preparation of detailed project report. Most such agencies get the project appraisal done by their own staff or consultants. Many countries/agencies have issued detailed guidelines for preparation of project reports. For example, the Government of India (1980) has issued such guidelines for preparation of detailed reports for river valley projects.

9.12 WATER RESOURCES PLANNING – CASE STUDIES

Major (1977) has described four applications of multi-objective planning: the North Atlantic Regional water resources study (discussed in detail by Major and Schwarz, 1990); the Rio Colorado study (described below); the Big Walnut study; and the Managua study. Several case studies related to specific aspects such as flood control planning, ground water planning, waste water management planning have been illustrated by Goodman (1984) and Grigg (1985). French et al. (1979) described a software for interactive water resources planning using computer graphics.

Major and Lenton (1979) applied WR planning techniques to Rio Colorado basin, Argentina. This river rises from the snowmelt runoff in the Andes and flows in generally easterly direction for about 1100 km through arid countries to its mouth in Atlantic. Rio Colorado is one of the largest rivers in Argentina and is used for irrigation and hydro-electric power. The river flows through several provinces and the interest of each of these riverine provinces are different from others and the national government. This basin has about 13 sites for hydropower generation, 20 sites for irrigation and the irrigable area is of the order of 800,000 hectares. The goals of this study were: 1) to illustrate the modern river basin planning methods by an application, and 2) to enable the decision maker to understand the physical, economical and social trade-offs involved in the choice of a development scheme for the river basin and thus assist them in choosing among the alternative development plans. A large number of experts from Massachusetts Institute of Technology (MIT), U.S.A., and professionals from Argentina took part in this study.

Three types of models were used in the Rio Colorado study. For screening purposes, a mixed integer programming model was used. The most promising sites were analyzed using the simulation approach. The system configuration that was analyzed through simulation model was further studied by a sequencing model. The objective was to schedule the development optimally in four future time periods taking into account benefits over time, budget constraints, constraints on the number of farmers available to work in new areas, and the project inter-relationships such as the necessity that the irrigated area is not developed before the construction of dam to supply water to it. The process of model use of this study is shown in Fig. 9.4.

9.12.1 Ganga-Brahmputra-Barak Basin Study

Chaturvedi and Rogers (1985) have presented the results of extensive studies on the Ganga–Brahmaputra–Barak basin in the Indian sub-continent. The following discussion is based on their book detailing the study. This basin lies in four countries: India, Nepal, China, and Bangladesh; the major portion being in India. They named this system as *Greater Ganga system* and this is the second largest international river basin in terms of runoff, second only

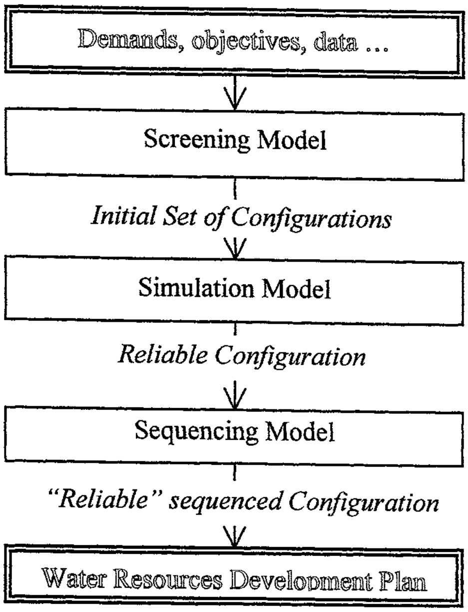

Fig. 9.4 Process of model use in water resources planning [adapted from Major and Lenton (1979)].

to the Amazon basin in South America. It drains an area of 1.38 million square kilometers and the peak outflow from the system at its estuary is 141,000 m^3/s (cumec). It carries about 127.61 m-ha-m of water in the Bay of Bengal each year of which about 80% is in the monsoon season. The north-eastern boundary of this system is formed by Himalayas which are geologically young mountains and it is bounded by Vindhyachal mountains in the south. A low watershed separates the basin from the Indus basin in the west. The extensive alluvial plains of Ganga basin are part of this system. The delta of the Greater Ganga system covering an area of 56,700 sq. km is one of the biggest in the world.

The Ganga River rises in the Himalayas at an elevation of 7010 m above the mean sea level. It flows for a distance of 2500 km which makes it the 15th longest river in Asia and the 39th in the world. It drains about one-third of the geographical area of India and supports more than 40% of its population. The monthly mean flow of Ganga River at its tail end reaches up to 57,000 cumec.

The Brahmaputra (the son of Brahma, the Creator of universe in the Hindu mythology) River rises in the great glacier in the northern-most chain of Himalayas in the Kailash range just south of a lake called Konggyu Tsho. After flowing for a distance of 1700 km through southern Tibet parallel to the main Himalayan range where it is known as Tsangpo, it enters India as the Dihang River. After its confluence with some streams, it attains the name Brahmaputra. The Majuli island, which is the largest river island covering an area of more than 1200 sq. km is part of the Brahmaputra. This river joins Ganga and together they flow to the Bay of Bengal through Bangladesh.

The Greater Ganga system has wide diversities in physiographic-geographical characteristics, topography, soil and land use as well as socio-economic aspects. The basin is like an elongated bowl with very high steep mountains in the north, comparatively low mountains in the south and east and a very flat fertile alluvial plain in between. The region has also witnessed rapid growth in population over the last few decades; there has been tremendous urbanization and demands for water have risen rapidly. The development in the basin has been largely on an ad-hoc basis. Although the region has huge water potential, due to various reasons including its international character, most of this potential remains unutilized. More than 80% of annual precipitation takes place in four months of monsoon; the area receives solid as well as liquid precipitation. The physiographic and meteorological characteristics of the system coupled with monsoon concentrated precipitation lead to heavy floods. Since Himalayas are geologically young and erodible mountains and have very steep slopes, the high flows also carry high sediment loads. Most of the storage sites and hydroelectric potential lie in Nepal and the North-East part of India. The emphasis on WR development in the past was on flow diversions limited to low flows.

The schematic diagram of the system used in the coordinating model is given in Fig. 9.5. There are 49 river–schematic nodes of interest at which junctions, diversions, ground water pumping, and return flows occur. In the first stage of preliminary screening, a single linear model was constructed to explore and coordinate all the demands placed on the system. This model was used as a tool to explore the various goals to be obtained and the constraints on development. The idea was that once the system has been fully explored by this inexpensive model it can be broken up into smaller, more manageable pieces for a more complete analysis. The model considered five reservoirs and 75 irrigation works as already developed. In the second stage, the entire basin was decomposed into smaller systems. Two types of decomposition were planned. In the first case of hydrologic decomposition, the system was divided into nine sub-basins. The operation of each sub-basin was optimized by varying the irrigation level under the given water releases and energy target levels. Each sub-basin then reports to the central organisation, its optimal irrigation level and search for energy production, shadow prices and their effective ranges on the water and energy target levels. The master problem was then solved by maximising incremental irrigation areas and the total irrigation level and energy production for the whole basin is computed. This process is done in an iterative fashion. In the second type of decomposition, the basin was decomposed by political units. The problem was analysed under two schemes: flow quota scheme and resource allocation scheme. These schemes were worked out by three algorithms. The first algorithm requires that the minimum flow at any point in the Ganga should be greater than the sum of the flow quota fixed by the central government for all the states above that point. Under the second algorithm, water that leaves an upstream state may be used by a downstream neighbor, provided that this neighbor allows a flow greater than or equal to the sum of all the upstream states quota into the next state. In the third algorithm, the restriction of algorithm two was lifted.

The authors emphasised the conjunctive use of surface and ground water for this system pointing out that ground water is a major user of energy and surface water is a rich source of energy through hydroelectric generation. In the conjunctive use study, it was proposed that infiltration may be increased during the monsoon season by heavy pumping

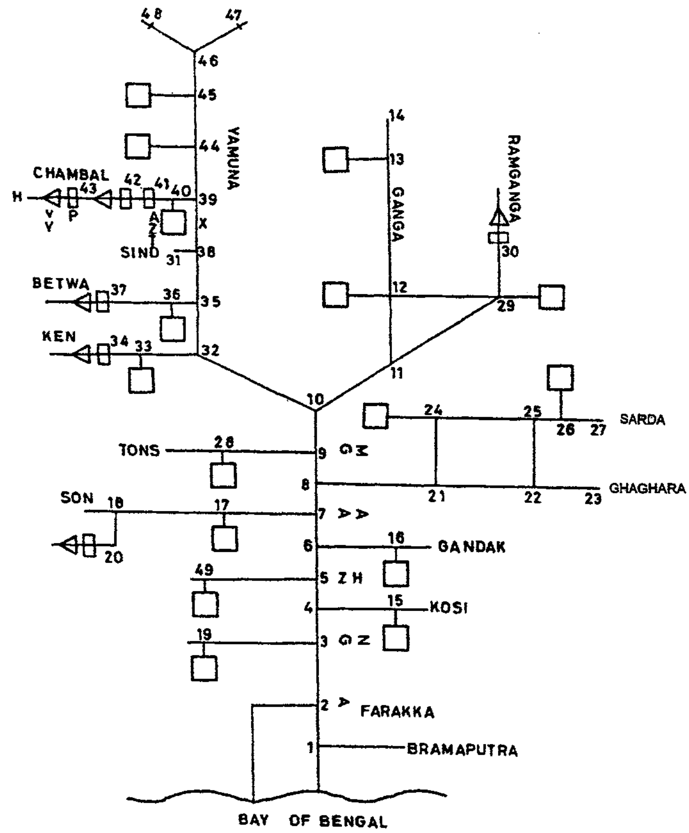

Fig. 9.5 Schematic diagram of Greater Ganga System [Source: Chaturvedi and Rogers (1985). Copyright © Indian Academy of Sciences. Used by permission].

during non-monsoon season and thus creating ground water storage. The extent and date of pumping was estimated such that it is replenished in 120 days of the monsoon season and equilibrium is achieved. The areas suitable for ground water storage were identified and it was concluded that in this scheme of underground storage of flood waters, the total potential irrigation in the Ganga basin may be limited by the area of irrigable land rather than water supply. Various alternative schemes of ground water recharge were proposed. The first involves pumping heavily along perennial rivers prior to monsoon so as to lower the water table and induce ground water recharge. The second proposes a similar approach along non-perennial rivers. The third involves irrigation during the monsoon season with groundwater lowered adequately in the non-monsoon period so that enough ground water recharge takes place to provide adequate supplies for non-monsoon months. A simulation-optimization model was applied to study the surface water-ground water interaction and comparative cost effectiveness of the three alternate approaches. The sensitivity analysis showed that the third scheme is the most attractive.

Chaturvedi and Rogers (1985) concluded that a reasonable approach for such large systems is that a programming model may be first used to find out the range for which simulation studies should be carried out, particularly taking into account the stochastic nature of inputs and outputs. For detailed modeling, simulation will be most convincing and convenient. However, simulating the entire system in diverse conditions will be extremely time consuming. They also emphasize that trained manpower is the most important prerequisite for WR development.

9.12.2 Water Resources Planning for Egypt

Egypt is said to be the gift of Nile River. Though the country has three sources of water, the Nile River, rainfall, and ground water, the Nile River is the most important because of its large flow in comparison to the other two sources. Probably, no other country is so completely dependent on a single source of water as Egypt is on Nile. The river sustains more than 98% of the population on a narrow green band bisecting a land that is otherwise nearly barren (see Fig. 9.6). Recognizing the importance of the Nile River flow for irrigation, hydropower, municipal needs, and navigation, Egyptians have devoted large efforts to regulate its flow. An index map of the Nile River is given in Fig. 9.6. Planning for WR in Egypt has aimed at the following:

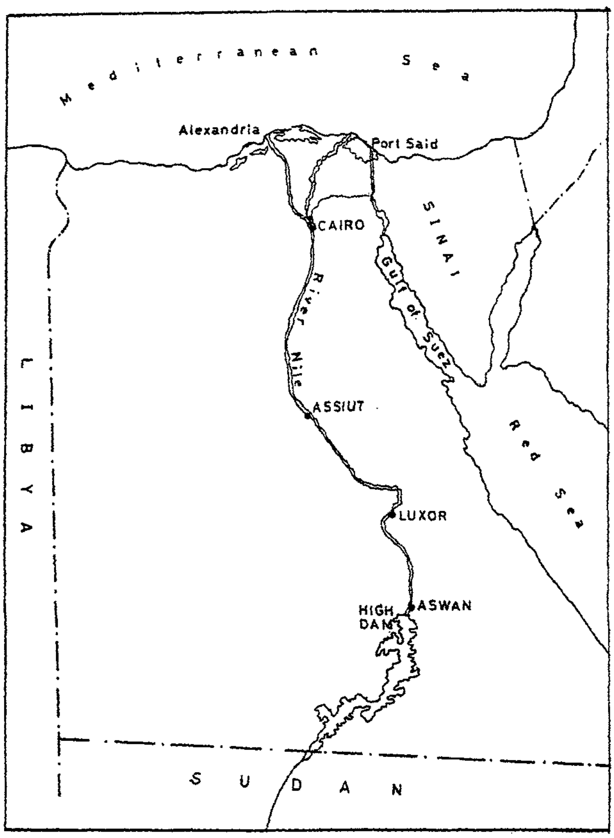

Fig. 9.6 Index map of the Nile River basin.

(i) Control of the river's waters, its preservation and development,
(ii) Securing navigation all the year through,
(iii) Production of hydro-electric power,
(iv) Laying down appropriate programs necessitated by the development policy fr the reasonable use of all water resources,
(v) Generalization of perennial irrigation for the provision of increasing water requirements for accelerating food requirements.

To realize these aims, a series of dams, barrages, and canals were constructed. The Aswan dam was initiated in 1902 with capacity of one milliard (10^9) m^3 (extended to 5 milliard m^3 in 1923) and Zefta and Assiut barrages in 1902. Undoubtedly, the key to utilization of the Nile water is the High Aswan Dam which was completed in 1967. The lake behind the dam is known as lake Nasser and its maximum storage capacity is 169 billion m^3. The lake extends over more than 500 km.

The Nile River is one of the most studied rivers of the world. Many premier institutes of the world have been associated for preparation of plans for WR development in Egypt. The Master Plan for WR development in Egypt was prepared by the Egyptian Ministry of Irrigation in association with experts from MIT. The long range objectives of this plan were to optimize the development and use of Egypt's WR and to reinforce the government's capability in water resources planning. The results of this project were described in Elassiouti and Marks (1979). Simonovic et al. (1997) applied the o-o approach for WR planning in Egypt and concluded that there was still a lack of integral national level planning. This work was further extended by Simonovic and Fahmy (1999) by the integrated use of the o-o and systems analysis.

9.13 CLOSURE

The decisions concerning water resources systems are not made by a single individual but rather by groups of individuals and at various levels. These may be legislative bodies, river valley authorities, a government set-up, etc. Each member of the group has a personal view of the significance, importance, and relative value of the various objectives being considered. Furthermore, each decision-maker may have a constituency to whom he or she is responsible. This means that the decision-maker must integrate the relative influence and views of the segments of this constituency into the evaluation of the merits of the alternatives. The critical influence of these decision-makers and stakeholders must be recognized throughout the planning process.

The application of systems analysis to water resources is growing rapidly. Mathematical models are gradually evolving into a support framework for decision-making in the form of decision support systems. Improved system models and better economic models are being developed and used at different levels. Of course, mathematical models and systems engineering are tools, not a substitute for the decision-making process. They can be very valuable in generating possible outcomes under certain conditions and assumptions. They are capable of generating alternative policies and plans that are optimal under specific assumptions and criteria. The use of interactive software make decisions more transparent and helps in accomplishing a two-way communication with the systems analyst.

There are continuous changes in the planning process, dictated by the need of ever-increasing complexities of economic and social institutions as WR projects are important components of the infrastructure. For example, at the local level a hydropower project is part of a regional electric supply grid; at the national level, it becomes part of the national grid. There is also a continuing need to review the planning decisions of yesterday. This is necessary in light of developments and evolution of the social and economic fabric of the country, and of the needs and demands which are placed on the water resources of the region.

It may be emphasized that the procedures discussed here do not guarantee the quality of the results of planning; these will ultimately depend on the correctness of the data describing the system, appropriateness of the tools, and the skills of the planning team. It is necessary to obtain all the needed information on each of the system element before any detailed analysis is performed. For this, checklists are sometimes used. However, even the best checklists and planning schedules can only be a guide, and must be used with care and discretion. They can supplement, but not replace, the skill and intuition of an experienced and creative planner. Finally, no hard-and-fast rules exist on what planning procedures are to be used -- to find the best approach to address the planning process is a difficult problem in itself.

9.14 REFERENCES

Buras, N. (1963). Conjunctive Operation of Dams and Aquifers. Journal of the Hydraulics Division, ASCE, HY6 pp. 111-131.

Buras, N. (1972). The Scientific Allocation of Water Resources. Elsevier Book Company, New York.

Chaturvedi, M.C. and P. Rogers (1985). Water Resources Planning – Some Case Studies for India. Indian Academy of Sciences, Bangalore.

Chaturvedi, M.C. (1987). Water Resources Planning and Management. Tata McGraw-Hill Publishing Company Ltd., New Delhi.

Doorenbos, J., and Pruitt, W.O. (1977). Guidelines for Predicting Crop Water Requirements. FAO Irrigation and Drainage Paper No. 24, Food and Agriculture Organization, Rome.

Dyck, S. (ed.) (1990). Integrated Planning and Management of Water Resources (Guidance material for course for engineers, planners, and decision-makers), International Hydrological Programme, Unesco, Paris.

Elassiouti, I.M., and Marks, D.H. (1979). Water Resources Planning in Egypt. Proceedings of the International Conference, held in Cairo, Egypt.

French, P.N., Johnson, L.E., Loucks, D.P., and Greenberg, D.P. (1979). Interactive Water Resources Planning using Computer Graphics. Dept. of Environmental Engineering, Cornell University, Ithaca, New Jersey.

Government of India (1980). Guidelines for Preparation of Detailed Project Reports of Irrigation and Multipurpose Projects. Working Group Report, Government of India,

New Delhi.
Goodman, A.S. (1984). Principles of Water Resources Planning. Prentice-Hall Inc., Englewood Cliffs, New Jersey, USA.
Grigg, N.S. (1985). Water Resources Planning. McGraw-Hill Book Company, New York.
Haimes, Y.Y. (1977). Hierarchical Analyses of Water Resources Systems: Modeling and Optimization of -Large-scale Systems. McGraw-Hill Inc., New York.
Haimes, Y.Y., J. Kindler, and E.J. Plate (1987). The Process of Water Resources Project Planning: A Systems Approach. Studies and Reports in Hydrology # 44, UNESCO, Paris.
Hamdan, (1961). Evaluation of irrigation agriculture in Egypt, in A History of Land Use in Arid Regions. Edited by L.D. Stamp, Unesco, Paris.
Herchy, R.W. and R.W. Fairbridge (Ed.) (1998). Encyclopedia of Hydrology and Water Resources. Kluwer Academic Publishers, Dordrecht.
Jacoby, H.D. and D.P. Loucks (1972). Combined use of optimization and simulation models in river basin planning. Water Resources Research, 8(6), 1401-1414, 1972.
Major, D.C. (1977). Multiobjective Water Resources Planning. Water Resources Monograph No. 4, American Geophysical Union, Washington, D.C.
Major, D.C., and Lenton, R.L. (1979). Applied Water Resources Planning. Prentice-Hall Inc., Engelwood Cliffs, New Jersey.
Major, D.C., and Schwarz, H.E. (1990). Large-scale Regional Water Resource Planning: The North Atlantic Regional Study. Water Science and Technical Library, Kluwer Academic Publishers, Dordrecht.
Meta Systems Inc. (1975). Systems Analysis in Water Resources Planning, Water Information Center Inc., New York.
NCIWRD(1999). Integrated Water Resources Development – A plan for action. Report of *The National Commission for Integrated Water Resources Development.* Govt. of India, Ministry of Water Resources, New Delhi.
Rogers, P. and Smith, D.V. (1970). An Algorithm for Planning Irrigation Projects, Bull. ICID.
Saha, S.K. and Barrow, C.J. (1981). River Basin Planning: Theory and Practice. John Wiley & Sons, New York.
Simonovic, S. (1989). Application of water resources systems concept to the formulation of a water master plan. Water International, Vol. 14, 37-50.
Simonovic, S., Fahmy, H., and El-Shorbagy, A. (1997). The use of object-oriented modeling for water resources planning in Egypt. Water Resources Management, 11(4), 243-261.
Simonovic, S., and Fahmy, H. (1999). A new modeling approach for water resources policy analysis. Water Resources Research, 35(1), 295-304.
Singh, V.P. (1996). Dambreak Modeling Technology, Kluwer Academic Publications, Dordrecht.
Stephenson, D., and Peterson, M.S. (1991). Water Resources Development in Developing Countries. Development in Water Science # 41, Elsevier, Amsterdam.
UN (1970). Integrated River Basin Developm[illegible]t, Report of a Panel of Experts, Department of Economic Affairs, The United Nation[illegible] [illegible]ew York.
UN (1972). Water Resources Project Plannin[illegible] [illegible]Vater Resources Series No. 41. The United Nations, New York.

UN (1976). The Demand for Water. Natural Resources – Water Series No. 3, The United Nations, New York.

UN(1997). Public Involvement Guidelines for Natural Resources Development Projects, The United Nations, New York.

US Water Resources Council (1973). Water and Related Land Resources, Establishment of Principles and Standards for Planning, Washington, D.C.

Weiss, A.O., and Beard, L.R. (1971). A multi-basin planning strategy, Water Resources Bulletin, 7(4), 750-764.

Willis, R. and Yeh, W.W-G. (1987). Groundwater Systems planning and management, Prentice-Hall, Engelwood Cliffs, New Jersey.

World Bank (1993). Water Resources Management; A World Bank Policy Paper, The World Bank, Washington, D.C.

Wurbs, R.A. (1987). Dam breach flood wave models. Journal of Hydraulic Engineering, ASCE, 113(1), 29-46.