INTEGRATED WATER RESOURCES PLANNING

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CONTENTS

SUMMARY

This report describes and discusses many water resources planning issues and technologies, ranging from broad-based concepts to specific modern planning techniques. It is not intended to be either a compendium of state of the art methodologies, or a manual to guide water resources planning. Its more modest objective is to be a basis for encouraging continued dialogue among water resources planners, decision makers and others interested in water resources planning, in or for the developing countries. This report and further discussions by water resources experts may also suggest additional lines of enquiry and research, with the accompanying need for additional reports.

The subjects in this report, while not organized as such in specific sections, fall under one or more of the following categories of issues, processes, methodologies, and results of planning:

- Reasons for developing water resources
- Planning processes and activities
- Plan evaluation and justification
- Modern planning tools and other special planning techniques
- Problems of implementation and sustainability of projects
- Other planning problems
- Other matters of professional or scientific interest.

A water resource plan refers to a project, programme, or policy that is developed at the national, sectoral, or local level. It should consider the missions of various governmental units, and the interests of those affected beneficially or adversely by the plan. The development of the plan should involve engineers, economists, biologists and other professional disciplines, and its formulation and analysis should extend beyond the physical components of the plan in order to take account of institutional, economic, environmental, social, and other effects. The phrase *effective integrated water resources planning* refers to the derivation of a plan, while paying proper attention to the foregoing, which is optimal to society. For developing countries, this implies that water resources development and management will contribute as much as possible to the amelioration of the basic problems of the human condition in these countries, while avoiding serious damages to ecological populations and environmental quality. These concepts provide a unifying theme for the objectives of water resources planning, and should be kept in mind while reading the various sections of the report.

Section 1 discusses a number of development planning issues. Many of these issues are germane to all types of planning, while others are more specific to water resources planning. Water resources plans are usually initiated to meet a demand for water, solve a problem caused by water, or take advantage of an opportunity. There can, however, be other reasons for planning, development and

management of water resources including, for example, to further the general welfare of a nation and its people, or to preserve and enhance waterbodies and related land resources. The impacts of water resources development are understood by planners to be both economic and noneconomic. Because of the physical nature of water resources development, and the large variety of economic and noneconomic impacts of development, good water resources planning involves many professional disciplines.

The term "project cycle" is largely attributable to the World Bank but this approach has also been adopted by most government agencies pursuing water resources planning. National and sector agencies must also allocate budgets and stage projects in the form of programmes of development.

A number of theories of development economics have been proposed to guide planners and policy makers in the use of resources and in the evaluation of costs and benefits. Theories favored today for developing countries are modifications of the neoclassical and structuralist approaches. The allocation of resources can proceed from such theories, and can also follow the concepts of efficiency, equity, or a combination of the two. Various components of society can be considered in national and sectoral planning, and these components can be involved in "top-down" and "bottom-up" approaches.

In addition to the foregoing theories and approaches to planning, there are a number of issues that are specific to water resources planning including the consideration of the water resource as a system; social and environmental impacts; institutional and legal aspects; physical threats to the water resources system; and the sustainability of water resources developments. These subjects are discussed further in succeeding sections of the report.

Section 2 presents some principles of integrated water resources planning. It begins with sixteen statements of what experience with current planning teaches. These conclusions are based upon published literature and the unpublished work of United Nations and World Bank staff. A number of these conclusions concern the processes and methodologies of planning. Others relate to increasing concern with the adequacy and reliability of water resources, the misallocations of water when viewed from the standpoint of society's best interests, the importance of giving more attention to the externalities of a plan, the question of tradeoffs between economic development effects and environmental and social effects, and various issues concerning international waters.

Sustainability of projects and programmes has, in recent years, been an increasingly serious concern of the United Nations, the World Bank and other international development agencies, donor countries, and, of course, the developing countries themselves. When projects fail completely, do not achieve their intended levels of performance, or do not adjust to future conditions, they represent poor use of scarce investment funds from outside the country, they are a drain on the country's monetary and other resources, and they may even be counterproductive to the country's goals of economic growth and improvement of the well-being of its people. This problem is discussed in terms of its significance in developing countries, and guidelines are presented that have been proposed for dealing with it.

The United Nations has been a proponent of effective planning of natural resources for many years. A number of reports, conferences, and projects (many under United Nations auspices) are mentioned in this section to show the historical evolution of water resources planning in the direction of integrated water resources planning.

The final portion of this Section outlines a number of characteristics of *effective* integrated water resources planning. It is hoped that this list of characteristics, and their extension and elaboration, will contribute to the continued dialogue among water resources experts. This activity must recognize that integrated water resources planning should have two principal goals: (1) to plan programmes and projects that are economically efficient and socially desirable and (2) to execute projects that will be sustainable over a long period of time, beyond the exodus of foreign financing and technical assistance and the repayment of loans. These principal goals should be kept in the forefront during all stages of planning, implementation, and maintenance and operation.

Section 3 discusses the water resource as a system. It is essential in water resources planning to understand this system, both regionally and globally, and to comprehend how man's activities affect the system. The system can be described in terms of the hydrologic cycle and the water balances that exist in the various parts of the world. Current threats to the system include such problems as inadequate surface and ground water supply, pollution, erosion and sedimentation, and destruction of wetlands. Other important problems are already evident due to acid rain, destruction of forests, increasing urbanization, and destruction of coastal ecosystems. Future threats to the system include potential climatic changes with greenhouse warming, sea level rises, and other problems with water supplies and environmental quality. Water augmentation technologies can provide a means to counteract some of the current and long-term problems of water supply.

Section 4 discusses the establishment of planning boundaries, which can correspond to natural hydrologic boundaries of a river basin, or boundaries established for administrative or other reasons. Interbasin transfers and other transbasin issues have become important both within a country and in connection with international water bodies. Water balances in a region are related to the hydrologic cycle and to the physical interrelationships and operations of projects that constitute a system.

Sections 5 and 6 describe the processes by which most plans are currently conceived and implemented. Section 5 discusses a number of topics that encompass "conventional project planning". These topics include the generalized process of water resources planning, the sequence of studies for a single engineering project, the comparison of projects prepared at different times by different planners, and the "comprehensive" planning studies for river basins.

Section 6 further discusses the preparation of the feasibility report. This provides the basis for an examination by decision makers in a government agency or in an international banking institution, to determine whether a project should be implemented and/or financed. It is clear that when such a report is prepared according to high contemporary standards, it can be quite complex and deals not only with physical problems but also with a multitude of other project effects. Increasingly, it emphasizes the interactions of project effects, and the results of interdisciplinary studies to define and solve problems and evaluate impacts.

Finally, Section 7 describes a number of modern planning tools that have been developed in the past several decades to improve the formulation and analysis of water resources projects. Such tools are available both to facilitate conventional water resources planning and to support the broader concepts of integrated water resources planning. Forecasting models assist in estimating the need for project services and in measuring the effects of a project; they may deal with both monetary and non-monetary effects. Economic planning models can facilitate the translation of studies of economic structures into water requirements and other water resources development needs. By estimating the direct and indirect effects on regional and national income accounts, they can also be more successful in capturing income effects than conventional analyses that focus on the utilization of project services and products by direct beneficiaries. Water resource mathematical models are widely used to generate alternatives for the planning process and to compare competing alternatives. They can provide solutions based on the optimization of a specific objective, usually monetary, such as least cost or maximum net benefits. They can also provide solutions to, or at least useful insights to problems involving multiobjectives, by considering societal preferences for tradeoffs or mixes of contributions to various objectives. Environmental planning models have been used widely to solve problems involving selections among water quality and wastewater treatment alternatives for minimum cost, and they are also becoming more useful than hitherto for dealing with different potential effects and tradeoffs for environmental, ecological, and related resources. More recently, social planning methodologies have also gained increasing acceptance, sometimes in models that consider environmental and social effects together, and other times in approaches that have been developed specifically for social impact evaluation.

Water resources projects and programmes are planned to meet future (therefore, uncertain) needs, using water and related land resources that are themselves uncertain. Problems of uncertainty have received increasing attention from planners. Planners should be familiar not only with methodologies that can be utilized to evaluate the probabilities of events involving water resources and their monetary and other consequences, but should also recognize that the willingness to accept risk varies with the organizations and individuals affected by a water resources plan. A developing country is much less resilient than an economically advanced country, in dealing with the implications of a failure to achieve expectations of a development and, in particular, the possibility of complete failure. The scarce capital and manpower resources available for development, and the severe inadequacies of basic services for a people having important basic needs and a fragile economy, provide on one hand, the *raison d'etre* for development itself and assistance in such development by international financial institutions and donor countries, and provide on the other hand, an especially serious exposure to the implications of failure.

A final issue needs to be raised here before going on to the main body of this report. This issue is not dealt with in the report, except by inference, but is obvious to any experienced water resources planner. Most of the methodologies described in Section 7 and, for that matter, in many of the other sections, have been conceived and developed to the present state of the art in economically advanced countries. In these countries, data are much more abundant than in the developing countries, on the physical parameters of water resources and on the environmental, social, and other factors needed for reliable conventional water resource planning, and especially so for effective integrated water resources planning. While planners in developing countries will find that many of the concepts and applications discussed in this report are useful in either guiding their work or in providing stimulation for exploring ideas, it is clear that more sophisticated methodologies (such as those involving mathematical models, stochastic parameters, risk, and tradeoffs among multiobjectives) require for their effective application, the amassing of data of *appropriate* quantity and quality and their *proper interpretation*. Approaches to data collection and interpretation are themselves amenable to mathematical methods (e.g. Bayesian decision theory). Programs for collecting and analyzing data, however, also require the input of persons with seasoned judgment who understand the uses and limitations of such data, and who are realistic in their demands and expectations.

SECTION 1

DEVELOPMENT PLANNING ISSUES

1.1 Purposes and Objectives of Water Resources Development

A water resources plan is initiated in order to *meet a demand* for water (municipal and industrial water supply, irrigation water supply), *solve a problem* caused by water (flood control, water quality improvement), or *take advantage of an opportunity* (dam site for hydroelectric power development). The following is a list of the principal *purposes* and *functions* of water resources projects.

- Water supply for municipal and industrial uses
- Water supply for rural uses
- Water supply for thermal-electric power plant cooling
- Irrigation, including water supply
- Flood control and damage prevention
- Hydroelectric power
- Navigation
- Water quality management, including wastewater treatment and disposal and flow augmentation
- Recreation
- Commercial fishing and trapping
- Drainage, sedimentation control, land stabilization, erosion control, and other measures for management of urban and rural lands and watersheds

Plans may be *single-purpose* or *multi-purpose*. They may also be *single-unit* or *multi-unit*. Special methods of assessment have evolved for multi-purpose and multi-unit projects. When a number of projects are staged over a *planning horizon*, this constitutes a *programme* of development. Projects and programmes may refer to a single *economic sector* such as electric power or may be multi-sectoral. Virtually all water resources projects and programmes involve not only their basic purposes and functions but also roads, marketing services, housing and community services, and other components of the physical, economic, and social *infrastructure*.

Planning, development, and management of water resources may also be used to further the general welfare, including:

- Regional economic development
- Income distribution
- Health and safety
- Educational and cultural opportunities

- Emergency preparedness
- Other measures to improve the "quality of life"

The growing environmental movement has also encouraged policies to plan and manage water resources for the preservation and enhancement of:

- Natural water and related land areas, including aesthetic values
- Archeological, historical, biological, and geological resources
- Ecological systems
- Water, land, and air quality

1.2 Economic and Noneconomic Impacts of Water Resources Development

From the standpoint of economic impacts, water resources projects, since they satisfy demands, solve problems, and strengthen the infrastructure, are needed as underpinnings of economic growth. If not undertaken, the economic growth of an area is slowed or set back. The direct and indirect economic benefits resulting from such investments increase national and regional income accounts, particularly in developing countries.

The United Nations Industrial Development Organization in its "Guidelines for Project Evaluation," (Dasgupta, et al, 1972) recommended that project analysis consider the following objectives for developing countries:

- Aggregate consumption
- Income redistribution
- Growth rates of national income
- Employment level
- Self-reliance
- Merit wants

Aggregate consumption is the basic economic or national income objective; it is measured by the willingness to pay for system inputs and outputs. If society considers that the consumption of poor persons should be given greater weight than that of rich persons, this is taken into account by the separate income redistribution objective.

Expansion of employment, or a reduction in unemployment, if it is considered to be important primarily for its impact on aggregate consumption or on income distribution, is largely taken into account by these measures. It may, however, be taken as a separate objective if "unemployment may be thought to be a denial of human dignity, and its reduction may be preferred irrespective of considerations of total consumption and its distribution. Then the size of unemployment may be a measure of costs, i.e. of negative benefits".

Self-reliance may be a goal when it is desired to reduce dependence on richer countries because of chronic shortages of savings or of foreign exchange. Such dependence may be estimated in terms of the trade deficit (gap between imports and exports) or by the deficit in the overall balance of payments.

Merit wants are objectives whose national importance is not determined by individuals in their capacity as consumers. Employment and self-reliance are considered to be examples of merit wants.

In a later document in 1980 by UNIDO, "Manual for Evaluation of Industrial Projects", *value-added* in terms of contribution to growth of the national product, is proposed as a means of economic assessment.

The UNIDO guidelines, in developing a system of objectives for industrial development, do not lay any stress on the quality of the environment or other intangible descriptors applying to the quality of human life. Although these aspects have not been ignored in developing countries, they have not been considered as explicitly as in the more economically advanced countries. In the latter countries, noneconomic factors can be on a par with or even more important than economic performance in formulating a project and achieving its implementation. In the World Bank publication "Environmental Management and Economic Development," (1989), it is proposed to adjust the measurement of economic growth in the United Nations *system of national accounts* to take account of environmental and natural resource effects such as the depletion and degradation of water resources.

Noneconomic considerations that permeate water policy decision-making processes may be classified under four broad headings, according to Engelbert (1968). *Ethical* considerations include the sustenance and protection of human life and the conservation of resources for future generations. *Social policy* considerations facilitate regional and national growth, influence the spatial distribution of population, and promote the public's general welfare. Standards of *due process* are procedures whereby individual rights are secured and maintained; they consciously establish water institutions and procedures that will minimize social conflict. *Aesthetic* factors are society's interest in using and conserving water resources to protect the beauty, quality, and reliability of the natural environment.

Successful implementation of water resource plans must also recognize the need to *satisfy political obligations* together with other economic and noneconomic goals. (U.S. National Academy of Sciences, 1968).

1.3 Interdisciplinary Nature of Water Resources Planning

Water resources planning involves a variety of professional disciplines. For example, the preparation of a complex flood control plan may require the following:

- Engineers--civil, structural, hydraulic, hydrologic, geotechnical, construction, cost estimating, mechanical, electrical, surveying and mapping, drafting
- Urban and regional land planning specialists
- Architects
- Economic and financial specialists
- Environmental specialists--biological sciences of various types, forestry, archeological, historical, geological, water and air quality, soils

- Sociologists
- Real estate and relocation specialists
- Public information specialists
- Report production specialists

If the project has multipurpose development opportunities, additional specialists may be needed to study them. Irrigation planning, for example, would involve soil and crop agronomists and other farm specialists, agricultural economists, and irrigation engineers. If sophisticated systems analyses are employed, computer specialists would be needed.

In a developing country, virtually all water resources planning is carried out by or under the auspices of public authorities. Such planning may be at the national, sectoral, or project levels and may involve national, regional or local agencies and the general public.

The term *integrated water resources plan* may refer to a national, sectoral, or project plan serving one or more purposes and functions, to be implemented in one or a group of stages. It may also refer to a policy statement or programme to guide planning activities. The word *integrated* implies that the planning work incorporates contributions of multi-disciplines and multi-sectors and considers a wide range of societal interests.

1.4 Project Cycle vs Programme Approach

1.4.1 *Project Cycle*

The concept of the "project cycle" is largely attributable to the World Bank. In the World Bank publication "Investing in Development -Lessons of World Bank Experience", Baum and Tolbert (1985, p. 334) state that project work may be thought of as taking place in "several distinct stages.... that ..... are closely linked to each other and follow a logical progression, with the later stages helping to provide the basis for renewal of the cycle through subsequent project work....The project approach has proved a potent instrument for rationalizing and improving the investment process. Its principal advantage lies in providing a logical framework and sequence within which data can be compiled and analyzed, investment priorities established, project alternatives considered, and sector policy issues addressed. It imposes a discipline on planners and decision makers, and ensures that relevant problems and issues are taken into account and subjected to systematic analysis before decisions are reached and implemented. Correctly applied, it can greatly increase the development impact of a country's scarce investment resources."

From the standpoint of the World Bank, the concept of a project goes back to the establishment of the Bank. The Articles of Agreement adopted at the Bretton Woods conference in 1944 stipulate that "loans made or guaranteed by the Bank shall, except in special circumstances, be for the purpose of specific projects of reconstruction or development."

The following terms are used by the Bank to describe the various stages of the project cycle:

- *Identification.* The first phase of the cycle is concerned with identifying project ideas that appear to represent a high-priority use of the country's resources to achieve an important development objective. Such project ideas should meet an initial test of feasibility; that is, there should be some assurance that technical and institutional solutions-- at costs commensurate with the expected benefits--will be found and suitable policies adopted.

- *Preparation.* Once a project idea has passed the identification "test," it must be advanced to the point at which a firm decision can be made whether or not to proceed with it. This requires a progressive refinement of the design of the project in all its dimensions--technical, economic, financial, social, institutional, and so on.

- *Appraisal.* Before approving a loan, external agencies normally require a formal process of appraisal to assess the overall soundness of the project and its readiness for implementation. For an internally generated and financed investment, the extent of formal appraisal varies widely in accordance with government practice. Some explicit appraisal, however, is a necessary, or at least a desirable, part of the decisionmaking process before funds are committed.

- *Implementation.* The implementation stage covers the actual development or construction of the project, up to the point at which it becomes fully operational. It includes monitoring of all aspects of the work or activity as it proceeds and supervision by "oversight" agencies within the country or by external lenders.

- *Evaluation.* The ex post evaluation of a completed project seeks to determine whether the objectives have been achieved and to draw lessons from experience with the project that can be applied to similar projects in the future. Although some lending agencies such as the World Bank routinely require an ex post evaluation of all projects that they finance, few developing countries have established a comprehensive *system* for evaluating the results of their project investment portfolio.

The identification and preparation stages, discussed in Sections 5 and 6, lead to a feasibility report which is the basic document for appraisal. The appraisal stage, which is discussed in Section 6, includes a review of the economic, technical, commercial, financial, and institutional, organizational and managerial aspects of a project. In more recent times, the review has also placed an increasing emphasis on social and environmental analysis.

1.4.2 *Programme Approach*

In most cases, a project in a developing country results from a proposal by an operating entity or by a line ministry in a specific economic sector, such as agriculture or electric power. The political implications of the project influence decision making at the national, regional, and local levels, and may be the principal driving force in developing countries with strong leadership at the national level. Some screening of projects occurs at the national level, where the effects of the project on broad economic and social objectives are considered. It is rare, however, that (at this level) the impacts of a project in a developing country are fully assessed in terms of its effects in a specific economic sector, its interrelationships with other sectors, and its sustainability through the periods of planning, construction, operation, repayment of loans, and beyond.

The World Bank and other international agencies and donor countries have an important interest in and make country-wide studies, focused on the growth and stability of the economy and the adequacy of the physical and commercial infrastructure. The World Bank reviews a proposed project (see Section 6) to assess whether an investment in a specific economic sector is justified, and whether the project represents a reasonable investment within that sector. However, as with the planners within the proposing country, a full analysis of the project in terms of its long-range implications and interrelationships is rarely undertaken.

Most water resources planners in developing countries place emphasis on projects which are identified as providing outputs and services that are desirable for specific economic sectors, and are concerned with feasibility studies that will pass review by the World Bank or other lending agency. The ideal programme approach, on the other hand, assumes that: (1) the national public investment programme for all economic sectors is developed to implement broad economic and social objectives, (2) after budgets are allocated to individual sectors, these sectors have a rational method of selecting projects, scheduling them in stages, and implementing them in order to achieve expected outputs over a long period and (3) short-, medium -, and long-range planning horizons are considered extending beyond the involvement of foreign entities.

Developing the budgets and schedules implied by the above discussion can be an extraordinarily complex activity, especially when a multitude of factors (economic, social, environmental, institutional, etc.) are involved and when many of these factors cannot be measured in monetary terms. Planning methodologies are, however, available that can greatly assist in this process (see Section 7). At the national level, macroeconomic models can assist in determining the economic impact of major courses of policy. Other planning tools that can be applied in water resources planning include forecasting models, economic planning models, water resources models to analyze alternatives, environmental and social planning models, and methods to analyze risk and uncertainty.

If the planning is focused on the selection and staging of projects in a single economic sector and from the standpoint of economic inputs and outputs only, each project can be formulated to yield maximum net benefits. This implies the availability of a social rate of discount for determining the present values of streams of inputs and outputs. Projects are then compared with each other by some measure of economic merit such as benefit-cost ratio or internal rate of return, in order to establish a ranking of projects. The projects are then staged, giving precedence to those that are better performing, but also taking account of other factors such as budgetary limitations, and social, environmental, institutional, and political considerations.

In principle, projects and segments of projects and their staging over a planning period should be designed as a whole for maximum discounted net benefits, given all constraints, including budget constraints on the amount of available funds. This would include the projection of budget amounts into the future until all justifiable projects are constructed. Many planners of projects for developing countries claim that this approach is not appropriate since: (1) typical rates of discount do not allow adequate credit for benefits that take a long time to fully develop but are then of broad significance to the country, and (2) this procedure cannot adequately consider values (e.g., environmental and social) that are not expressed in monetary terms.

1.5 Neoclassical vs Structuralist Approach

Characteristics of developing countries typically include:

- low per capita real income
- high rate of population growth and burdens of dependency
- unemployment, underemployment, and low productivity
- pervasive poverty
- highly unequal income distribution
- predominance of agriculture in the national economy
- foreign trade overly dependent on primary product exports and/or constituting a small part of national income

Developing country governments, international financial institutions such as the World Bank, and donor country officials are generally agreed that appropriate economic planning and development projects are essential to the promotion of improved standards of living and stronger national economies. However, such efforts are hampered by an inadequate understanding of the dynamics of the economic sectors of developing countries and their interrelationships, due to deficient data and models and the unavailability of a reliable underlying economic theory. The extent of public and private enterprise varies substantially from one developing country to another, often being a function of historical and political circumstances. The degree to which a country is dependent on foreign economic, social, and political influences may be related to its size, natural resources, and political history. It is clear that an economic theory of prices and resource allocations that has been developed for an economically advanced country with its more modern, more urbanized, more industrialized, and more diverse service sectors, cannot apply fully to a poor underdeveloped country with traditional subsidence agriculture and with highly fragmented product, resource, and financial markets.

Two extreme approaches are appropriate starting points for considering economic theories: (1) a fully planned economy in which goals for production and services are defined in accordance with perceived needs and available resources, with little regard to market forces, and (2) an economy in which all public and private decisions depend heavily on free market considerations. Most developing countries have "mixed" economies of some type.

The rise of development economics paralleled the establishment and growth of international financial aid and technical assistance programs established to assist the developing countries after World War II. Baum and Tolbert (1985, p.

5) mention various theories and doctrines of development that have been studied: physical capital formation, balanced growth, and the "big push"; dependency theories; backward linkages; industrialization or rural development; import substitution or export promotion; structuralism or market-based development; and investment in human capital with an emphasis on basic needs, and conclude that: "In retrospect, it is clear that these offered not so much a comprehensive theory of development as a guide to a better understanding of one aspect or another of the complex process of development."

Structuralism, a modification of the theory of a fully planned economy, was the dominant view of development from the 1940's to the early 1960's. In the past several decades, developmental economists have endorsed more of the concepts of market-based development corresponding to the neoclassical view which has been mainstream economics in Western industrialized countries for more than a century.

Differences between these views of development, and their applicability to developing countries, have been discussed by Baum and Tolbert (1985, p 20-21, and p 65): "....The structuralist view of development....holds that developing countries are characterized by accumulated cultural, social, and institutional rigidities, which inhibit or prevent change; that resources tend to be "stuck" (or, in economic terms, that the supply of most goods and services is inelastic); and that only determined government action to change the structures of production and trade, and to reallocate resources within the economy, can bring about modernization and development. Furthermore, this view stresses managing quantities rather than prices, since it is implicitly assumed that price signals are not adequate tools for allocating resources. Any distortions in prices that arise in the course of managing quantities are regarded as innocuous or else necessary for achieving social objectives.... In the neoclassical view, quantities are in fact flexible and resources mobile, producers and consumers do respond to price signals, businessmen seek to maximize profits by shifting their production methods when input prices change -- and, despite particular failures, markets do generally work if allowed to do so. Few economists accept that the underlying assumptions of the neoclassical view -- namely, the prevalence of free competitive markets that allocate resources efficiently and establish prices reflecting true economic values -- correspond fully to reality. Nevertheless, the neoclassical position is generally regarded as an indispensable starting point for the analysis of the workings of developed economies, and as an essential frame of reference for understanding the role of prices. The structuralist approach assumes greater availability of data, more wisdom as to what government measures are needed, and much greater administrative capacity to devise and implement those measures than exist in most developing countries. The neoclassical approach suffers from the weakness of its basic assumptions about the existence and the efficacy of free competitive markets in developing countries....There are no simple theoretical principles for efficient management of national investment. Above all, it is important to have the right "vision" of the development process; in a growing number of developing countries, this vision now encompasses the importance of prices, markets, and private initiative within a framework of incentives and infrastructure provided by the government. Given this vision, the crucial element is the pragmatism of decisionmakers, who must steer a middle course between the extremes of the laissez-faire and the structuralist varieties. They need not seek perfection nor look for answers only from models and sophisticated analytical techniques. Common sense is an essential ingredient in the process, and it consists largely of asking the right questions and focusing on the right issues. In virtually all countries, much can be done to improve the effectiveness of the public investment program simply by systematically questioning the principal choices it embodies, remedying the more obvious shortcomings, and remaining flexible in adjusting to new information and changed circumstances. Supporting the investment program with a policy framework that avoids price distortions and provides incentives for efficient performance in both the public and private sectors is also an area in which practicality and realism yield high returns. The foregoing discussion, concentrating as it does on an economic calculus, is not meant to underplay the political aspects of development. In the end, the allocation of resources has to be guided by the political aspirations of the country. What the economic planners can do is to clarify the choices involved and emphasize the economic costs of alternative courses of action. But they can be effective only to the extent that governments do accord priority to economic development."

1.6 Efficiency vs Equity Approach

The allocation of resources can proceed according to the economic theories of *efficiency* or *equity*, or a combination. For water resources, this can refer to the allocation of monetary or manpower resources to water resources development, or to the allocation of outputs such as water supplies. For the latter, North (in Viessman and Welty, 1984, p. 134) comments on the efficiency effect and the equity or distribution effect as follows: "The efficiency effect refers to the size of the economic pie available (net national product or welfare) whereas the distribution effect refers to the number and size of the slices (income or wealth) accruing to each party or segment of society. Optimum economic efficiency may be defined as the allocation of resources (land, labor, capital) among competing users such that desired results (profits or sales) are maximized. Optimum economic distribution may be defined as the allocation of payments for resources such that the needed resources are retained in the desired productive activities. However, society is not always satisfied with the distribution of benefits and costs that results from an unrestrained market. Institutions are devised by society to effect redistributions through systems of transfers. These redistributions are defined in subjective terms such as "social benefits" or "social costs." The objective of economic activity is to maximize net social welfare,which includes consideration of both individual and societal benefits as well as all private and social costs... The final allocation of water and products produced by water ...is an equity issue. If, as is sometimes the case with water resources, there is no market mechanism for the transfer of the water and some arbitrary and uncompensated assignment of the water is made... (between two parties)... one party gains at the expense of the other."

When considering the equity issue for developing countries, Todaro (1985), states that: "Any realistic analysis of development problems necessitates supplementation of strictly economic variables such as income, investment and saving with equally relevant noneconomic factors including the nature of land tenure arrangements; influence of social and class stratifications; structure of credit; education and health systems; the organization and motivation of government bureaucracies; machinery of public administration; nature of popular attitudes toward work, leisure and self-improvement; and economic elites."

1.7 National and Sectoral Planning

Typical responsibilities for planning, or "project work", are maintained at various levels of government, according to Baum and Tolbert, (1985, p. 575):

- At the national level, where national investment plans are formulated, priorities among sectors are established, and the macroeconomic framework of policies for economic growth is put in place

- At the sector level, where priorities for investment within each sector are determined and the issues and problems affecting the development of the sector are addressed

- At the project level, where individual projects are identified, prepared, and implemented and attention is given to their technical, economic, financial, social, institutional, and other dimensions.

Public investment programs and budgets are the key products of planners in the water resource field. According to Baum and Tolbert (1985, pp. 577-9), the World Bank's experience with public investment programs and budgets indicates that: "... In formulating public investment programs, detailed and overly sophisticated forecasting exercises have generally proved counterproductive because of inadequate data and limited understanding of how sectoral investments and outputs are linked. Analytical efforts should therefore concentrate on designing investment programs in key infrastructure sectors, where the market alone cannot guide investment decisions, and on checking the consistency of these programs with the likely requirements of the productive sectors. Governments also need to be selective; they can effectively address only the most important public investment issues at any one time....Establishing investment priorities among sectors -- the attention to be given, for example, to programs in health, education, or housing relative to the productive or infrastructure sectors -- is particularly difficult and untimately entails political choices. Economic analysis can make only a limited contribution to this process, but it may still be crucial in clarifying the costs of alternatives and providing data on which informed judgments can be based. In establishing investment priorities within a sector, however, cost-benefit analysis can be very helpful in improving choices."

They indicate that "experience has taught a number of other lessons about formulating and implementing public sector investment programs:

- Care should be taken that the investment plan is not too ambitious given the available resources. There is a widespread tendency to underestimate the cost of implementing specific projects and the time required. When too many projects are started at the same time, available skills are dispersed, project implementation is slowed, and economic and financial returns from the investments are reduced.

- New projects should not be started at the expense of adequate funding for those projects already under way. Completion of ongoing projects, if they are still justified given the incremental costs and benefits, should have a high priority for funding as should the operation and maintenance of completed projects.

- The "free" resources left after the needs of ongoing and completed projects have been met should be calculated. This makes possible rational decisions about how much funding can be devoted to new projects in any budget year.

- Planning agencies need to strengthen their project appraisal capacity and to make greater use of cost-benefit analysis to identify and screen out projects with low rates of return.

- Investment plans need to be kept flexible and modified as circumstances change. In addition, a "core program" of investments should be identified so that cuts in programs made necessary by a shortfall in resources can be determined by priorities established in advance. Another technique found useful in many countries is to have a rolling investment program -- usually a three-year program -- that is updated annually or more frequently if circumstances warrant.

As outlined above, the allocation of scarce investment funds among sectors is usually made at the national level. Inputs from sector planning, particularly information on economic and non-economic costs and benefits of different choices, can greatly influence this process. Special sector studies are the basis for specific policy recommendations and for the design of individual projects. They are also required for another very practical reason: "... Over a period of time a wide range of issues must be examined in each sector, including institutional and decision making structures, manpower and training needs, sector investment plans, incentives for resource allocation, technology policy, shadow prices for project evaluation, statistical requirements, and so on. No single study can adequately cover all the relevant issues; moreover, much is gained from having up-to-date analyses of specific issues based on current data, rather than a comprehensive survey report that can, at best, be done no more often than every five to ten years. Governments will accordingly find it desirable to devote most sector work to a program of special studies of priority issues, phased over several years." (p. 71) Baum and Tolbert (1985, p.71) comment that, of the three levels in which planning and analysis is carried out - national, sector, and project - "sector analysis is still a relatively neglected area in many countries--even though it furnishes essential information both for formulating a sound national investment program and for selecting and designing projects that respond to the most pressing needs of the sector....Compared with the elaboration of theories and models for national investment planning or of cost-benefit and other analytical techniques for project assessment, theoretical and practical guidelines for the conduct of sector analysis are much less developed...Because no sector functions in isolation from the rest of the economy, an important contribution of sector analysis is to determine the impact of a sector on the development of other sectors and to ensure consistency in policy and investment recommendations from one sector to another. Therefore, sector analysis--while obviously focused on a particular sector--should ideally be conducted in close coordination with studies and analyses being done of other sectors and of the economy as a whole Admittedly, this will cause difficult problems of coordination for many governments. When properly done, however, sector work is highly useful to governments because it points up intersectoral relations, constraints, and opportunities that previously were either not perceived or not fully appreciated."

1.8 Top-down vs Bottom-up Approach

The preceding subsection has outlined the normal division of responsibilities for planning to the national, sector, and project levels. However, "...only in the abstract can the ... process be described as a sequence of steps proceeding in logical order from the national to the project level.... (It) is in fact a continuum; decisions or actions affecting individual projects may take place at each of the three levels simultaneously and in interactive ways" (Baum and Tolbert, 1985, p 575). Furthermore, "...successful planning requires translating nationwide objectives and policies into the specific requirements of individual sectors and subsectors, as well as into the still more specific details of individual projects. Too often, this process of translation is not done very well. Or it may not be done at all, in the sense that people working in the central planning agency and in the sectoral ministries may not communicate adequately with each other.... The typical development program moves forward with weak connections between "the top" and "the bottom." A basic purpose of sector analysis is, therefore, to bridge the gap between the macroeconomics of country-level policies and investment programs and the microeconomics of individual projects. It promotes "top down" and "bottom up" activity in several ways. First, it complements macroeconomic work by analyzing the effects on the sector, and on projects within the sector, of such general policy variables as the exchange rate, tax structure, wage policies, and interest rates. (Policies and problems in important sectors of the economy -- such as agriculture and industry -- act, in turn, on the macroeconomic setting.) Second, sector analysis provides estimates of output and employment potential and investment requirements for the sector as a whole; these are essential inputs into the central planning agency's decisions regarding the national investment program and priorities. Third, by assessing the development potential and the relative advantages of different projects and programs within a sector, sector analysis helps to ensure that individual projects are selected and designed on the basis of a sector's needs and priorities, and that policy and institutional changes necessary for good performance at the project, or microeconomic, level are identified." (p. 74)

In the United States and other more developed countries, the trend in planning is toward a more open process, usually referred to as the "public participation process", in which the organization sponsoring a plan or project and its staff seek an increasing level of interaction with all entities that have an actual or perceived interest in the plan or project. This trend is in accord with ethical behavior in democratic types of societies and has also emerged as a practical response to heightened environmental and social concerns. It may be formalized by legal mandates for public participation in natural resources planning.

The public participation process provides information to generate public interest and increase understanding of a plan or proposal. Interaction with the public elicits information and encourages a continuing dialogue. By these means, planners establish credibility for the plan or project and the agency or firm involved. Increased public participation in water resources planning and decision making has arisen as a result of mounting public pressure on decision makers. Opposition to some proposals has resulted in long delays or abondonment of projects which have been perceived as unacceptable. Planners have recognized that big or complex projects need the support of many groups to be acceptable. Effective participation is the way to gain public acceptance of worthwhile projects or, alternatively, to recognize early which projects are not likely to be acceptable.

Public involvement in planning may be justified as good management practice in both economically advanced and developing countries since it often presents opportunities to:

- Identify legal requirements, funding limitations, or other constraints and ensure that the plan is compatible with them.

- Take advantage of technical expertise that may be reached through the process.

- Identify and clarify positions of different groups and individuals affected by the plan.

- Identify sensitive issues and ways of preventing or reducing adverse impacts.

- Overcome conflicts and reach a consensus when there are different points of view with respect to plan components, particularly when multiple objectives are involved.

- Gain support for the project or project implementation.

The public participation process should involve a preplanning phase in which information is obtained for individual communities such as:

- The general characteristics of the community, including socioeconomic data

- Local values and concerns relevant to the project, including attitudes about the resource under consideration and the agency or firm doing the planning

- The history of similar projects, if any, including interest groups or individuals involved in these earlier projects or programs

- Community experience with citizen participation and community cohesiveness

- The political decision-making framework in the community

- Local groups or individuals who are interested in or affected by the proposal

1.9 Other Issues Specific to Water Resources Planning

There are a number of issues that are specific to water resources planning, in contrast to the issues discussed in the foregoing subsections which apply to all areas of public investment in infrastructure. These include:

- *The water resource as a system.* This is discussed in Section 3 in terms of the global situation, in Section 4 in terms of the interrelationships of individual projects and in Section 7 in terms of modelling of systems.

- *Social and environmental impacts.* The incorporation into water resources planning of a multitude of considerations of social and environmental effects is recognized as desirable by all responsible agencies and individuals involved in planning and decision making. This is discussed in Section 6 in connection with the preparation of feasibility reports and their appraisals by the World Bank and other international financing instructions and in Section 7 in terms of environmental and social planning models.

- *Institutional and legal aspects.* The successful implementation of water resources planning recommendations, and the sustainability of projects beyond the construction and early operation stages, depends upon the clearing of legal impediments to development and the establishment of effective institutional structures to carry out the construction, maintenance, and operation of these projects. When international bodies of water are involved, international agreements concerning the control and use of water may be required and, in some cases, international compacts may be necessary. This is discussed further in terms of planning boundaries in Section 4 and in terms of project appraisals in Section 6.

- *Physical threats to water resources systems.* Contemporary issues include the overdraft of surface and ground waters; quality problems due to pollution; and impacts to land/water/air interelationships. Other physical threats to water resources systems that are important primarily in terms of their implications for the future have been identified and assessed by many investigators but the experts are not agreed on their importance and rate of impact. These include the effects due to acid rain, destruction of forests, conversion of many populations toward increasing urbanization, and global warming due to modifications of the ozone layer. These issues are discussed in Section 3 and Section 7.

- *Sustainability of water resources developments.* Many water resources projects in developing countries have not been successful in providing benefits for a long time after project completion for a variety of reasons. Some were poorly conceived from the beginning or poorly executed. Others did not have an adequate and stable management and facilities to ensure that after they were completed they were properly maintained and operated, and secured the anticipated products and income. Still others did not adjust to changing conditions of supply or demand or failed to take proper account of environmental and social considerations. This problem is discussed in Section 2.

SECTION 2

PRINCIPLES OF INTEGRATED WATER RESOURCES PLANNING

2.1 What Experience with Current Planning Teaches

Published literature and the unpublished work of United Nations and World Bank staff provide information on what has and has not worked in the planning of water resources in developing countries. The following are some of the conclusions from these experiences.

1. The planning of water resources is an important activity in all developing countries. Water is critical to mankind's existence and to the economic development of these countries. There are many problems inherent in the control and utilization of water -- in satisfying demands for water, solving problems of too much or too little water, and in taking advantage of water resources to produce products and services. The development of water resources requires major capital investments, strains domestic budgets, and often cannot be accomplished without financial and technical assistance from international financial and technical institutions. These considerations provide ample reasons to improve and strengthen the organizations and processes whereby water resources developments are identified, planned in their myriad details, implemented, and maintained and operated.

2. The planning and implementing of water resources projects will continue to involve organizations and individuals at the national, sector, and project levels.

3. Overall leadership, preparation of investment programs and budgets, allocation of funds for sector investments, and approval of major projects, will continue to be functions of the national government. Various guidelines for planning may be issued by government central planning agencies and line ministries, for consideration by project planners in the identification, formulation, and analysis of projects. Guidelines indicating the relative allocation of funds for development in the principal economic sectors (such as agriculture, power, and industrial development) may result from macroeconomic model studies, but will also depend on political and institutional considerations. Budgets for each of the principal economic sectors, rules to determine priorities within each of the sectors, and criteria for analysis (such as discount rate, and shadow pricing details) may be provided to the planner. In most cases, however, the planner must supplement this information with special planning tools, tempered with substantial amounts of judgment, in order to carry out planning activities.

4. Because most of the planning of water resources development, at both master planning and project levels, will continue to be carried out at the sector level, it is essential to strengthen the institutions and personnel that prepare the plans at this level in order to overcome the problems that have been identified in the planning, implementation, and sustaining of projects after they are placed into operation.

5. The project, either alone or as a component of a master plan, will continue to be the principal vehicle for implementation of plans and programmes

for water resources development. A major reason for this is the adoption and long history of this approach by the World Bank, other international institutions, and the planning and operating agencies in developing countries.

6. All professionals in the water resources field must continue to recognize the interdisciplinary nature of planning in this field. In addition to the effects on the income, health, and safety of those affected by the project, planners must consider the beneficial and adverse environmental, social, and regional and national economic impacts of the project. They must also take account of other issues such as those of a political, institutional, and financial nature that determine whether a project is acceptable and can be implemented successfully. It is not enough for planning organizations to have highly trained individuals in fields such as engineering, economics, biology, and the social and political sciences. Responsible planning by an individual in one discipline requires a basic understanding of the other disciplines and a willingness to work cooperatively toward common objectives.

7. Strong efforts are necessary to bring about improved intersectoral cooperation and decision making. This must involve informal and formal structures (which may be political, institutional and administrative) to ensure that adequate consideration is given to factors that affect project feasibility and successful implementation and operation over a long period in the future. The organizational structure that facilitates such planning must take account of the roles of the country's leadership, its central planning agencies, and the various line ministries. This is particularly important for water resources planning because of the multitude of sectors and agencies involved. A water resources development in a developing country could involve, in addition to the water development sector, the transportation, agriculture, power, industrial, and public health sectors. The history of conflicts among these entities, and the adverse effect of such conflicts on planning, is understandable given the missions of individual agencies, overlapping jurisdictions and interests, and the political agendas of individuals and organizations.

8. Effective water resources planning requires not only the appropriate relationships among planners at the national, sectoral and project levels but also adequate participation in the planning process of the beneficiaries of projects and others interested in the plans that are prepared.

9. Methodologies are available for water resources planning drawn from systems analysis, operations research, and other academic disciplines which are capable (particularly with mathematical models and computers) of considering the interrelated factors of engineering, cost, and economic benefits for individual projects and highly complex systems of projects. Specialized methods, including models, are also available for studying social, environmental, and institutional issues. The implementation of these methods requires specialized skills and much data, in order to obtain useful and reliable results. Sophisticated methodologies, however, do not substitute adequately for skills derived from experience and good judgment.

10. Planners must recognize that dangers to the adequacy and reliability of water resources systems are increasing. In the short and near terms, the most important problems are related to overuse, insufficient control of water, and contamination by pollutants produced by mankind. In the long term, global problems may be critical, such as those caused by global warming. Since water resources projects are planned to be operated into the indefinite future, and

since a developing country can suffer more from the failure of one or a few projects than a more robust economy with more varied and extensive natural resources, uncertain futures or problems having small likelihood of occurrence cannot be ignored.

11. Because of a variety of historical reasons that vary from country to country, there are many cases of misallocations of water when viewed from the standpoint of society's best interests. There is a need to redistribute water from existing projects among agricultural, industrial, municipal, and other uses and to improve the methods of optimizing allocations of water from new projects. Rational allocations require good estimates of the long run marginal costs of water and of the value of water in alternative uses, which are often not available or unreliable. In this context, the value of water comprehends not only monetary value but other values that reflect social, environmental and other considerations.

12. In planning, more attention needs to be given than hitherto to the externalities (both positive and negative effects) of an economic, social, and environmental nature that are attributable to a plan but fall outside of the "project area" drawn for the plan.

13. In the operation of projects, improvements are needed in policies such as those on pricing, subsidies, and cost recovery, that affect economic and financial performance. The question of pricing at lower than cost, special support to the poor, and other aspects of subsidy management need particular attention. Improvements are also needed in the institutions and personnel responsible for the operation and maintenance measures that are needed for the sustainability of projects beyond the construction and initial operation stages.

14. Water resources projects depend for their success, on the availability of an infrastructure to supply the products and services to beneficiaries, to support the marketing of products and services from these beneficiaries, and the other components of infrastructure (e.g. education and training, housing, etc.) that are essential to the security and well being of a nation and its inhabitants.

15. The question of tradeoffs between economic development effects and environmental and related social effects has not been adequately addressed. Neither the position that holds that every economic development must result in negative environmental/social effects, nor the position that claims that every economic development can be fully compatible with its environmental and social setting, is reasonable.

16. Nations, through their political, legal and planning institutions must continue to strive to solve problems of international rivers, lakes and reservoirs, ground water regions and marine waters. Such issues have become more complex as more is learned about the interrelationships of water withdrawals and discharges, and the effects of pollutants on health and property and the ways these pollutants move through water, land, and air routes.

2.2 The Problem of Sustainability

A report for the Organization of American States (1984) states that: "Development carries with it the concept of sustainability. This goes beyond the controversy of "growth" vs. "growth with distribution." Indeed, sustainability requires dynamic stability achieved through change that is economically sound and socially just and that maintains the natural resource base. Development, according to this model, means change with growth and equity. The central development challenge is to initiate and sustain a process whereby the material and spiritual well-being of a population is improved and development proceeds are fairly distributed according to principles of social justice."

Sustainability of projects and programmes has, in recent years, been an increasingly serious concern of the United Nations, World Bank, other international development agencies, and donor countries. When projects fail completely or do not achieve their intended levels of performance, they represent poor use of scarce investment funds from outside the country, a drain on the country's monetary and other resources, and may even be counterproductive to the country's goals of economic growth and improvement of the well-being of its people.

The importance of project and programme sustainability has been expressed as follows in a World Bank publication by Bamberger and Cheema (1990): "Both governments and international development agencies are increasingly aware that development planning focuses mainly on project *implementation* and that much less attention is paid to issues of operation, maintenance, and sustainability. While many countries have developed sophisticated computer systems to monitor project implementation and to compare intended and actual physical and financial performance, few if any developing countries produce regular monitoring reports on project operation and maintenance and on whether projects are actually producing the intended benefits. Neither governments nor international development agencies receive systematic information on how well their investments are producing their intended social and economic benefits. As resources become increasingly scarce, this lack of information on the performance of public investment programs is becoming of increasing concern, and the demand for more systematic monitoring and evaluation of sustainability is likely to grow. There is increasing criticism (particularly from environmental groups and nongovernmental organization) that international funding agencies and national governments are mainly concerned with ensuring their projects' economic viability (and sustainability), but that little attention is paid to the impact of projects on broader development concerns, such as the environment or the conditions of the poorest sectors of society. These concerns are broadening attention from concerns about *project sustainability* to wider issues of *sustainable development*."

These commentators claim the following consequences of the low priority attached to project sustainability:

- Increased maintenance costs and more rapid deterioration of infrastructure
- Reduction in the level and duration of project benefits
- Reduced quality of services
- Reduced accessibility of certain groups to project benefits
- Low priority of long-term institutional development objectives.

They also point out that, at the macro level, lack of concern with the impacts of development strategies on the sustainability of the natural environment can have even more drastic effects. They cite the following examples from "The State of India's Environment" (Centre for Science and Environment, 1984-85):

- Due to lack of concern with pollution control, all but two of India's high-altitude lakes are dying.
- Uncontrolled deforestation has resulted in a lack of fodder for cattle.
- Conncern with reducing the repayment period on social forestry projects has encouraged the planting of eucalyptus trees which grow quickly, but which cannot be used for fodder. Consequently forests can no longer sustain cattle production.
- Uncontrolled deforestation has resulted in 4 million hectares of land being swallowed up by ravines.

Table 2.1 by the authors provides a set of indicators which can be used to assess the degree of sustainability. They indicate how these indicators can be converted into a "sustainability checklist" and how a "sustainability index" can be computed by assigning numerical values of each indicator.

In connection with the International Drinking Water Supply and Sanitation Decade, proclaimed by the United Nations General Assembly in 1980, the UNDP and the World Bank in collaboration with developing countries and the international donor community formulated a strategy "Toward Equitable and Sustainable Development" (July 1988). This document noted that beyond the sheer magnitude of investment, the following other major obstacles were identified by governments and the international community:

- Fragmented sector policies.
- Weak or nonexistent institutions and inadequate coordination among sector agencies.
- Lack of adequately trained and motivated manpower.
- Use of technologies inappropriate for developing country conditions, and lack of knowledge of lower-cost technologies.
- Lack of community involvement.
- Inadequate operations and maintenance.
- Problems with resource mobilization and utilization, including cost recovery.

Table 2.1 Indicators of Project Sustainability
(Source: Bamberger and Cheema, 1990)

A. *Continued Delivery of Services and Production of Benefits*

A-1 Comparison of actual and intended benefits and services and their stability over time

A-2 Efficiency of service delivery

A-3 Quality of services (benefits)

A-4 Satisfaction of beneficiaries

A-5 Distribution of benefits among different economic and social groups

B. *Maintenance of Physical Infrastructure*

B-1 Condition of physical infrastructure

B-2 Condition of plant and equipment

B-3 Adequacy of maintenance procedures

B-4 Efficiency of cost-recovery and adequacy of operating budget

B-5 Beneficiary involvement in maintenance procedures

C. *Long-Term Institutional Capacity*

C-1 Capacity and mandate of the principal operating agencies

C-2 Stability of staff and budget of operational agency

C-3 Adequacy of interagency coordination

C-4 Adequacy of coordination with community organizations and beneficiaries

C-5 Flexibility and capacity to adapt project design and operation to changing circumstances

D. *Political Support*

D-1 Strength and stability of support from international agencies

D-2 Strength and stability of support from the national government

D-3 Strength and stability of support from provincial and local government agencies

D-4 Strength and stability of support at the community level

D-5 Extent to which the project has been able to build broad base of support and to avoid becoming politically controversial

The strategy for the water and sanitation sector recognized that this sector is "a closely knit fabric of economic, social, political, technical, institutional, and policy factors." To achieve sustained development in the sector, it recommended coordinated action including:

- Sector work leading to the adoption of sound sector policies as a framework for national sector plans and investment programs;

- Demonstration projects to refine implementation strategies that can be replicated on a national scale for the delivery of water supply and sanitation services to low-income people;

- Human resource development and training to strengthen institutions and respond to the manpower, including community members and workers, needed for delivery of services using low-cost systems;

- Development of necessary supporting institutions and services in both public and private spheres, including promotion of local industries and consultants and support of nongovernmental organizations (NGOs);

- Support to investment and development of projects ultimately leading to large-scale implementation of services using low-cost water supply and sanitation systems; and

- Continuous dialogue with the government and with the external support agencies active in the sector to integrate these elements into a coherent approach to sector development.

The preceding discussion has dealt largely with water resources development and economic effects. Another dimension to the problem of sustainability is the degradation and destruction of environmental systems and natural resources as the result of a water resources plan. The analysis of environmental impacts is now generally accepted as a requisite of water resources plan preparation and its assessment by reviewing authorities. The range of environmental considerations should be widened to include not only matters of water, land, and air quality, but also the long-term sustainability of ecological species, particularly when the survival of specific species is threatened.

The Development Committee of the World Bank and the International Monetary Fund received a report prepared by the staffs of these organizations dated May 8, 1990 reviewing development issues faced by world community. This report stressed the need for funding for the global environment and referred to a meeting on this subject in Paris on March 15-16, 1990 attended by representatives of the World Bank, the United Nations Environment Programme, the United Nations Development Programme and 17 donor countries. A discussion paper at this meeting proposed the creation of a Global Environment Facility to address four key areas of concern: protection of the ozone layer, reduction of emissions of greenhouse gases, protection against degradation of international water resources and protection of biodiversity. This paper, in elaborating on the last issue, referred to the The World Commission on Environment and Development, chaired by Prime Minister Brundtland of Norway, which issued a report in 1987 urging that "serious consideration be given to the development of a special international banking program or facility to increase substantially investments in conservation projects and national strategies that enhance the resource base for development." In follow-up to this recommendation the UNDP commissioned the World Resource

Institute (WRI) to develop a series of options for achieving the goals set forth in the Commission's report. The WRI Report, issued in September 1989, outlined a number of proposals including one for the creation of an International Environment Facility to further the preparation and financing of conservation projects. Conservation was broadly defined as maintaining natural resources as the basis for meeting the needs of current and future generations.

The paper indicated that this concept of sustainability of resource use is already accepted in Bank operations as an important objective and would not, by itself, justify additional concessional funding, but that the more narrowly defined objective of preserving biological diversity and intact ecosystems could justify such an approach based on the benefits accruing to the world community. It noted that "many examples exist to illustrate the general point that the earth's endowment of biological resources is a precious asset, which needs to be conserved and managed with allowance for the benefits that cannot be captured by the country directly concerned. Species and ecosystems contribute a wide range of goods and services, from harvestable material for medicine or industrial products and genetic resources for food production, to regulating the climate and rainfall patterns. The preservation of specific areas to ensure biodiversity conservation competes with other land uses in many countries. Thus the provision of funds on a concessional basis could provide the incentive to take action with respect to biodiversity conservation in the interests of the global community."

2.3 Attempts at Effective Integrated Water Resources Planning

The United Nations has been a proponent of effective planning of natural resources for many years. The United Nations Scientific Conference on the Conservation and Utilization of Resources in 1949 demonstrated that resources in general, and water resources in particular, are limited.

A Manual of River Basin Planning, under the overall title of Multiple-Purpose River Basin Development, was prepared by the United Nations Economic Commission for Asia and the Far East in 1955. This document emphasized advantages of multiple-purpose river basin development. It discussed procedures for the formulation and execution of a development plan for a river basin, and determining priorities among projects. It stated: (1) that a unified river basin plan can be formulated through a single authority which coordinates the efforts of various departments or provinces involved in drawing up the plan, or "through other administrative arrangements", and (2) that where a central water authority exists, it should maintain close contact with the river basin planning unit at every stage of the planning process and should synthesize all basin programmes into a single national programme. It pointed out that, in addition to scheduling rates of investment, the national programme might indicate the relationship between resource development expenditures and total national expenditures on other items such as defense, public health, welfare, education and buildings and roads; make sure that measures are taken for constant improvement of national production; and provide a useful guide as to whether all of the related programs taken together are sufficient to achieve within a reasonable period important goals set for the nation.

A Report on Integrated River Basin Development was prepared by a Panel of Experts for the United Nations Department of Economic and Social Affairs in 1958. This report continued the emphasis on the river basin as a planning unit, and stated that: "In regions where economic development is already well advanced, a river basin may lose some of its cohesion as an economic entity because the boundaries of what may be considered an economic unit do not coincide with the physical limits of the basin area. The situation is often different in less developed areas where, because of the very lack of economic development, water projects may have a more dominating influence. When the works are extended to the physical boundaries of a river basin, there will be a tendency for these boundaries to coincide with those of an economic unit... The influence of any river basin development on the rest of the economy is likely to be considerable". The specific problems of river basin planning and development were indicated to be in the areas of economic evaluation, financing, organization and administration, and citizen participation and local projects. It discussed administrative solutions ranging from the case of a programme conducted within one of the regular departments or ministries of the government, to the case of a new and largely autonomous regional agency. The Tennessee Valley Authority in the United States and the Damodar Valley Authority in India were cited as examples of government agencies of corporate form which invest in and operate a variety of water functions ordinarily exercised by specialized government departments. The report recommended that systems analysis be considered in long-range planning because integrated water resource problems were complicated and "optimum solutions could be found only with sophisticated mathematical methods and the use of computers."

A Report on Water Resources Planning based on a series of seminars conducted in 1970 and 1971 was issued by the Economic Commission for Asia and the Far East and the UN Office of Technical Cooperation in 1972. This report stated that "the contributing factors to productivity are human skill, natural resources and capital. Human endowments and natural resources are to be put to the best possible use to achieve the highest enrichment of man's life, betterment of his well-being and enhancement of his outlook. To meet the needs for progress, all available resources (human, natural and capital) are assessed for use in water resources planning." The report pointed out that the following needed to be assessed: water resources, land resources, power resources, scenic and wildlife resources, financial resources, and human resources. It also discussed the need for infrastructure analysis indicating that plans for water resource utilization must consider the "social overhead capital" such as transportation and communication facilities which are available or must be added for successful development. The report also discussed the needs for data acquisition and information management.

Applied water resource systems techniques, particularly with respect to their hydrologic, economic, and engineering aspects, and their tradeoffs, were advanced substantially in several years of cooperative studies in the early 1970's by experts from the Massachusetts Institute of Technology working with counterparts in Argentina (Major and Lenton, 1979). A United Nations sponsored report on "Integrated Development of the Vardar/Axios River Basin - Yugoslavia/Greece" (Tippetts Abbett McCarthy Stratton and Mass. Inst. of Technology, Dec. 1978), which benefitted from the Argentina studies, was a landmark in water resources planning technology in the high degree by which it incorporated the interrelated factors involved in determining the engineering and economic scales of projects related to each other in a large river basin system. Approximately 150 projects and river basin locations were studied in which the principal considerations were economic sector development (principally agricultural, municipal and industrial, and electric power); balanced regional development; engineering and economic feasibility of facilities; and compatibility with existing power and hydraulic systems. A study of this type, referred to in the 1970's as "integrated water resources planning", if carried out appropriately in the 1990's should consider environmental and social effects and political and institutional aspects that affect the implementability and sustainability of projects, more explicitly than in an earlier planning era.

In January 1984, the Department of Regional Development (DRD) of the Organization for American States, in cooperation with the U.S. National Park Science and the U.S. Agency for International Development issued a document entitled "Integrated Regional Development Planning: Guidelines and Case Studies from OAS Experience", which stated: "The common critical need in all regions is more effective management of renewable natural resources using integrated approaches to regional planning and project design. The goal of integrated planning is the preparation of a rational plan in which all development sectors have been assessed for their effects on all the resources in a given geographic area. It implies significant coordination among sectors and flexibility to modify activities to avoid resource depletion and assure long-term economic productivity."

The guidelines and case studies in the OAS book follow an "integrated approach to regional development planning." Although the book refers to the "realities of Latin American development", it claims that the approach has been used under a variety of conditions and draws partially on the experiences of other regional planners, some of them on other continents including Africa and Asia: "Hard experience counsels that comprehensive regional development plans are too expensive, too time-consuming, too detailed, and therefore too fragile to withstand the realities of Latin American development. They may be intellectually satisfying to create, but rarely are they converted into reality. There are simply too many uncontrolled variables and political vagaries to justify investment in highly detailed regional plans. Indeed, the expression "comprehensive regional development planning" has been banished from DRD's working vocabulary. On the other hand, a simple grouping of projects is no basis for planned development."

DRD has evolved an "intermediate" approach inspired by practical experience in Latin America and the interpretation of development expressed in the OAS Charter. This approach to integrated regional development is characterized by distinct phases emanating initially from an overview of the region within the context of the national plan and proceeding to more detailed analysis of promising development areas. The three essential elements are diagnosis, strategy, and project development which the DRD defines as follows:

> *Diagnosis*--A rapid analysis to determine the principal problems, potentials, and constraints of a region. The development diagnosis can include evaluation of natural resources and socio-economic conditions; delineation and analysis of subregions; identification of critical institutions, sectors,and geographic areas; generation of new information; and assembling ideas for investment projects.
>
> *Strategy*--Selection of pressing issues and opportunities for addressing them with the resources available. These opportunities suggest actions that are politically feasible within a time frame short enough to maintain momentum. (Less critical issues can be left for another round.) Alternative strategies can be presented so the government has a choice.

Projects--Preparation of interrelated investment projects to implement the selected strategy. The projects, developed usually through pre-feasibility.., provide a balance among infrastructure, production activities, and services. Collectively, their benefit-cost ratio must be acceptable to governments and funders. The projects are presented to the government, together with any ancillary actions required, in an action plan of short - to middle-term duration.

A number of case studies, experiences and issues in developing countries were reported on in an interregional seminar on assessment and evaluation of multiple objective water resources projects in 1985 by the United Nations Department of Technical Cooperation for Development in co-operation with the United Nations Environmental Programme and the Hungarian People's Republic. This seminar considered techniques for identifying, measuring and presenting the economic, environmental and social benefits and costs of development projects and proposals. It also considered the problems of risk and uncertainty. It implemented a recommendation of the Mar del Plata Action Plan, which arose out of the United Nations Water Conference in Argentina in March 1977.

The resulting publication (Assessment of Multiple Objective Water Resources Projects, United Nations, 1988) stated that: "Multiobjective planning is...a procedure to increase the awareness of those involved in project planning, selection, and implementation of a wider variety of probable economic, environmental, and social impacts than might otherwise be the case. These impacts will usually include aspects that cannot all be expressed in economic or monetary units, but which may be important to those responsible for planning and making decisions. Decisions based on a broader spectrum of information regarding project impacts can lead to a more efficient use of resources allocated to development and to a higher and more stable rate of sustained social and economic development....While in many cases, developed countries can afford to argue about project priorities among economic, environmental, social, and perhaps other objectives, developing countries are by necessity primarily concerned about economic growth in an environment that can sustain that growth. How can a poor country best increase rapidly the general level of income derived from its available resources so as to improve the standard of living of a largely undernourished, unskilled, and undereducated population?...Such conditions in developing countries often lead to project investment decisions before sufficient data are available to assess all possible impacts. Hence the emphasis is on establishing minimum sustainable threshold levels of various environmental and social conditions, and treating these as constraints in project planning and assessment....One of the conclusions...was that it would not be possible to develop a manual indicating how multiobjective water resources planning should be carried out for all situations. This is simply because the conditions (institutions, personnel, and political and social environment) under which such planning would take place are so very different from country to country."

A number of other publications have been prepared by the United Nations Department of Technical Cooperation for Development to carry out recommendations of the Mar del Plata conference, including a 1988 report on Water Resources Planning to Meet Long-Term Demand: Guidelines for Developing Countries.

Several examples from the United States experience may be considered to have important relevance to the development of water resources planning methodology, not only in economically advanced countries but also in developing countries. Several types of organizations for planning and managing river basins have been established in the United States. These include river basin commissions, interstate compacts, federal-interstate compact commissions, and federal-state interagency committees. Other ad-hoc organizations have been established for special studies that represent various constituencies. The Tennessee Valley Authority is an independent Federal corporation established for water management activities in the Tennessee River Basin. It constructed and operates an extensive system of dams, power-plants and transmission system, and other structures. The TVA continues to plan and develop the water and land resources of the basin. While considered successful, this type of organization has not been adopted for any other basin in the United States. However, it has served as a model for initiatives in a number of developing countries. According to Crossman and Bruch (1987) the benefits generated by the reservoir system that stores water and regulates flows with the aid of 40 dams, amounted to the following for the period 1934-1983, in 1982 dollars: flood control 4.1 billion, navigation 3.7 billion, recreation 6.4 billion, and hydroelectric 8.3 to 12.9 billion depending on measurement method.

There is a long history in the United States of the evolution of national objectives and the development of planning procedures by federal agencies in the water resource field that are consistent with these objectives. The U.S. Inter-Agency Committee on Water Resources in its "Proposed Practices for Economic Analysis of River Basin Projects" ("Green Book," issued May 1950 and revised May 1958) recognized (p. 5) that "the ultimate aim of river basin projects and programs, in common with all other productive activity, is to satisfy human needs and desires." Although it "recognized that public policy may be influenced by other than economic considerations," the report restricted itself to the economics of project development and justification in terms of benefits and costs from the standpoint of aggregate consumption principles as applied to the unadjusted market place. Presumably, any broader considerations related to the public welfare were taken into account in the practices of the individual agencies. In fact, since the adoption of the Green Book principles was not mandatory, emphases on different objectives could be continued if they were implicit in the legal and institutional framework under which the agency (e.g., Bureau of Reclamation) operated. Since agencies had specialized missions and political constituencies, concern with noneconomic objectives was not uncommon.

U.S. Senate Document 97 (U.S. President's Water Resources Council, 1962) took a broader view of planning policies that were desirable from a national viewpoint, and specified policies that were supposed to be applied uniformly by the agencies except when prevented by law (the President's Water Resources Council consisted of the secretaries of the principal federal agencies dealing with water resources). The basic objective in the formulation of plans was stated (p. 1) "to provide the best use, or combination of uses, of water and related land resources to meet all foreseeable short and long-term needs." In "pursuit of this basic conservation objective," planning would fully consider the following objectives and make "reasoned choices" between them when they conflict:

1. Development

2. Preservation

3. Well-being of people

Development included both national development and regional development, and applied to the various purposes of water and related land resources development and management (water supply, navigation, outdoor recreation when provided or enhanced by development works, etc.). Preservation was defined (p. 2) as "proper stewardship in the long-term interest of the Nation's national bounty" and referred to such aspects as protection and rehabilitation of resources; maintenance and use for recreational purposes of natural water and land areas; and preservation and management of areas of natural beauty, historical, and scientific interest. The document stated that "the well-being of all the people shall be the overriding determinant in considering the best use of water and related land resources. Hardship and basic needs of particular groups within the general public shall be of concern, but care shall be taken to avoid resource use and development for the benefit of a few or the disadvantage of many. In particular, policy requirements and guides established by the Congress and aimed at assuring that the use of natural resources, including water resources safeguard the interests of all of our people shall be observed."

Following the establishment of a Water Resources Council (WRC) in 1965 replacing the President's Water Resources Council, the WRC in 1967 appointed a Special Task Force to review and revise the then current evaluation practices (according to Senate Document 97). Following a preliminary report in June 1969, the Task Force presented recommended principles and standards for planning in July 1970. The set of objectives recommended in the 1970 report were: (1) national economic development; (2) environmental quality; (3) social well-being; and (4) regional development. This document recommended the use of four accounts (tables) that displayed the beneficial and adverse effects toward each objective. After further study, review, field testing, and public hearings, the Council published its "Proposed Principles and Standards" on December 21, 1971, which retained as objectives national economic development, quality of the environment, and regional development. Although the system of accounts was to include "social factors," these were not given equal status as a major national planning objective. Finally, after further comments were received and various governmental agencies were consulted, the Water Resources Council on September 10, 1973, established its "Principles and Standards for Planning Water and Related Land Resources" in which a complete display or accounting would be made on only two objectives: National Economic Development and Environmental Quality. For each alternative plan, the beneficial and adverse effects on regional development and social well-being were, however, to be displayed (p. 24782) "where appropriate."

The "Principles and Standards" were revised in 1979 and 1980 and "Procedures" for detailed evaluation were developed and published by the Water Resources Council for the National Economic Development objectives in 1979 and 1980 and for the Environmental Quality objective in 1980. The categories for presentation were revised somewhat and renamed National Economic Development (NED), Environmental Quality (EQ), Regional Economic Development (RED), and Other Social Effects (OSE).

In 1983, in order "to reduce the burden on agencies in complying with detailed and legally binding technical rules" (Federal Register, vol. 48, no. 48, March 10, 1983), the "Principles and Standards" and "Procedures" were replaced by "Principles and Guidelines" based on the single NED objective (p. *iv*). The NED account would be required, while other information would be included in the EQ, RED, and OSE accounts, or "in some other appropriate format" (p. *v*).

A system of accounts was specified by the WRC in 1973 and illustrated by tables for a hypothetical project. The WRC published extensive guidelines for the NED and EQ accounts in 1983 in its "Principles and Guidelines." This document provided much less information for the RED and OSE accounts. Other material is available in the WRC 1973 document for the Regional Development (RD) and Social Well-Being (SWB) accounts and in the publications of other federal agencies.

The Corps of Engineers, Office of Appalachian Studies, (U.S. Department of the Army 1969) prepared an Appalachian Water Resources Study covering all or portions of 13 states. Historically, there was a downward trend in the Appalachian region for population, employment, and income as compared with values for the United States as a whole. The goal of the Appalachian Regional Act of 1965 and its extensions was to provide economic stimuli to reverse the downward trend. A major thrust of the act was that water resources development alone cannot be sufficiently effective. It was recognized that it was necessary to remove "bottlenecks" and impediments in a variety of economic sectors, in order to provide the synergism that is needed for economic development. Thus, projects were to be considered not only for large water resources developments but also for highways into rural areas, community water and wastewater treatment and supply, vocational education, child and maternal health, industrial parks, and other physical and social infrastructure.

Extensive studies of the economic impacts of water resources projects were carried out by the Office of Appalachian Studies which emphasized this concept in its "comprehensive economic planning" and also sponsored a number of research projects pertaining to induced economic growth. The investigations for Appalachia drew upon theoretical economic concepts developed earlier in pioneering work by developmental economists, and systematic procedures were developed by its staff and outside consultants. The studies sought to evaluate what was then referred to as "expansion benefits"; this term is not now in general use. The Water Resources Council "Principles and Standards" (1973, 1979, 1980) do not apply special distinctions to direct and indirect effects. The literature of water resource planning does, however, often use descriptors such as "primary and secondary" and "direct and indirect." Expansion benefits were defined as the total change in income brought about by a project. Such benefits tend to be equal to the user benefits when a project is built in a fully employed economy and where no externalities are brought about by the project. When a major reason for a water resource project is to stimulate economic growth (as in Appalachia or in a developing country), however, it is anticipated that the economic benefits will include not only user benefits, but will also include indirect effects *induced* by or *stemming* from the project.

Following the completion of this report, water resources planning activities reverted to sector organizations such as the Corps of Engineers and state agencies; however the broad concepts of multi-sector development have remained, and the Appalachian region is in better economic shape, relative to the nation as a whole, than in the 1960's. For example, in 1987, the per capita income was 80 percent of the national average and within 10% of the national average for the more urbanized areas.

2.4 Characteristics of Effective Integrated Water Resource Planning

The term *water resources planning* refers to planning for projects, programmes, or policies that involve:

- A single-purpose, single-unit plan to meet a demand for water, solve a problem caused by water, take advantage of an opportunity for water development, or preserve and enhance water and related land resources.
- A multi-purpose and/or multi-unit plan
- A regional plan for water resources development, preservation, or enhancement, staged over a period of time with one or more planning horizons.
- A national plan for water resources development, preservation, or enhancement.

The term *integrated water resources planning* comprehends the preceding and, in addition, assumes proper attention to:

- Legal and institutional, and budgetary and other constraints.
- Planning objectives at national, regional and local levels
- Physical interrelationships among the units of a water resources plan
- Supporting infrastructure that is needed to secure the products and services of a plan, their distribution to beneficiaries, and the benefits and costs of the plan
- Identification of all appropriate alternatives for development, preservation and enhancement with different contributions to planning objectives and different amounts of products and services.
- Possible tradeoffs among objectives, purposes, and effects of a plan
- Externalities of the plan
- All effects of the plan including those of an engineering, economic, environmental, social, legal and institutional nature
- Contributions by engineers, economists, biologists, and other disciplines related to the plan
- Contributions by agencies representing all economic sectors affecting or affected by the plan
- Involvement of individuals affected by or interested in the plan
- Method of presenting the features and expected results of the plan so that it can be commented upon by all interested parties and assessed and acted upon by decision makers.

Finally, *effective integrated water resources planning* refers to the derivation of a plan, while paying proper attention to the foregoing, which is optimal to society. For developing countries, this implies that water resources development and management will contribute as much as possible to the amelioration of the basic problems of the human condition in these countries, while avoiding serious damages to ecological populations and environmental quality.

Many studies of the United Nations and anecdotal experiences of its personnel involved in water resources planning have, in the past two decades, considered the failures or inadequate achievement of goals of water development projects. Comments in recent years have focussed on shortcomings such as: (1) projects that are too ambitious considering the limited financial and other resources of developing countries; (2) inadequate attention to environmental, social, institutional and legal aspects of project planning, implementation, and operation; (3) failure of comprehensive plans to guide development properly and/or failure of projects to correspond to these plans; (4) failure to create an organization with adequate staffing and responsibilities to ensure that projects are sustained beyond the construction and early operation stages.

A single framework for effective integrated water resource planning is not possible for all countries and regions, considering that they are different in their natural resources; population distribution and styles of living; economies; political, institutional, and legal structures; and other characteristics. However, some overall principles of planning may apply based upon experiences with planning in many developing countries and the tools that are available for assessment and analysis.

It must be recognized that integrated water resources planning should have two principal goals: (1) to plan programmes and projects that are economically efficient and socially desirable, and (2) to execute projects that will be sustainable over a long period of time beyond the exodus of foreign financing and technical assistance and the repayment of loans. These principal goals should be kept in the forefront during all stages of planning, implementation, and maintenance and operation.

Furthermore, the full benefits to the water user beneficiaries of a project cannot be achieved unless there is an adequate infrastructure of facilities and services such as roads, marketing organizations and other components.

In addition, full benefits of water resources development cannot be achieved unless national, regional, local and individual costs and benefits are all recognized in formulating and analyzing projects and selecting priorities.

Appropriate administrative organizations and good leadership within these organizations are very important in water resources planning and development. Adequate manpower, manpower training, organizational powers, and removal of legal impediments, are needed for effective exertion of leadership. Mechanisms must be developed for proper coordination of the national, sectoral, and project organizations involved in planning, and for other organizations and individuals involved in or interested in water resources planning.

With respect to the aspect of institutions, the Organization for Economic Co-operation and Development in a report on the Management of Water Projects (1985) commented that the optimum institutional framework will obviously differ from country to country, depending on the culture, history, and level of development. It may also differ from region to region. While this report did not recommend a uniquely optimal framework, it gave some general guidelines and criteria for appropriate institutional frameworks:

1. Does the institutional framework permit the consideration of a wide range of alternatives, once it has been decided that water can efficiently contribute to problem solution?

2. Will the planning agency (or agencies) involved have the expertise needed for multiple objective design and evaluation procedures, especially in the economic, social and environmental fields?

3. Does the institutional framework permit and stimulate adaptation of plans to changing national and local priorities?

4. Does the institutional framework permit and stimulate the representation of the interests of all parties affected by water development and management?

5. Does the institutional framework reward initiative and innovation among the members of the technical team and within co-operating agencies?

6. Is the technical team sufficiently free from day-to-day responsibilities that they can concentrate on long range planning and anticipation of future problems?

7. Do the institutions have the capacity for learning and improving the project over time, including sufficient continuity over time and the utilization of *ex post project analyses*?

8. Is there sufficient authority within the institutional framework to enforce conformity with construction and operating plans once they are made?

9. Is the institutional framework capable of guaranteeing and acceptable minimum level of professional performance by the technical team?

SECTION 3

THE WATER RESOURCE AS A SYSTEM

3.1 Unique Nature of the Water Resource

Application of good water resources planning techniques is needed not only to solve the problems of water supply and other water resource developments, but also to take advantage of the opportunities for improved conservation and enjoyment of water and related land resources. The water resources planner is challenged to overcome the problems of too little or too much water, to develop the best logistics and facilities to meet water needs, and to develop, preserve and enhance water bodies. It is essential in such planning to comprehend the water resource as a system, both regionally and globally, and to understand how man's activities affect this system.

The water resource has unique characteristics and is a limited and fragile resource, that is affected by man's activities, as discussed in a USSR Committee (1978) study of the world water balance and water resources of the earth: "Water differs markedly from most other natural resources by its remarkable property of continuous renewal in the water cycle, the main link in which is water exchange between oceans and the land. The world ocean is a gigantic evaporator which, in this natural cycle, is the main source of fresh water. This fresh water falls as atmospheric precipitation and is the source of all water flows and water accumulations on land. Another important property of water is that, regardless of the number of times it is used by man, the quantity of water on the earth is not reduced, and in the water cycle its purity is restored and it is available for use once again. It may be precisely because of this capacity of water for self-regeneration and self-purification that for a long time water was regarded as an inexhaustible resource. But within the lifetime of the present generation..., the attitude towards resources has changed completely. From being an unlimited gift of nature, as it was still regarded until quite recently, water has become a dominant factor which greatly influences economic development and the well-being of human society. The main causes of water problems are (1) that as man's needs increase, the quantity of water required rises proportionately; (2) that, according to forecasts for the first half of the 21st century, this requirement in the developed countries will equal or even exceed the available water resources; and (3) that unused natural water is quickly polluted by the discharge into rivers and other waters of non-purified, or poorly purified industrial, agricultural and domestic waste. As time passes fewer and fewer areas of land and water remain which are not affected by the activities of man. In our own century -- the century of technological progress and use of powerful technical aids -- man is cutting trees, draining marshes and waterlogged earth, increasing the areas of irrigated land, regulating and redistributing river flows on a large scale, and transferring very large quantities of water from one place to another. The results of human activity, which are by no means always sensible, are becoming evident, not only in the quality and quantity of water in rivers, lakes and ground-water reservoirs, but also in the regimes of inland seas and even in the world ocean."

3.2 The Hydrologic Cycle

The hydrologic cycle explains the occurrence and variability of water. Linsley, et al, (1982) visualize the cycle: "as beginning with the evaporation of water from the oceans. The resulting vapor is transported by moving air masses. Under the proper conditions, the vapor is condensed to form clouds, which in turn may result in precipitation. The precipitation which falls upon land is dispersed in several ways. The greater part is temporarily retained in the soil near where it falls and is ultimately returned to the atmosphere by evaporation and transpiration by plants. A portion of the water finds its way over and through the surface soil to stream channels, while other water penetrates farther into the ground to become part of the groundwater. Under the influence of gravity, both surface streamflow and groundwater move toward lower elevations and may eventually discharge into the ocean. However, substantial quantities of surface and underground water are returned to the atmosphere by evaporation and transpiration before reaching the oceans.... The hydrologic cycle is a convenient means for delineating the scope of hydrology as that portion between precipitation on the land and the return of this water to the atmosphere or ocean. The cycle also emphasizes the four phases of interest to the hydrologist: precipitation, evaporation and transpiration, surface streamflow, and groundwater. The discussion of the hydrologic cycle should not give an impression of a continuous mechanism through which water moves steadily at a constant rate. The movement of water through the cycle is erratic, both in time and over area.... Hydrologists are interested in more than obtaining a qualitative understanding of the hydrologic cycle and measuring the quantities of water in transit in this cycle. They must be able to deal quantitatively with the interrelations between factors so that they can predict the influence of human activities on these relationships. They must concern themselves with the frequency with which extremes of the cycle may occur, for this is the basis of economic analysis, an important determinant for all hydraulic projects.....The hydrologic characteristics of a region are determined largely by its geology and geography, climate playing a dominant part. Among climatic factors that establish the hydrologic features of a region are the amount and distribution of precipitation; the occurrence of snow and ice; and the effects of wind, temperature, and humidity on evapotranspiration and snowmelt...."

The climate is greatly affected by the general circulation of airflows over the earth, the regional and local modifications of these airflows, and the evaporation and condensation of moisture in air masses above the earth. Climate differs from place to place due to the location, extent and shape of the earth's land forms and their elevations, uneven heating of the oceans and continents, and other influences.

3.3 Application of Hydrology to Water Resources Planning

The discipline of hydrology provides the analytical techniques for estimating the components of the hydrologic cycle. Eagleson (1970) defines the following three major categories of hydrologic problems:

1. *Mean values*. These are the problems of concern to water-resource planners and policy makers and involve monthly, seasonal, annual, or other long-term time averages of precipitation, streamflow, evaporation, groundwater level, etc., which are themselves spatial averages over geographical areas often so large as to be climatologically, geologically, and topographically heterogeneous.

2. *Extreme values*. Maximum or minimum values of precipitation, stream flow, river stage, groundwater level, etc., are usually the criteria which, along with economics, determine the hydraulic engineering specifications for spillway size and elevation, levee and flood wall height, pump sizes and pumping rates, bridge openings and elevations, culvert sizes, reservoir volume, storm inlets and sewer sizes, water-treatment facilities, irrigation works, and many other design problems.

3. *Time histories*. Optimization of the design and operation of systems of hydraulic structures, as well as real-time forecasting, often requires the complete history of the response of a hydrologic system to some particular excitation.

Eagelson states that problems in category 3 require simulation of the system dynamics, while problems in categories 1 and 2 can usually be handled adequately by considering only the statistics of the hydrologic variable in question. However, in the latter case,these variables are often the dependent (i.e., "output") variables of a nonlinear hydrologic-hydraulic system, the parameters of which are increasingly subject to change by man. It then becomes convenient in these problems, also, to obtain the desired "output" statistics by passing the statistics of the independent (i.e.,"input") variable through a simulation of the system dynamics.

The development of reliable analytical techniques to study the components of the hydrologic cycle and to model their interrelationships are of relatively recent history. Eagleson (1970), has suggested that the United States has experienced two "golden ages of hydrology", the first between 1930 and World War II as the result of the appropriation of large sums of money by the Federal government for studies and projects in the fields of conservation, irrigation, and flood control, and the second beginning in the 1960's when the heavy federal expenditures on military technology during World War II and on defense and space during the 1950's, (which created new equipment and analytical techniques) were adapted to research in the earth sciences and the rational solution of problems in water resources.

The development of water resources planning has paralleled that of the field of hydrology. Although water resources projects have been constructed for thousands of years, modern water resources planning has evolved over only about 50 years. In the United States, it extends from the enactment of the Flood Control Act of 1936, which initiated the requirement for benefit-cost analysis. Until recently, water resources planning in the United States was carried out almost entirely by engineers. Economists and natural resource planners have been represented extensively in the literature for many years, but have had influential roles in professional practice and in the promulgation of policies and rules of government agencies only since about 1950. Ecologists, sociologists, and other environmental and social scientists have also participated in important water resource planning, particularly since the passage of the National Environmental Policy Act in 1969, which requires the preparation of an environmental impact statement for every significant Federal action.

3.4 The World's Water Balance

Table 3.1 shows estimates collected by the USSR Committee (1978) for the global relationships among precipitation, evaporation and runoff (for land, ocean and overall) according to different authors. Table 3.2 shows estimates for the continents, by Lvovitch (1973). As shown in Table 3.3, also by Lvovitch, the world-wide per capita water resources are very substantial. Water related problems occur, therefore, due to a mismatch of population and resources, inadequate and inappropriate planning and development, and other reasons.

Table 3.1 Water Balance of the World (mm.)
(Source: USSR Committee, 1978, p. 587

Author	Year	Land			Ocean		Globe
		Precipitation (P_l)	Evaporation (E_l)	Run-off (Q_l)	Precipitation (P_{oc})	Evaporation (E_{oc})	Precipitation (evaporation) ($P_g = E_g$)
Black	1864/81	—	—	—	1 019	—	—
Reclus	1883	—	—	188	—	—	—
Voeikov	1886	524	410	114	—	—	—
Murray	1887	819	651	168	—	—	—
Bezdek	1904	813	—	—	—	—	—
Brückner ..	1905	819	651	168	994	1 063	940
Fritsche	1906	752	544	208	978	1 063	910
Lüttens	1911	—	—	—	—	1 401	—
Schmidt	1915	752	544	208	670	756	690
Kerner	1919	—	—	—	1 005	—	—
Wüst	1922	752	504	248	739	842	743
Kaminsky ..	1925	544	343	201	850	933	760
Eckhart	1930	—	—	—	—	—	970
Brucks-Hant	1930	665	—	—	1 102	—	975
Cherubim	1931	752	504	248	925	1 027	880
Meinardus	1934	665	416	249	1 141	1 243	1 000
Halbfass	1934	671	349	322	1 135	1 268	1 000
Wüst	1936	665	416	249	822	925	780
Mosby	1936	—	—	—	—	1 061	—
Wundt	1938	665	416	249	958	1 061	880
Lvovich	1945	719	477	242	1 141	1 241	1 020
Albrecht	1949	—	—	—	—	—	770
Moeller	1951	665	416	249	897	1 000	832
Reichel	1952	671	470	201	872	955	810
Wüst	1954	671	490	181	897	972	830
Budyko	1955	671	443	228	1 025	1 130	930
Albrecht	1960	671	450	221	1 047	1 138	940
Budyko	1963	719	410	309	1 119	1 252	1 000
World Atlas	1964	725	483	242	1 141	1 241	1 020
Nace	1968	671	463	208	883	969	820
Kessler	1969	671	403	268	1 135	1 246	1 000
Lvovich	1969	732	483	249	1 138	1 241	1 020
Mater	1970	712	463	250	1 058	1 160	955
Budyko	1970	719	430	289	1 141	1 260	1 020
Lvovich	1972	760	480	280	—	—	—
Baumgartner, Reichel	1973	748	481	267	1 067	1 177	973
Data of the present monograph .	1974	800	485	315	1 270	1 400	1 130

The distribution of the world's water resources in the different types of water bodies and the atmosphere is estimated in Table 3.4. According to the USSR Committee (1978), large quantities of fresh water have accumulated as ice in Antarctica, in Greenland, in the islands of the Arctic Ocean and in high mountainous areas. The total volume of water in these areas amounts to approximately 24 million cubic kilometres, and almost all of this water is excluded from the annual water cycle. Changes in the amounts of water stored in the ice affect the level of the world oceans. This study estimated that if all

Table 3.2 World Water Balance, by Continent
(Source: Lvovitch, 1973 in Water Encyclopedia, 1990)

Water Balance Elements	Europe[1]	Asia	Africa	North America[2]	South America	Australia[3]	Total Land Area[4]
Area, millions of km^2	9.8	45.0	30.3	20.7	17.8	8.7	132.3
			in mm				
Precipitation, P	734	726	686	670	1,648	736	834
Total river runoff, R	319	293	139	287	583	226	294
Groundwater runoff, U	109	76	48	84	210	54	90
Surface water runoff, S	210	217	91	203	373	172	204
Total infiltration and soil moisture, W	524	509	595	467	1,275	564	630
Evaporation, E	415	433	547	383	1,065	510	540
			in km^3				
Precipitation	7,165	32,690	20,780	13,910	29,355	6,405	110,303
Total river runoff	3,110	13,190	4,225	5,960	10,380	1,965	38,830
Groundwater runoff	1,065	3,410	1,465	1,740	3,740	465	11,885
Surface water runoff	2,045	9,780	2,760	4,220	6,640	1,500	26,945
Total infiltration and soil moisture	5,120	22,910	18,020	9,690	22,715	4,905	83,360
Evaporation	4,055	19,500	16,555	7,950	18,975	4,440	71,475
			relative values				
Groundwater runoff as percent of total runoff	34	26	35	32	36	24	31
Coefficient of groundwater discharge into rivers	0.21	0.15	0.08	0.18	0.16	0.10	0.14
Coefficient of runoff	0.43	0.40	0.23	0.31	0.35	0.31	0.36

[1] Including Iceland.
[2] Excluding the Canadian archipelago and including Central America.
[3] Including Tasmania, New Guinea and New Zealand, only within the limits of the continent: P - 440 mm, R - 47 mm, U - 7 mm;, S - 40 mm, W - 400 mm, E - 393 mm.
[4] Excluding Greenland, Canadian archipelago and Antarctica.

Table 3.3 World-Wide Per Capita Water Resources, by Continent
(Source: Lvovitch, 1973 in Water Encyclopedia, 1990)

	Population in Millions (1969)	Annual Volume of River Runoff, km^3		Runoff Volume per Capita, m^3/year	
		Total	Stable Runoff	Total	Stable Runoff
Europe	642	3,110	1,325	4,850	2,100
Asia	2,047	13,190	4,005	6,440	1,960
Africa	345	4,225	1,905	12,250	5,500
North America	312	5,960	2,380	19,100	7,640
South America	185	10,380	3,900	56,100	21,100
Australia[1]	18	1,965	495	10,900	2,750
Total land area	3,549	38,830	14,010	10,940	3,950

[1] Including New Guinea and New Zealand.

the ice on the earth at the present time melted, it would cause a rise of 66 metres in the level of the ocean and changes in some aspects of the water cycle. The level of the world oceans at the climax of the Ice Age had fallen by 110 metres, whereas during the interglacial periods, it rose by 10 metres above today's level. Therefore, the quantity of water involved in the water cycle has changed. It is also mentioned that the volume of water on the earth is also regulated by the process of photosynthesis in plants. During the time that vegetation has existed, several fundamental changes in the water cycle have taken place, and during these changes the water tied up in the process of photosynthesis was released. It is indicated that the long-term fluctuations in other kinds of water reserves, such as the water accumulated in the subsurface ice zones of permafrost areas, and in lakes and marshes, cannot affect changes in the water cycle of the earth to any substantial extent because of their relatively small volume in comparison to the total world water supply.

The water resources that are suitable for most types of water supplies in the foreseeable future are the "fresh" water resources. Thus, the waters in the oceans , ice caps and glaciers are generally not available. Figure 3.1 by *Doxiadis (1967) is a representation* that reflects the fresh water situation on a global basis. The percentages of groundwater and surface water do not indicate their overall availabilities. Much of the groundwater is located far from points of need, or at depths and in aquifer materials that make retrieval impossible or uneconomic. Much surface water is flowing water that replenishes the volume of a stream typically on the average of 30 times per year.

Table 3.4 World Water Reserves
(Source: USSR Committee, 1978, p. 43)

Form of water	Area covered (km^2)	Volume (km^3)	Depth of run-off (m)	Share of world reserves (%) of total water reserves	of reserves of fresh water
World ocean	361 300 000	1 338 000 000	3 700	96.5	—
Ground water (gravitational and capillary)	134 800 000	23 400 000[1]	174	1.7	—
Predominantly fresh ground water	134 800 000	10 530 000	78	0.76	30.1
Soil moisture	82 000 000	16 500	0.2	0.001	0.05
Glaciers and permanent snow cover:	16 227 500	24 064 100	1 463	1.74	68.7
Antarctica	13 980 000	21 600 000	1 546	1.56	61.7
Greenland	1 802 400	2 340 000	1 298	0.17	6.68
Arctic islands	226 100	83 500	369	0.006	0.24
Mountainous areas	224 000	40 600	181	0.003	0.12
Ground ice in zones of permafrost strata	21 000 000	300 000	14	0.022	0.86
Water reserves in lakes	2 058 700	176 400	85.7	0.013	—
Fresh water	1 236 400	91 000	73.6	0.007	0.26
Salt water	822 300	85 400	103.8	0.006	—
Marsh water	2 682 600	11 470	4.28	0.0008	0.03
Water in rivers	148 800 000	2 120	0.014	0.0002	0.006
Biological water	510 000 000	1 120	0.002	0.0001	0.003
Atmospheric water	510 000 000	12 900	0.025	0.001	0.04
Total water reserves	510 000 000	1 385 984 610	2 718	100	—
Fresh water	148 800 000	35 029 210	235	2.53	100

(1) Not taking into account ground-water reserves in Antarctica, broadly estimated at 2 million km^3 (including about 1 million km^3 of predominantly fresh water).

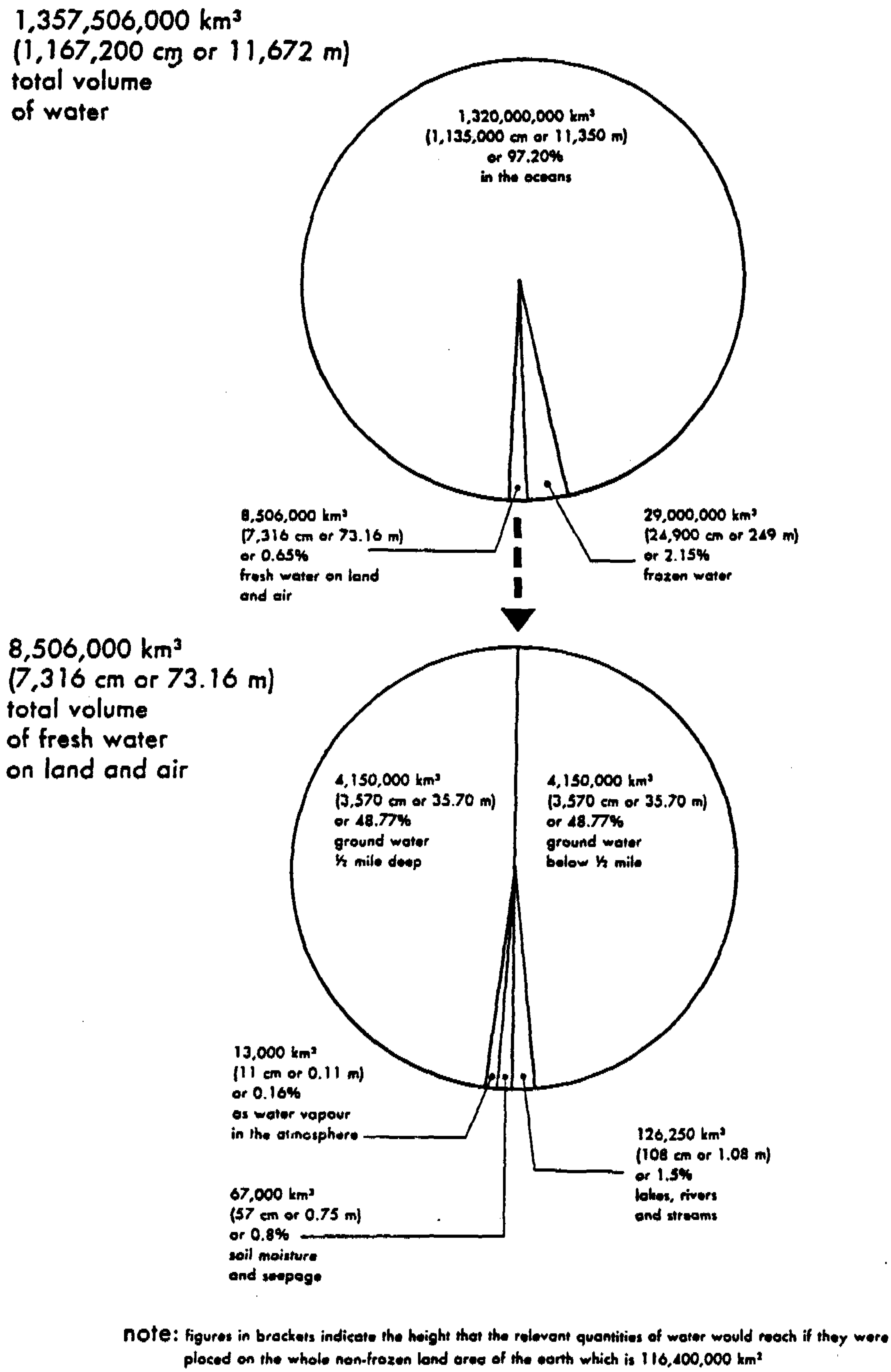
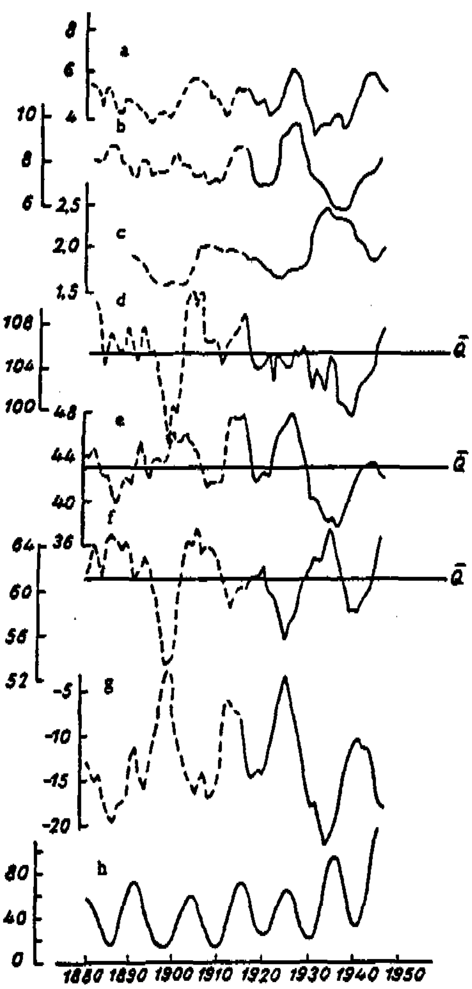


Figure 3.1 Water Availability on Earth
(Source: Doxiadis, 1967, in Water Encyclopedia, 1990)

3.5 Regional and Temporal Variations

Kalinin (1971) has made a study of global variations in the runoff of rivers, which is the source of water for most large water resource developments. Figure 3.2 shows the runoff variations of various large rivers in the world between 1880 and 1950 which indicates that they were subject to substantial cyclic variations. He also studied the variations of annual runoff throughout the world in terms of their coefficients of variation (ratio of standard deviation to mean) as shown in Figure 3.3. It is not difficult to appreciate the reasons for very large variations in project performance and the dangers inherent in plans based on short records of hydrologic parameters.



Graph of runoff variations of the rivers Mississippi (a), Volga (b), Angara (c), rivers of the northern hemisphere (d), rivers of groups I and II (e and f), runoff difference between rivers of groups I and II (g), and Wolf numbers (h), by sliding five-year periods

Figure 3.2 Runoff Variations of Rivers
(Source: Kalinin, 1971)

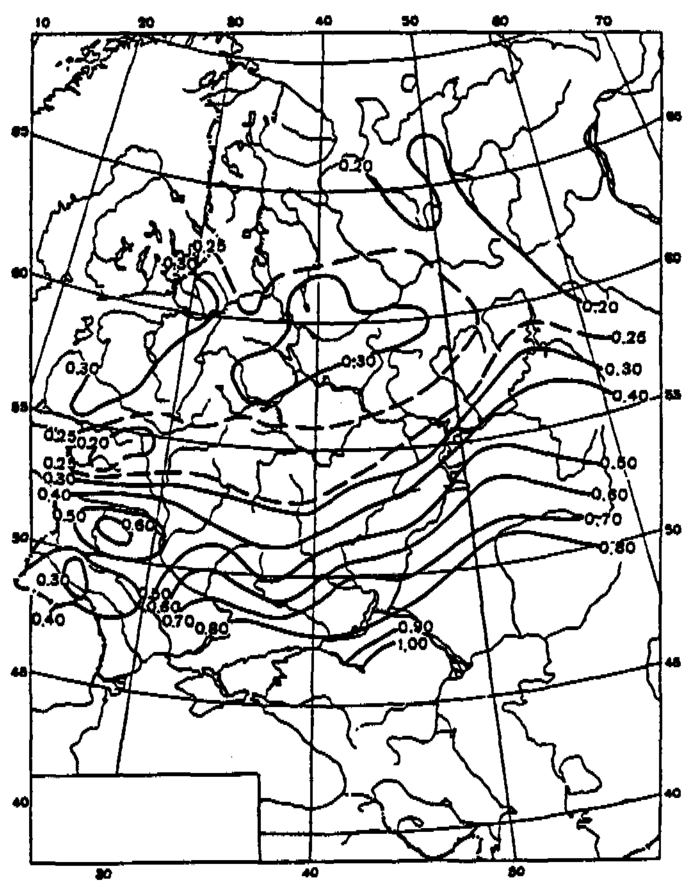


Figure 3.3 Coefficient of Variation of Annual Runoff
(Source: Kalinin, 1971)

The large global changes that have occurred in the geologic past have been referred to earlier, and are of interest when considering the potential effects of global warming on the water resources of the world and on the water resource developments that exist or are planned. At the present time, the community of engineers and scientists has not reached an agreement on the potential effects of global warming and their likelihoods, and most water resources planning is based upon recorded river flows and other data.

Table 3.5 shows the variability of total run-off over a 50 year period by continent and for the world. (USSR Committee, 1978). For such large expanses, the annual runoff coefficients of variation are much lower than those shown in Figure 3.3, and the coefficient for all rivers of the globe is only 0.027. The greatest and the smallest run-off deviations from the mean in this 50-year period lie within ± 6%, that is, they do not exceed the calculation errors for run-off, which are usually considered to be 4 to 5%. Thus, total world river run-off is almost stable, and during the 50 years considered no tendency to change could be detected. As discussed by Kalinin (1971) "The principle of relatively steady runoff from the earth's surface is geophysically important. In particular, it follows that when computing the global water balance we may choose a comparatively short period for runoff determination, provided it is well supplied with observational data for the entire territory. The relatively constant global runoff and positive correlation at very great distances are the two causes responsible for inevitable appearance of large zones with predominantly opposite water-abundance variations... If a relatively large region is considered, prolonged large deviations from average can be traced over enormous territories, owing to the positive runoff correlation. For instance, such a large-scale runoff deviation from average occurred during the sharp drop in the Caspian Sea level.... Because of the constancy of global runoff as a whole (particularly in the northern hemisphere), such a large runoff deficit must inevitably have been accompanied by excess runoff elsewhere. Runoff variations must be reduced by their being the difference of two simultaneously increasing (or decreasing) quantities, precipitation and evaporation."

Table 3.5 Variability of Total River Runoff (1918-67)
(Source: USSR Committee, 1978, p. 517)

Continent (including islands)	Area (10^3 km²)	Annual run-off: Mean amount (km³)	Highest: km³	Highest: Years of recording	Lowest: km³	Lowest: Years of recording	Coefficient of variation	Limits of deviation of extreme amounts from mean value (%)
Europe	10 500	3 210	3 800	1926, 1936, 1960	2 410	1921	0.09	+18, —25
Asia	43 475	14 410	15 950	1956	12 370	1965	0.05	+11, —14
Africa	30 120	4 570	4 930	1935	4 140	1943	0.04	+8, —9
North America ..	24 200	8 200	8 910	1960	7 170	1940	0.05	+9, —12
South America	17 800	11 760	12 870	1934	10 570	1936	0.04	+10, —10
Australia (plus Tasmania)	7 680	348	918	1956	138	1961	0.43	+164, —60
Oceania	1 267	2 040	2 940	1946	1 185	1940	0.17	+44, —42
Antarctica	13 980	2 310	—	—	—	—	—	—
Whole land area..	149 000	46 800	49 650	1927	43 750	1940	0.027	+6, —6

3.6 Demands on the System

Although there is enough water worldwide for everyone, its distribution in space and time is quite variable. Population intensities and water availabilities often are not compatible. People live in water-deficient areas (e.g., the southwestern United States or subSaharan Africa) because of attractive climatic or cultural reasons, or because relocation is impractical due to political, societal, or economic constraints. Areas that are deficient in precipitation for agriculture often have excellent soils and are thus good candidates for irrigation. Some of the best economic developments lie in the floodplains of streams, but they must be protected to survive and grow. The greatest shortages of water occur in areas of very low precipitation but the problems of developing water supply sources and their conveyance facilities may exist anywhere. The uneven distribution of surface flows throughout the year result in floods, droughts, and inadequate supplies. Groundwaters fluctuate less than surface flows but are subject to overpumping.

The use of water has been studied rather carefully over a number of years in the United States. The U.S. Geological Survey has published reports containing estimates of water withdrawals in the United States for every fifth year since 1950 (Murray et al, 1977). Nonwithdrawal or on-site uses for navigation, recreation, and water quality management are not included. The Geological Survey categories of withdrawals are public supply (for domestic, commercial, and industrial uses); rural (domestic and livestock); irrigation; self-supplied industrial (including thermoelectric power generation); and hydroelectric power. The physical limit of water supply in the United States is the annual runoff of 4.5 billion cubic metres per day. The Geological Survey estimates that the maximum economically dependable supply based on extensive measures to reduce evaporation and increase recharge is about 1.9 billion cubic metres per day. Neither the limit of runoff nor the dependable supply can be compared directly with total use since the latter may represent multiple uses of the same water. It is significant, however, that the total consumption in 1975 was less than 20% of the estimated economically dependable supply. The foregoing figures indicate that the nation as a whole has adequate water supplies.

Wide differences exist in the water uses of different countries and in the changes of these uses over time. Tables 3.6 and 3.7 show such variations for the United States and the USSR, respectively. According to the reference for these data (USSR Committee, 1978), total water use in both the United States and the U.S.S.R. was insignificant at the beginning of the century-- only a few tens of cubic kilometres per year, used mainly to satisfy irrigation requirements. By 1970, however, total water use in the U.S.S.R. increased by more than five times and reached 239 cubic kilometres per year. In the United States at the same time water use amounted to 461 cubic kilometres per year, an increase by more than eight times since the beginning of the century. This study indicated that in the year 2000, water use is expected to be 2.5 times higher in the United States and almost three times higher in the U.S.S.R. as compared to 1970.

Table 3.8 shows volume of total water use for each continent from the same reference, and Table 3.9 shows the volumes irrecoverable, due largely to evaporation and transpiration with agriculture being responsible for the major consumptive uses.

Table 3.6 Water Consumption in the United States (km^3/yr.)
(Source: USSR Committee, 1978, p. 604

User	1900	1910	1920	1930	1940	1950	1965	1970	1975	1985	2000
Public utilities	4/0.8	6/1.3	8/1.6	11/2.2	14/2.8	19/3.8	33/6.5	37/8.0	42/10	48/15	70/23
Industry	20/0.6	28/0.8	37/1.1	58/1.7	72/2.1	115/3.5	179/5.4	242/7.5	305/9.6	470/14	810/23
Agriculture	30/18	56/34	80/48	86/52	102/60	143/86	157/94	169/101	181/108	200/120	220/130
Reservoirs	0/0	0.2/0.2	0.4/0.4	0.7/0.7	1/1	2/2	9/9	13/13	16/16	20/20	25/25
Total (rounded) ..	54/19	90/36	125/51	156/57	189/66	279/95	378/115	461/130	540/140	740/170	1 120/200

Note. Numerator: full use; denominator: irrecoverable use.

Table 3.7 Water Consumption in the U.S.S.R. (km^3/yr.)
(Source: USSR Committee, 1978, p. 604)

User	1900	1940	1950	1960	1965	1970	1975	1980	1985	1990	2000
Public utilities ...	1.6/0.6	3.0/0.9	3.5/0.9	5.0/1.0	6.0/1.1	9.7/1.7	14/2.3	20/2.6	26/3.0	33/3.4	42/4.0
Industry	1.0/0.1	7.0/0.5	10/0.8	25/1.7	46/2.0	66/2.8	83/3.9	108/5.7	141/7.8	185/10.8	220/12
Agriculture and fisheries	40/26	77/47	89/53	105/64	123/74	149/90	181/107	236/139	270/162	317/181	420/238
Reservoirs	0/0	0.5/0.5	2/2	10/10	12/12	14/14	16/16	18/18	20/20	21/21	22/22
Total (rounded) .	43/27	88/49	104/57	145/77	187/89	239/108	290/130	380/170	460/190	560/220	700/280

Note. Numerator: full use; denominator: irrecoverable use.

Finally, Table 3.10 shows the influence of economic activities on river runoff. The USSR Committee (1978) estimated that water use in the early 1970's in Europe and Asia comprised 10% of river run off and was expected to reach 20 to 25% in the future. At the same time, in South America only 0.6% of river flow was used, and by 2000 this percentage will not increase substantially. It was pointed out, however, that a more marked imbalance between flow distribution and water use occurs in certain continents, leading to water deficiency in some river basins and natural economic regions of the earth, and that for small areas with more or less homogeneous physical and geographic conditions, the situation can be even more critical because of large variations in the time of river flow; in low-water years water resources can decrease by several times while water requirements remain the same or even increase. It is especially important, in order to estimate quantitatively the changes water resources sustain under the influence of man's activity, to know not the full but the irrecoverable water use, since the latter characterizes directly the additional losses (mainly through evaporation) in a given area. The amount of contemporary irrecoverable water use in 1978 was relatively unimportant and varied, according to the continents, from 4% (South America) to 8% (Asia) of total annual river flow. It is expected that towards the year 2000 this amount will have doubled.

The largest amounts of irrecoverable water use occur in areas of mass development of irrigation agriculture, namely Asia, where they amount are expected to increase to 14 to 15%.

Table 3.8 Volume of Total Water Use per Continent (km^3/yr.)
(Source: USSR Committee, 1978, p. 609

Continent	User	Computation					Forecast		
		1900	1940	1950	1960	1970	1975	1985	2000
Europe	Population	9	13	14	19	29	36	55	77
	Industry	9	31	43	90	160	185	240	320
	Agriculture	23	47	60	95	125	150	240	320
	Reservoirs	0	0	0.5	5.0	10	13	15	17
	Total (rounded)	40	90	120	210	320	380	550	730
Asia	Population	7	12	19	25	40	50	100	200
	Industry	2	6	12	26	60	80	200	500
	Agriculture	260	440	550	1 100	1 400	1 500	1 700	2 400
	Reservoirs	0	0	0.5	6.0	25	35	60	100
	Total (rounded)	270	460	580	1 200	1 500	1 700	2 100	3 200
Africa	Population	1	1.5	2	3	4	6	15	40
	Industry	0.5	1.0	1.5	2	3	6	20	50
	Agriculture	30	50	60	80	110	120	140	220
	Reservoirs	0	0	0	1.0	15	35	50	70
	Total (rounded)	30	50	60	90	130	170	220	380
North America	Population	4	15	21	33	41	46	53	77
	Industry	20	80	125	180	270	340	540	920
	Agriculture	35	110	160	190	210	230	270	310
	Reservoirs	0	1	2	6	16	20	25	32
	Total (rounded)	60	310	310	410	540	640	890	1 300
South America	Population	0.5	1.5	2	3	4	7	20	40
	Industry	1	2	3	5	8	12	50	120
	Agriculture	4	8	25	40	55	60	80	120
	Reservoirs	0	0.0	0.5	1.0	3.5	7	12	20
	Total (rounded)	5	10	30	50	70	90	160	300
Australia and Oceania	Population	0.1	0.3	0.5	0.7	1.1	1.5	2.3	3.5
	Industry	0.5	2	3	5	8	10	15	22
	Agriculture	0.8	2.4	4.0	8.0	13	14	18	25
	Reservoirs	0.0	0.0	0.5	0.7	1.0	2.5	3.5	5
	Total (rounded)	1	5	8	14	23	30	40	60

3.7 Threats to the System

3.7.1 *Current Threats to the System Related to Water Resources Development*

The "Second National Water Assessment" by the United States Water Resources Council (1978) reviewed the following critical problems for the United States, which are also the problems met throughout the world in varying degrees: inadequate surface water supply; overdraft of groundwater; pollution of surface water; contamination of groundwater; quality of drinking water; flooding; erosion and sedimentation; dredging and disposal of dredged material; wet-soils drainage and wetlands; and degradation of bay, estuary, and coastal water;

The Mar del Plata conference on water development and management in 1977 pointed out that: "... globally there may be potentially enough water to meet forthcoming needs. But, frustratingly, it tends to be available in the wrong place, at the wrong time, or with the wrong quality. And in one way or another,

Table 3.9 Volume of Irrecoverable Water Use per Continent (km³/yr)
(Source: USSR Committee, 1978, p. 610)

Continent	User	Computation 1900	1940	1950	1960	1970	Forecast 1975	1965	2000
Europe	Population	1.8	1.9	2.0	2.3	3.2	3.8	5.5	6.0
	Industry	0.9	2.5	3.4	5.2	8.0	9.3	13	16
	Agriculture	16	31	41	65	84	100	144	200
	Reservoirs	0	0	0.5	5.0	10	13	15	17
	Total (rounded)	20	40	50	80	100	130	180	240
Asia	Population	1.8	2.8	3.8	4.3	6.1	7.7	13	24
	Industry	0.2	0.4	1.0	1.8	3.5	4.5	11	18
	Agriculture	200	330	420	860	1 100	1 170	1 430	1 900
	Reservoirs	0	0	0.5	6.0	25	35	60	100
	Total (rounded)	200	330	420	870	1 130	1 200	1 500	2 000
Africa	Population	0.2	0.4	0.5	0.6	0.7	0.9	2	5
	Industry	0.0	0.1	0.1	0.2	0.2	0.4	1.2	2.5
	Agriculture	25	40	50	70	90	100	120	170
	Reservoirs	0	0	0	1.0	15	35	50	70
	Total (rounded)	25	40	50	70	100	140	170	250
North America	Population	1	3.1	4.2	6.6	8.8	11	14	25
	Industry	0.7	2.3	3.8	7.2	8.2	10	15	25
	Agriculture	20	70	100	120	130	140	170	200
	Reservoirs	0	1	2	6	16	20	25	32
	Total (rounded)	20	80	110	140	160	180	220	280
South America	Population	0.2	0.3	0.4	0.5	0.6	1	3	4
	Industry	0.1	0.2	0.3	0.5	0.8	1.2	3	6
	Agriculture	3	6	20	30	45	50	60	100
	Reservoirs	0	0.0	0.5	1.0	3.5	7	12	20
	Total (rounded)	3	7	20	30	50	60	80	130
Australia and Oceania	Population	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.4
	Industry	0.0	0.2	0.3	0.4	0.6	0.7	0.9	1.1
	Agriculture	0.6	2.0	3.2	6.4	10	11	14	20
	Reservoirs	0.0	0.0	0.3	0.7	1.0	2.5	3.5	5
	Total (rounded)	0.6	2	4	8	12	14	20	30

Table 3.10 Total Annual River Runoff and Water Use
(Source: USSR Committee, 1978, p. 613)

Continent	Mean total annual run-off (km³)	Water use (km³) 1970 Full	1970 Irrecoverable	2000 Full	2000 Irrecoverable	Water use (in % of run-off) 1970 Full	1970 Irrecoverable	2000 Full	2000 Irrecoverable
Europe	3 210	320	100	730	240	10.0	3.1	23.0	7.5
Asia	14 410	1 500	1 130	3 200	2 000	10.4	7.6	22.7	13.9
Africa	4 570	130	100	380	250	2.8	2.2	8.3	5.5
North America	8 200	540	160	1 300	280	6.6	2.0	15.8	3.4
South America	11 760	70	50	300	130	0.6	0.4	2.6	1.1
Australia and Oceania	2 390	23	12	60	30	1.0	0.5	2.5	1.2
Total (rounded)	44 540	2 600	1 600	6 000	3 000	5.8	3.4	13.0	6.7

all societies are affected, however rich, however poor.... These problems affect different societies in different ways. The immediate concern may be unpotable water and human waste in the shanty town of a tropical city, multiplying wastes in an industrialized high-income country, shortage of water impeding agricultural development in an arid land, watershed destruction and ground-water depletion in an entire nation."

The summary proceedings of the conference listed the following problem areas:

(a) Reasonably safe supplies of drinking water are unavailable for at least one fifth of the world's city dwellers and three quarters of its rural people; in many countries, less than one half of the urban population and less than one tenth of the rural population are served with an adequate and safe water supply;

(b) Increasing and unplanned concentration of population and industry in large urban areas strains water supply: this leads to problems of waste disposal which, in turn, degrade the quality of life and environmental health;

(c) Proliferation of industrial processes, greater use of energy and increased agricultural activity are causing progressive and chronic degradation of the quality of available water by the increase of toxic compounds and other pollutants: the mutagenic and carcinogenic effect of these substances poses a potential threat to human life;

(d) Backwardness and relative isolation of rural areas where the great majority of the world population now lives aggravate the difficulty of providing adequate and safe supplies of drinking water, improved sanitation and waste disposal;

(e) Expansion of food production in water-short areas and in marginal lands has necessitated rapid development of irrigation and land reclamation, to the degree that water and land resources have been exploited to their limit in many areas;

(f) Ever-growing land degradation from such causes as water-logging, salinization and erosion is leading to losses in production potential, investment and employment;

(g) Ground-water supplies are being exhausted, while both surface - and ground-water sources are deteriorating in many areas;

(h) Water use is often needlessly inefficient and wasteful, considering the possible application of scientific knowledge and the setting of appropriate service levels;

(i) Expensive technology for water development to compensate for shortage is straining inadequate resources in many regions;

(j) Conflicts about rights and priorities among users intensifies as the demand for available water accelerates.

A recent report sponsored by the World Health Organization deals with global freshwater quality (Meybeck, 1990). This report indicates that water problems are worst in the developing countries. It discusses the problems resulting from population growing faster than water supplies, severe water pollution, global deforestation, and destruction of wetlands.

In the case of rural and urban water supply, the World Health Organization (1976) carried out a survey on the extent of water supply and sewerage at the end of 1975, to which 67 developing countries responded. In urban communities, some 130 million people (25%) had no access to potable water by house connections or standpipes. In rural areas, almost 1000 million people (80%) did not have reasonable access to safe water. Considering both rural and urban populations together, only 35% (638,000,000) were adequately served. These are averages. There are several countries where 91 to 100% of the urban population was served while in other countries less than 5% of the rural population was served.

Biswas (1979) found large variations and enormous insufficiencies of water for other major sectoral uses: agriculture, industry, and hydroelectric. He also identified a number of places where there have been severe social and environmental impacts of water development, where conflicts have occurred between federal and local jurisdictions, and between neighboring states, and where problems have involved international waters. He concluded that the problem of water availability in the future is basically that of rational management.

The construction and operation of reservoirs is probably the most common means whereby mankind alters the hydrologic system and its associated ecological system. Ortolano (1973) found that environmental quality is affected starting with preconstruction facilities. Before the main construction activities for a reservoir commence, it is usual to begin the purchase and destruction or relocation of highways and buildings and to construct access roads. Such activities may have environmental impacts, in addition to causing dislocations and inconvenience of travel for the residents and businesses in the project area. Land speculation and changes in land utilization may result in anticipation of the project (particularly if changes in water configurations, recreation opportunities, and floodplain protection are included). Construction activities that have environmental impacts include those related to the housing and services for construction workers, the operation of construction equipment (air pollution, noise, delays), excavation and earth-moving operations (spoil disposal, river turbidity), and care of water during construction (diversions and other changes in flow). In addition to the user benefits of reservoir construction the project outputs may induce other recreational land development and industrial plants, and other economic growth may occur as the indirect result of the reservoir. Finally, nonstructural measures such as floodplain zoning or land purchase may change the patterns of land development and rates of economic growth.

Hagan and Roberts (1972) have identified many environmental and socioeconomic impacts of water storage and diversion projects and have classified them according to their location in areas of impoundment, areas downstream from the impoundment or diversion or both, along the conveyance route, and in the areas of project water use.

There are important hydrologic and ecological impacts that result from many other types of water resources developments, and which affect both water and land resources. These impacts are due to physical alterations to the land itself, release to the hydrologic cycle of various substances associated with particular land use activities, and withdrawals of water.

The clearing of vegetation is usually one of the steps in land development for urban or commercial uses and, to a certain extent, for agricultural uses. This can have three major environmental impacts: (1) the rate and quantity of runoff increases, while infiltration decreases because the soil loses its capacity to absorb water; (2) erosion of the bare soil increases, producing sediment which becomes a burden in waterways and may diminish water quality, or which becomes trapped in reservoirs and reduces their storage capacity (erosion not only strips away topsoil, but also deteriorates the beds and banks of watercourses); and (3) any function performed by the vegetation of filtering pollutants from runoff is lost.

The replacement of vegetative cover with impervious roofs and paved areas will reduce erosion but will tend to accentuate other problems associated with increased runoff and reduced infiltration. When impervious surfaces collect precipitation and rapidly direct it into watercourses, groundwater recharge is blocked, streams experience rapid fluctuations, flood peaks are increased, and low flows of dry periods are diminished. In addition, pollutants that have been deposited on the land surface are leached from the ground and may be washed downstream.

Filling and draining wetlands may result in particularly severe impacts. Lying at the interface between uplands and aquatic system, wetlands are the location of intensive biological activity whose destruction causes harmful effects on both terrestrial and aquatic systems. Wetlands also have very important roles in the hydrologic cycle. A number of examples of hydrologic function and related water quality effects have been shown (U.S. Senate Committee on Public Works, 1976). Wetlands act as a buffer against rapid hydrologic fluctuations. The natural storage of floodwaters reduces flood peaks and the severity and duration of droughts by causing excess waters to be gradually absorbed or released. The U.S. Army Corps of Engineers estimated that a 40% reduction in wetlands along the Charles River in Massachusetts would elevate flood stages 0.6 to 1.2 meters. By slowing the velocity of floodwaters, wetlands reduce damages when flooding does occur. Bridges below a Pennsylvania wetland that had been preserved were unharmed after widespread flooding, whereas similar bridges elsewhere were destroyed. Wetlands purify the water that flows through them and thus mitigate the effects on the aquatic system caused by land development. A study of Lake Minnetonka in Minnesota for the period from June 1969 to May 1970 showed that although 35,000 kilograms of phosphorus was released into the watershed, only 23,000 kilograms reached the lake. Wetlands help to prevent siltation of downstream areas by slowing the flow of water, thus decreasing the erosion of stream banks and settling out a portion of the sediment load. Finally, wetlands are important sites of groundwater recharge in some areas.

Another impact of land use on water arises from pollutants. The runoff from a construction site, for example, may carry 40,000 times as much sediment as the runoff from unaltered watersheds (Wildrick et al. 1976). Other substances, such as agricultural chemicals, are deposited on land and subsequently carried by runoff into water bodies. Leachates from landfills for the disposal of wastes may have a severe impact on the quality of surface waters and groundwaters. The waste generated by a land use activity may be deliberately discharged into adjacent waters. The type of land use directly affects the type and quantity of pollutants that enter receiving waters.

The amount of water withdrawn for land uses is directly related to the character of the land use, its intensity, and the techniques used in the consumption of water. For example, if a section of land is used for a thermal-electric power generating plant, much more water will be needed than if it is used as a nonimproved pasture needing no other water than rainfall.

Not only do land uses have an impact on water, but conversely, the quality, quantity, and location of water have a substantial impact on land uses. The availability of sufficient quantities of clean water determines whether lands can be used for many purposes. Industry, agriculture, and residential development cannot occur without adequate supplies of water. The critical importance of water quantity and quality is also reflected in the market values of land associated with available water.

Because land and water are so closely related as physical systems, programmes for the development or management of these resources should also tend to be functionally related. For example, a decision that is made in a land use management program will affect whether the goals of a water quality improvement program are met. Similarly, the construction of a project for water quality improvement or the control of floods is likely to affect the success of land use planning. There are many examples of these types of interrelationships and, unfortunately, they often arise as unintended secondary effects rather than as well-conceived interactions. Better integration of land and water management can help to harmonize conflicting programs or to use programs in mutually reinforcing ways.

Many governmental programs designed for the protection and improvement of water quality provide excellent examples of how land and water management programs need to be better integrated. One of the most notorious in the United States has been the effect of sewage treatment construction on land use patterns. Such facilities are typically designed with excess capacity in order to avoid problems of early obsolescence. The availability of sewers, however, often stimulates growth in areas that are unsuitable or unprepared to accommodate it. Runoff and other nonpoint sources of pollution can then cause water quality degradation as severe as that which the facilities were intended to correct. Also, because of the need to increase tax revenues to finance the local share of the cost of building and operating these facilities, local governmental officials may be reluctant to implement measures to control growth. On the other hand, the failure to build new water pollution control facilities can have equally severe impacts on land use patterns and the growth management plans of local governmental officials. When connections from new buildings threaten to exceed a treatment plant's capacity, a moratorium may be required on new hookups. Unless alternative treatment systems are available, this action translates into a moratorium on new construction. Similar restrictions on industrial usage of land may result from the enforcement of effluent limitations in areas with badly degraded water quality.

The linkage between land and water management has become most evident in the control of nonpoint sources of water pollution. The traditional emphasis of water pollution control programs has been on regulating the discharge of wastes from point sources such as sewage treatment plants and industrial facilities. Water quality goals, however, cannot be achieved with such a limited approach because much of the pollutant load comes from nonpoint sources such as runoff from construction sites, agricultural operations, and urban streets. Land use control is necessary if the nonpoint sources are going to be controlled.

Floodplain management is another need that requires an integrated land and water management approach. Flooding is a natural and necessary hydrologic phenomenon. Problems occur because structures are built that are susceptible to damage within the floodplain. In many cases structural improvements have been made to the flood channel at great cost, permitting additional encroachment on the floodplain and negating any reduction in flood damage potential.

Wetlands protection is another need of environmental management which cannot be solved by traditional autonomous water management or land use controls. The hydrologic benefits of wetlands have been described above. Wetlands also provide excellent wildlife habitat, timber, open space, and recreational areas. The degradation of wetlands and the loss of their water control functions generally come from changing land use patterns, such as conversion to agricultural use or housing development. Although wetlands may be threatened by certain water management actions, such as lowering water levels in a river to provide water supply or canalizing streams to reduce flooding, these actions are generally taken to accommodate land use changes.

Although a close physical relationship exists between land and water resources, and their management programs should be at least functionally related, as discussed above, this has not been adequately reflected in the multitude of decisions, laws, and institutions that affect natural resources. Land and water have frequently been used and abused, studied and regulated, spoken of and acted upon as though they were entirely separate systems. Even people who understand that there is a relationship between what is done on the land and what happens to nearby water, and vice versa, frequently exhibit a lack of concern for the impact of their own actions on the environment. When they cause environmental damages, they may even gain substantial economic benefit by ignoring the effects.

Because neither ethics nor economics have effectively restrained environmental degradation, government has had to intervene. However governmental regulations and the actions of government agencies have often failed to integrate land and water management adequately. One reason is that the people who staff government agencies may lack sufficient information on environmental problems or may not be sufficiently concerned. They may also be subject to political pressure from interests that may sustain economic costs from effective environmental regulations. Other reasons suggested by commentators implicate institutional factors. Government has historically attacked problems in a piecemeal rather than a comprehensive manner. Numerous single-purpose agencies have been created to deal with such specific problems as a need for roads, flood protection, or irrigation water. The emphasis of these agencies has been on achieving narrow goals while other factors have been deemed less important. This approach has compounded other problems, even as it has helped resolve the one for which it was designed. Thus, problem solvers have often failed to recognize the synergism involved and to consider secondary impacts, such as stimulus to growth and development. Even federal agencies and line ministries have been slow to perceive, and often unable to correct, undesirable secondary effects because correction would require departure from the single-purpose missions typically thrust on them. When adherence to this assigned role has been the standard by which their effectiveness has been measured, more efficient and cost-effective methods outside the scope of traditional activity may be ignored. For example, a government organization that was created, staffed, and funded to build dams would tend to promote the construction of dams to control floods and not adequately consider less expensive alternatives of floodplain management if the latter solution would not be implemented by that agency.

Numerous undesirable consequences have flowed from the failure to integrate and coordinate land and water management effectively. Despite considerable progress, the environment still is not generally managed as an integrative, holistic, natural system. Numerous decisions regarding development or regulatory activities are being made each day without adequate consideration of their effect on the resources as a whole or on other governmental programs. The quality of the environment, therefore, continues to be degraded.

The problems caused by lack of integration are most acute when programs are conflicting and inconsistent. For example, one arm of government may authorize the destruction of wetlands, while another seeks to protect them. Although conflict is necessary and beneficial as long as there are different points of view, in many cases too much effort is spent on such interagency struggles. Such counterproductive action not only wastes energy, but the potential benefits of having programs reinforce one another may also be lost.

There are many direct and indirect public health benefits that result from water resources development. More varied and increased agricultural yields assist in improving nutrition. Better water supplies and wastewater treatment reduce the incidence of waterborne diseases. Recreation opportunities and environmental quality enhancement raise the spirit and morale. Economic benefits of water resources development increase income, which improves the standard of living and associated health care. Along with these benefits, however, adverse effects to the public health may also occur. According to a United Nations report (Lagler 1969), deforestation in the USSR led to an increase in tick-borne encephalitis, increased rice growing in Asia brought epidemics of mosquito-borne encephalitis, and urbanization without adequate drainage contributed to the spread of filariasis. The same report recommends that advisors on public health biology and sanitation be associated at an early stage for each new reservoir project in a developing country to provide guidance on the studies and to anticipate infections that might break out. Water resources projects can pose threats to health through the inadvertent improvement of the habitat for certain disease vectors. Not only are water bodies themselves involved, but changes to the countryside during project construction can radically alter the insect and snail populations which act as carriers of many infections. Problems can also arise from resettlement of populations, either to make way for a project or to provide the labor needed for construction and operation (e.g., irrigation projects), since parasites travel with the people.

Biswas (1980) has discussed the enormous social costs of water resource developments in spreading disease in the developing countries. He has also discussed the problems of aquatic weeds, which are a great nuisance in blocking water passages, increasing evaporation, and improving the habitat for disease vectors.

In addition to the effects of the vectors themselves, the use of pesticides, herbicides, and other poisons in connection with agriculture (and fishing in some places) and for control of diseases may themselves also cause problems when they are washed into public water supplies.

3.7.2 Current Global Problems Affecting the System

Acid rain is already an important problem. The Swedish government alone has spent over $200 million dollars for acidification research and for liming to restore some 4000 lakes and streams (Informator AB, 1988). Lower yields of salmon and trout in Norwegian rivers has resulted with increased acidity. Severe damage has also been observed in the Adirondack Mountains in New York State and in parts of Canada. The effects of acid rain are not yet fully understood, but damage has already been observed not only in lakes and streams but on forests, soils, crops and nitrogen-fixing plants (The Global 2000 Report to the President, 1982).

Destruction of forests, along with the burning of fossil fuels, are major contributors to the long-range concern with climatic change. World Bank and United Nations studies (Repetto, 1989) have found that every year more than 11 million hectares of forests are cleared for other uses, and in most developing countries deforestation is accelerating. In this century, the forested area in developing countries has fallen by half, with severe environmental consequences. In the tropics, forest clearance leaves only degraded soils that are unsuitable for sustained agricultural production. In watersheds, deforestation increases erosion, flooding, and sedimentation. In semi-arid areas, it robs the soil of essential organic matter and shelter from wind and water erosion. Moreover, in the tropics, loss of forest areas threatens the survival of uncounted species of animals and plants.

The Global 2000 Report notes that in many tropical forests, the soils, land forms, temperatures, patterns of rainfall, and distribution of nutrients are in precarious balance. When these forests are disturbed by extensive cutting, neither trees nor productive grasses will grow again. Even in less fragile tropical forests, the great diversity of species is lost after extensive cutting. An estimate prepared for this report suggested that between 1980 and 2000, between half a million and 2 million species could be extinguished by 2000, mainly because of loss of wild habitat but also in part because of pollution. It pointed out that extinction of species on this scale is without precedent in human history.

Urbanization is increasing at a rapid rate in many parts of the world placing enormous stress on water and other natural resources, not only in terms of exploitation for water supplies and wastewater disposal but also from the standpoints of environmental and ecological modifications. The clearing of forest land for urbanization, with the slash burning involved, taken together with combustion of fuels in motor vehicles, thermal power and industrial plant developments and home heating, which continues at a faster rate than urbanization itself, are already causing microclimatic change and are contributing to concerns for global changes.

Destruction or pollution of coastal ecosystems is an increasingly important problem according to the Global 2000 Study. It indicates that rapidly expanding cities and industry are likely to claim coastal wetland areas for development; and this effect must be considered along with coastal pollution problems due to agriculture, industry, logging, water resources development, energy systems, and coastal community development.

3.7.3 *Future Threats to the System*

Climatic changes are probably the most worrisome threat for the long term future of the world's water systems. The U.S. Global Change Research Program has instituted a research program to investigate the potential for climatic change, and the effect of such change on climate and hydrologic systems. The following is quoted from its most recent report (Committee on Earth and Environmental Sciences, 1990)

The physical climate and hydrologic systems include the atmospheric, oceanic, cryogenic, and land processes that govern the planetary distribution of temperature and water. The exchange of water and energy between the Earth's surface and atmosphere is controlled by these processes over a wide range of spatial and temporal domains. Increasing abundances of greenhouse gases in the Earth's atmosphere are altering the radiative balance of the planet. How these changes in radiative forcing are manifested in climate change is a function of the natural response of the climate and hydrologic systems. For example, the period from roughly 1940-1980 was characterized by steady or slightly declining global mean surface temperatures, during a period when radiative forcing was increasing *steadily. On shorter time scales, the Earth's climate system shows* definite preferred modes of variability as well, notably the El Niño - Southern Oscillation (ENSO). Effective national and international policy formulation thus requires the ability to account for this natural variability in increasing abundances of greenhouse gases.

An accurate prediction of the magnitude and timing of a change in climate (changes in the patterns of temperature, precipitation, and severe weather) due to increasing atmospheric concentrations of greenhouse gases is limited by significant uncertainties in the understanding of the system, including: (i) how clouds modulate the Earth's radiative balance and, conversely, how their distribution may respond to a change in the radiative forcing or aerosol loading of the atmosphere; (ii) how the exchange of water, momentum and heat between the ocean and the atmosphere may change, especially if the circulation patterns of the ocean change, (*iii*) how the exchange of water and energy will be impacted by changes in land cover and the extent of sea ice, glaciers, and snow cover; (iv) how climate and land-surface hydrology will interact; and (v) how water and energy are exchanged between ice sheets and the ocean and the effect of this exchange on sea level.

The *report states that a strong predictive capability for the Earth's* climate and hydrologic systems will be a "positive force influencing policy responses for a wide range of major environmental and economic issues", including:

- *Greenhouse warming* A key issue is how the physical climate system changes naturally and will respond to changes in radiative forcing caused by increasing atmospheric concentrations of greenhouse gases. Of particular concern are changes in temperature, precipitation, soil moisture, and severe weather. Clouds strongly influence the magnitude of climate change, while the oceans influence the timing and patterns of climate change.

- *Sea level rise* Of major concern to coastal communities are the problems of coastal erosion, loss of wetland and inland penetration or intrusion of saltwater due to changing sea level, a problem linked to climate and tectonic change.

- *Water supplies* The future availability of adequate water supplies is one of the most significant natural resource questions in many regions. Information on the rate and magnitude of climate change relative to the future availability of water is vital for water resource planners.

- *Agricultural policy* Crop yields are strongly tied to rainfall and retention of soil moisture. For example, the 1988 drought in the U.S. had a significant impact on the national economy, and prolonged droughts in other parts of the world, e.g., the Sahel, have had severe consequences for human life. The ability to anticipate such events would have strong implications for farm assistance programs, agricultural trade, and relief programs.

- *Stratospheric ozone depletion* In addition to changing surface ultraviolet radiation, changes in stratospheric ozone will also influence the Earth's climate to an undetermined degree. Regulation of chlorofluorocarbons (CFCs) based on ozone depletion concerns would also influence the global radiative balance, since CFCs are also greenhouse gases.

- *Environmental quality* Climate change, whether natural or human influenced, can have a profound impact on environmental quality. Changes in temperature, precipitation, atmospheric stability, and/or wind velocity can all influence attainment of air quality standards, while changes in hydrology and stream flow could impact water quality of both fresh water and estuarine systems and could also affect the disposal of waste products by allowing water intrusion into previously dry land fills.

The report also states that developing the predictive capability necessary to provide scientific input to the national and international policy decisions implicit in these issues has three necessary components: global-scale observations, process studies, and simulation and predictive modeling: and outlines a research plan to advance knowledge in these areas.

Many within the scientific community believe that the process of global warming has already begun. The seven warmest years since 1880 have all occurred in the last 11 years according to climatologists at the Goddard Institute for Space Studies in New York (Stevens, 1991). As pointed out previously, severe global warming in past ages resulted in disastrous changes in water levels throughout the world. Recent simulation studies indicate that some areas would be subject to large reductions of water availability while others would suffer higher flood damages. Changes in precipitation and temperature could significantly affect evapotranspiration, streamflow and groundwater recharge. Changes in sea level would affect freshwater/salt water interfaces in estuaries and other bodies of water connected to the sea.

3.8 Augmentation of Water Supplies

Adverse impacts of water resource development (e.g. environmental, social, institutional) can often be prevented or mitigated by reducing the scale of the project to fit smaller needs, or by management techniques and other nonstructural alternatives. Project cost will generally also be reduced by this approach. The reduction of demand for water from existing projects by more efficient use of water or by recycling, has also been found to be effective. The U.S. Water Resources Council Principles and Standards (1979 revisions) and Principles and Guidelines (1983) outline measures to control demand for municipal and industrial water supply, irrigation water supply, and other types of water resource developments.

Water supply augmentation technologies provide another means to counteract some of the problems outlined in the previous subsection. Apart from interbasin exchanges of water, the most promising alternative method, which has already found wide application in oil exporting countries in desert areas and also in other higher-income areas with deficient rainfall and/or storage capabilities, is desalination. The United Nations (1985) has reported on this and other methods of "non-conventional" water resources development in developing countries. Desalination plants of various capacities and applications with both sea-water and brackish water were studied. For prices in the early 1980's, sea-water distillation costs including capital recovery and operating costs ranged from $2.68 per cubic metre for 3,800 cubic metres per day to $1.31 per cubic metre for 38,000 cubic metres per day. Brackish water electrodialysis costs ranged from $0.47 per cubic metre for 3,800 cubic metres per day to $0.26 per cubic metre for 94,600 cubic metres per day. Sea water reverse osmosis costs ranged from $3.28 per cubic metre for 38 cubic metres per day to $1.54 per cubic metre for 1,900 cubic metres per day. Brackish water reverse osmosis costs ranged from $0.41 per cubic metre for 3,800 cubic metres per day to $0.30 per cubic metre for 95,000 cubic metres per day. It was concluded that, at present, desalination costs are still beyond the means of poorer rural-dominated countries.

Transportation of large quantities of water by tanker may become attractive, but only with economies of scale and with the availability of cheap excess tanker capacity. Towing of icebergs is considered too risky and expensive, and remains in the "realm of speculation".

Most developing countries do not yet have sewerage systems to collect used water, that may be considered for reuse or recycling. It is unlikely that this approach will be feasible in the forseeable future for domestic uses in the developing countries for reasons of cost and concerns about safety. Reuse and recycled water have been increasingly used for agriculture and industry in industrialized countries and may become more important in the developing countries.

Many years of research on the enhancement of water supplies by increasing rainfall (e.g. by cloud seeding) or reducing evaporation of reservoirs have not given encouraging results for general application.

SECTION 4

PLANNING BOUNDARIES AND INTERRELATIONSHIPS OF PROJECTS

4.1 The River Basin

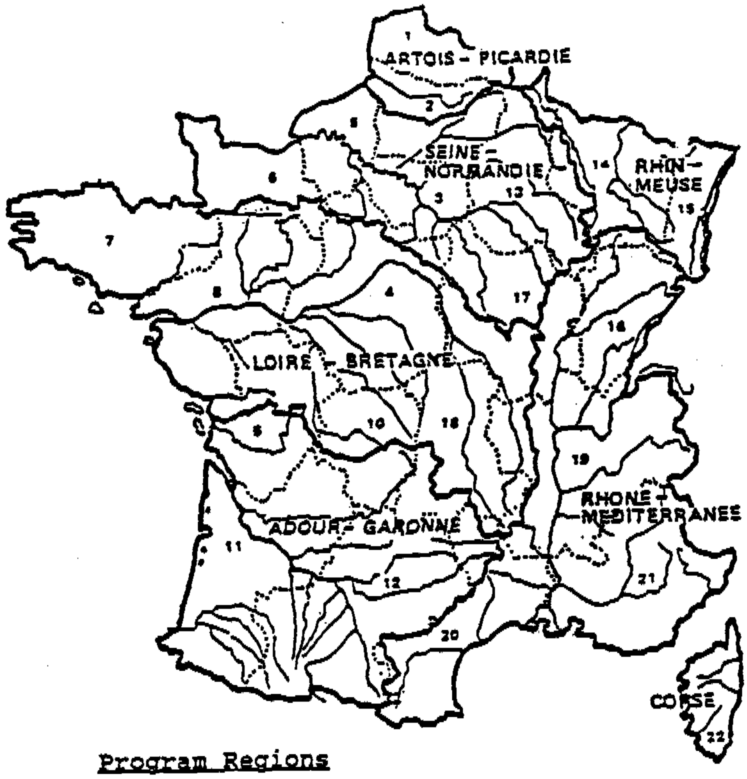
The following general definition of a suitable area for planning was proposed in a report by the Organization of American States (1984):"... (A) *region* (is) any subnational area that a country calls a region for purposes of planning or development. A region may also comprise parts of more than one country. It may be a geographic unit such as a river basin, or a political subdivision... It may be the locus of a problem... or an empty area losing its national identity due to an influx of foreign settlers, or it may even be an arbitrarily defined spatial planning unit... In short, regions as study area have no general distinguishing characteristics. But methodology for regional development planning does..."

A Consulting Panel on Water Resources Planning in a report to the U.S. National Water Commission (1972) recommended establishing the geographic area of interest for planning so that a minimum of external effects need to be taken into account and that subareas are "united by economic interests, political interests, physical characteristics, or common areawide development problems." The *river basin* often meets these criteria. As noted in U.S. Senate Document 97 (U.S. President's Water Resources Council, 1962, p. 3):" "River basins are usually the most appropriate geographical units for planning the use and development of water and related land resources in a way that will realize fully the advantage of multiple use, reconcile competitive uses through choice of the best combination of uses, coordinate mutual responsibilities of different agencies and levels of government and other interests concerned with resource use."

A river basin encompasses the drainage area extending upstream from the mouth of the main stream of the area, and is defined by outlining the drainage divide between this and adjacent basins on a topographic map (see Figure 4.1). The geologic structure sometimes indicates an underground water system with somewhat different boundaries than shown on the surface. Water balance estimates and other hydrologic studies involve subbasins as well as the river basin as a whole.

4.2 Administrative Boundaries

Because of legislative or political factors, or because data are organized by such divisions, the study area may be selected to have governmental boundaries (e.g., province, town). Eligibility requirements for specific government programs (e.g., for sewerage, water supply, and wastewater treatment) may require consistency with specific area-wide plans. This is shown on Figure 4.1. The projects in a river basin may also have service areas that extend beyond the boundaries of the drainage area. The output of a hydroelectric project may be fed into a power utility's regional transmission and distribution system whose boundaries are determined by the franchises awarded by a governmental regulatory authority. The water supply for a large city may be conveyed in a long pipeline extending from a water body to a location many kilometres away.



<u>Program Regions</u>

1. Nord
2. Picardie
3. Région parisienne
4. Centre
5. Haute Normandie
6. Basse Normandie
7. Bretagne
8. Pays de la Loire
9. Poitou Charentes
10. Limousin
11. Aquitaine
12. Midi Pyrénées
13. Champagne
14. Lorraine
15. Alsace
16. Franche Comté
17. Bourgogne
18. Auvergne
19. Rhône Alpes
20. Languedoc
21. Provence Côte d'Azur
22. Corse

—— basin limit

.... program region limit

0 100 km

Figure 4.1 Outline of French River Basins
(Source: Noel, 1990)

4.3 International Water Bodies

Virtually every country has international waters, and these may be tributary and main river components of a river basin, lakes and reservoirs, or coastal waters. Problems result from water withdrawals and returns, pollution, and land developments that produce hydrologic changes.. Compacts, treaties, and administrative arrangements are often needed to cope with the problems of these international waters, to make studies, and to assess costs and benefits.

United Nations data (Nagy, 1987) indicate that 200 river basins are shared by two or more countries which cover about 50% of the total land area of the world. Of the 13 largest river basins, only four are in one country (Mackenzie, Lena, Volga and Yangtze) with the remainder shared by two or more countries. According to Vlahos (1990): "... present and expanding water uses will increase trans-national dependencies and assorted conflicts, especially since almost 40 percent of the world's population lives in river basins shared by more than two nations. Competing and conflicting demands, complex socio-economic systems, increasing population, urbanization and industrialization all coalesce to create a situation requiring thoughtful, shared, coordinated, and long-term planning and management by riparian countries....Countries share not only the blessings of nature, but also the common fate of diminishing and deteriorating water supplies. Furthermore, as development takes place, the intensified use of resources alters the patterns of water distribution by different users and uses. The complex ecosystems of river basins across political frontiers can lead to serious confrontations as water depletion and despoliation may contribute to ecological disequilibria and social upheavals. Diversified demands, limiting supplies, as well as natural and man-made vagaries, all require coordinated and shared development and management by surrounding countries.... More recently, such global issues as acid rain, ocean pollution, conventional water pollution, "greenhouse effect," etc., have all brought additional pressures by new participants beyond the traditional public policy makers and diplomats. This has underscored the necessity for further treaties, agreements, alternative dispute resolution methods, and innovative institutional mechanisms for resolving existing or emerging differences in the use of water. Transboundary environmental relations, environmental diplomacy and conflict resolution efforts characterize, then, the use and further development of water resources..."

4.4 Interbasin Transfers and Other Transbasin Issues

Galloway (1989) has described interbasin transfers as "an issue in search of a policy" and has commented on the complexities of such transfers in terms of their heavy expense, their ecological consequences, possible micro-climate effects, and potential to create large scale socio-cultural impacts. He points out that existing methods of presenting such effects, in federal agency planning in the United States, along with economic and other effects, are "intuitively not satisfying and leaves the question of tradeoffs unanswered."

Viessman and Welty (1985) have discussed the history and current status of interbasin transfers in the United States for domestic and industrial uses and for irrigated agriculture. They state that as of 1965, 146 such existing projects were identified. Among these are:

- Transfer from the Croton, Catskill and Delaware River Systems of 1.3 billion cubic metres per year up to 400 km to New York City for municipal water supply.

- Transfer from Owens Valley of 580 million cubic metres per year 300-500 km to Los Angeles for municipal water supply. Transfer from Feather River of 2.5 million cubic metres per year 800 km to Los Angeles for municipal water supply.

- Transfer from Northern California of 3.4 billion cubic metres per year 600 km. to San Joaquin Valley for irrigation (Central Valley Project). Transfer from Colorado River of 2.7 billion cubic metres per year 600 km for irrigation and 370 million cubic metres per year 80 km for irrigation and municipal use to San Joaquin Valley (Colorado-Big Thompson Project).

- Transfer from Colorado River of 1.5 billion cubic metres per year 400 km for recharge and 580 million cubic meters per year 500 km to California south coastal area.

Numerous proposals for additional interbasin water transfers have been made, particularly during the 1960's. The Texas Water Plan would transfer water from areas of surplus in eastern Texas to the water-short areas of El Paso, the Trans-Pecos area, and the High Plains. The Great Replenishment and Northern Development Canal would transfer 11,330 cubic metres per second of fresh water runoff from the James Bay Basin to the Great Lakes for storage for subsequent distribution to mid-North America. The North America Water and Power Alliance Plan would transfer about 111,000 million cubic metres of water annually from northwest Canada and Alaska to drier parts of Canada, the United States, and Mexico. These solutions to water supply problems may be impractical due to high construction costs, potential environmental impacts, and strong protests on political and legal grounds in the areas where the waters would be diverted and along the supply routes.

Vlahos (1990) has identified a number of proposed water transfers involving international water bodies, and various approaches that are being taken to forge agreements to solve conflicts related to these transfers. The Mekong Secretariat has been considering a proposal by Thailand to construct a diversion structure on the Mekong River between that country and Laos for an out of basin diversion. In 1972, India, following a preliminary agreement with Bangladesh, completed the Farraka Barrage to divert 1130 cubic metres per second from the Ganges River into the Bay of Calcutta. After repeated complaints from Mexico about the increased concentrations of salt in the Colorado River, the United States implemented a scheme to reduce the level of salt concentrations at the Morales Dam in Mexico. Countries on the Amazon have formed an association to explore the needs of the countries and assess the environmental concerns as a result of a 1978 Treaty. The Nile River, subject of the 1959 treaty between two of seven of the states (Egypt and Sudan), has again become a subject of discussions for participation by other riparian states. Other present and potential surface water conflicts involve the Senegal, Niger, Zambezi and Orange Rivers in Africa; the Jordan River; the construction of the Ataturk Dam in Turkey and its far-reaching consequences on the Euphrates in Iraq; the proposed Kumgang Dam in North Korea and the potential reversal of the southward flow of the Han River.

A number of large aquifers are also shared by several countries. The Northeastern African aquifer underlies Libya, Egypt, Chad, and Sudan. On the Arabian peninsula, aquifers are shared by Saudi Arabia, Bahrain, and perhaps Qatar and the United Arab Emirates. The Northern Sahara Basin is shared by Algeria, Tunisia, and Libya, and the Chad aquifer shared by Chad, Niger, Sudan, Nigeria, and Cameroon. Other shared aquifers are found in Southeast Asia, the Indian Subcontinent, in many countries of Latin America, and in Europe where more than three-fourths of the public water supply in Denmark, the Federal Republic of Germany, and the Netherlands comes from groundwater sources.

Vlahos (1990) states that: "The common thread in any discussion of trans-boundary water conflicts emphasizes how new strategies are needed because water (and for that matter natural) resources problems are becoming both highly complex and globalized. Some even argue that the traditional spatial environmental envelope has collapsed and project boundaries - and their impacts and consequences - are now much more diffuse. Thus, there is a need for bringing back an environmental approach that requires drastic measures of ecological rehabilitation, innovative institutional mechanisms, and a balance between autonomy and cooperation. Such global approaches entail also improvement of environmental monitoring and information by expanding the factual basis of comprehensive river basin models. In addition, they also imply a framework for negotiations which stresses the importance of comprehensive institutional formats and clarity in national and international decision making processes."

The legal aspects of international water resources systems were reviewed in a National Symposium on River Basin Development in December 1981 in Dacca (Zaman, 1983). As noted by Caponera (p. 176): "International custom has provided some of the most important rules for the use of shared waters:

(a) duty to co-operate and to negotiate with a genuine intention of reaching an agreement;

(b) prohibition of management practices likely to cause substantial and lasting injury to other states;

(c) duty of prior consultation;

(d) equitable utilization of shared water resources.

Another set of norms emanates from the general principles of law recognized by civilized nations, for example: that the use of water resources by one country should not impair the rights of use of other countries; that rights are not to be abused; that co-basin states should promote good neighborly relations; and that the internal water laws of each of the basin states should be applied harmoniously in mutual disputes. Water law principles regulating the relations among basin countries have also been developed by international courts and arbitral tribunals, although arbitrators and tribunals usually limit themselves to the resolution of specific disputes."

Within the United Nations family of organizations, a number of different bodies have been at work on matters related to international water resources law. These include the UN Economic Commission for Europe, the UN Environment Programme, and the General Assembly itself which set up an International Law Commission in 1970.

The United Nations (1987) has prepared a report on institutional issues in the management of international river basins. This report covers a number of important issues including determining the programme or project area; data collection and fact sharing; employment and contractual relationships; legal aspects of project and programme financing; allocation of costs and benefits; and ownership of works, facilities and equipment.

4.5 Water Balance Elements

The major inflows and outflows from a river basin are shown on Figure 4.2 and the total water balance can be written in terms of the various components of the hydrologic cycle as follows:

$$P - (Q_{out} - Q_{in}) - (E_s + E_g) - (T_s + T_g) - (G_{out} - G_{in}) = \Delta (S_s + S_g)$$

The water balance components may be substantially affected by diversions to and from the basin; modifications of flow, evaporation, and transpiration by projects located in the basin; and by conjunctive operations of the surface and ground water resources.

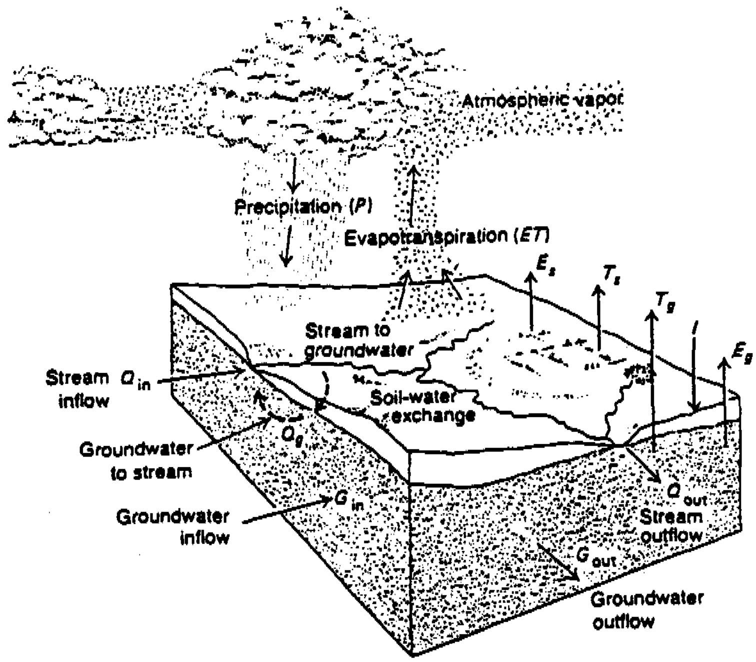
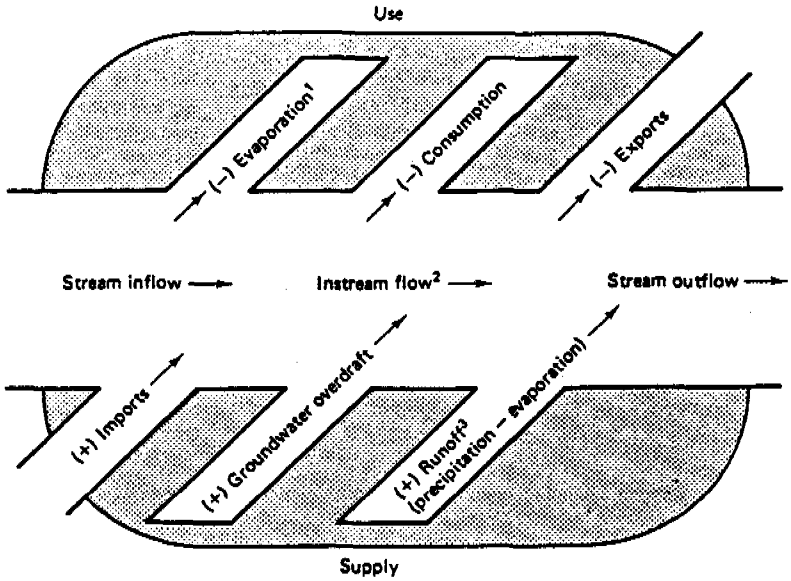


Figure 4.2 Inflows and Outflows from Parcel of Land.
(Source: Marsh and Dozier, 1986)

The broadest water resources studies carried out in the United States have been referred to as "framework"studies and assessments. The "Second National Water Assessment" by the U.S. Water Resources Council (1978) is an example of this type. It was based on analyses of data for the 1975 base year and projections for 1985 and 2000. The country was divided into 21 water resource regions and 106 subregions for the purpose of data collection and analysis, and to incorporate input from various federal, state, and regional sources. The assessment provided estimates of water balances based on appraisals of water supply and water use, and identified critical problems. Water supply and water use projections were projected from a socioeconomic baseline for 1975. Two futures were considered: the national future, representing the federal viewpoint, and the state-regional future, representing state and/or regional viewpoints. A regional report was prepared for each of the 21 water resource regions. Water uses analyzed included "offstream" (withdrawal) uses and "instream" uses such as fish and wildlife needs, hydroelectric generation, navigation, and recreational activities.

To assist in identifying the nation's critical water problems, a water supply adequacy analysis model was developed. It was based on the concept of a balance between water use and water supply, and took into consideration both groundwater and fresh surface water. This model, which is shown schematically in Figure 4.3, was used to provide a subregional analysis for each of the water resources regions and subregions. Subregions have water inflow and supply from upstream subregions, interbasin imports, precipitation runoff, and groundwater. Requirements for water include interbasin exports, consumption, and evaporation, which are deducted from the potential supply. Groundwater recharge is accounted for in the model and is not considered a loss.



[1] Includes only evaporation from man-made reservoirs.
[2] Includes flow requirements for navigation, hydroelectric, conveyance to meet downstream treaty and compact commitments, fish and wildlife habitat maintenance, waste assimilation, recreation, sediment transport, and freshwater inflow to estuaries.
[3] Includes precipitation minus natural evaporation from the land surfaces and plant transpiration, and drainage to groundwater.

Figure 4.3 Water Balance Elements
(Source: U.S. Water Resources Council, Second National Water Assessment, 1978)

Comparison of water supply and water use data showed that the nation's water supplies generally are sufficient to meet water needs for all beneficial purposes. However, major water problems were identified in most of the 21 water resources regions, and local problems of varying intensity were found in nearly all of the 106 subregions. Maps were prepared that showed the locations of major problems.

Assessment programs such as this, since they provide guidance for national or regional water policies, should be updated periodically. Water resource problem profile statements can be used to target programs for effective water management and to assess the adequacy of current programs and policies.

4.6 Interrelationships of Projects in a System

A master plan formulation was sponsored by the United Nations for the 24,000 square kilometre Vardar/Axios River Basin in Yugoslavia and Greece in which a variety of developments was considered (TAMS, 1978). The studies considered diversions in and out of the basin, and between sub-basins, flow interchanges between surface and ground water bodies, and flows across a boundary between two countries. Subsection 5.7.2 provides more information on this project.

Early in the study, a schematic diagram was prepared indicating existing and potential projects, the sources of their water supplies, and their interconnections with the river system and other projects. This diagram is too detailed for reproduction here, but Figure 4.4 shows the structure of such a diagram. This work was accomplished by the completion of an inventory, examination of reports and other information documents, and evaluation of principal project features.

The system was represented as a network of "nodes" and "arcs." Nodes can either represent elements of the system that use water for consumptive or nonconsumptive purposes; or locations in the basin where flows are added, subtracted, or simply recorded, and the statistics of the resulting stream flow series computed. Nodes for water use are: reservoir/power plant, irrigation, and municipal and industrial diversion. Nodes for stream flow are: start, confluence, diversion, terminal,and low-flow. Nodes are also provided for groundwater cells and for groundwater recharge. Arcs represent conveyances linking the nodes of the network. In some cases, fictitious diversion, terminal, and confluence nodes may be included to achieve a more accurate representation of real conditions in the system.

4.7 Externalities

The effects of a plan may extend beyond the boundaries drawn for a project and may include external economies and diseconomies. For examples of external economies, a flood control plan would, as a result of regulating flows to obtain direct outputs of flood control, also increase the recreational potential of land and water in the lower reaches of the river system, improve the fish and wildlife on this area, lower water treatment costs for firms and households, and increase groundwater recharge.

The following are examples of external diseconomies: increased downstream flood damages caused by channel modifications, dikes, or the drainage of wetlands; increased water supply treatment costs caused by irrigation return flows; erosion of land along streambanks caused by dams that prevent the replenishment of bedload material; loss of land and water recreation values through channel modifications, reduced instream flow due to consumptive use of water by irrigated agriculture or inundation by reservoirs; increased transportation costs caused by rerouting traffic around a reservoir; new or increased vector control costs caused by the creation of wetlands; and decreased output or increased cost per unit of private firms caused by project-induced decreases in raw materials. (U.S. Water Resources Council, Principles and Guidelines, 1983)

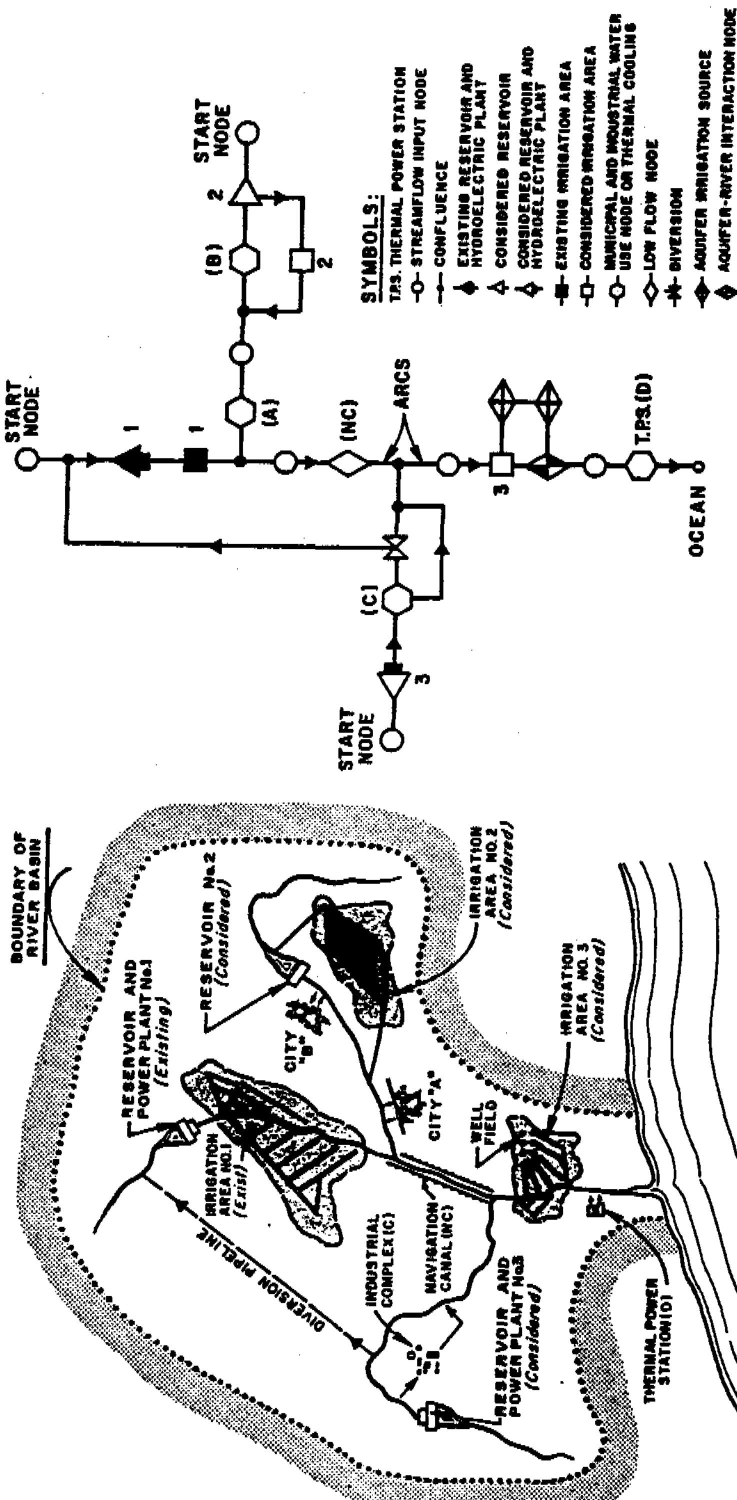


Figure 4.4 A Water Resources System and its Schematization
(Source: TAMS, 1978)

SECTION 5

CONVENTIONAL PROJECT PLANNING

5.1 Introduction

This and the next two sections draw liberally from a book by Goodman (1984) on the principles of water resources planning. In this section, a generalized process applicable to water resources planning is outlined and some basic terms used by water resources planners are defined. This is followed by descriptions of the following planning activities:

- Studies from preliminary through implementation stages of a single engineering project.
- Identification and screening of potential projects in a river basin or other geographic area to identify projects warranting further studies with a view to possible implementation.
- Comparison of alternative projects prepared at different times and by different planners.
- Comprehensive regional planning, usually carried out for a river basin, to select a potential set of projects and define their principal characteristics such as scale, capacity, and general operation rules.

5.2 Generalized Process of Water Resources Planning

The following phases are usually involved in the planning and management of a major water resources project:

- *Establishment of goals and objectives*--broad policies; legal and other constraints
- *Problem identification and analysis*--collection of data; projection of demand/supply relationships; uses of water and land; opportunities for development and management
- *Solution identification and impact assessment*--structural solutions; non-structural (management) solutions; preliminary assessment of impacts
- *Formulation of alternatives and analysis*--criteria and procedures for comparison of measures; detailed assessment of impacts
- *Recommendations including priorities and schedules for implementation*
- *Decisions*
- *Implementation*--organizations for action, if required

- *Operation and management*

In proceeding from the initial to the final phases of the planning and management process, the work in one phase can suggest changes in one or more of the other phases. This effect can be referred to as *feedback*, and the linkages may be in both forward and backward directions. Even when the water resource system plan is implemented, it should be updated from time to time during the operation and management phase.

The methods of water resources planning range from fairly simple techniques employing substantial professional judgment to sophisticated mathematical optimization approaches. The selection of methods for a planning effort depends on the type of project; the formal requirements of the planning organization; the available personnel, money, and equipment for investigations; and the capabilities and preferences of the planning staff.

The *goals* of water resources planning may be advanced by the use of constructed facilities, or *structural* measures, or by management and legal techniques that do not require constructed facilities. The latter are *nonstructural* measures and may include rules to limit or control water and land use (e.g., flood warning systems, restrictive zoning on floodplains) which complement or substitute for constructed facilities. A project may consist of one or more structural or nonstructural measures. The implementability of a structural or nonstructural measure, or a system of measures, depends not only on technical effectiveness but also on acceptability from other standpoints, such as economic, financial, environmental, social, legal, and institutional *impacts*.

Whereas the terms *purpose*, *goal*, and *objective* have similar meanings in ordinary usage, they are different in water resources planning. Traditionally, a purpose has referred to a category of water needs and problems (e.g., municipal and industrial water supply, flood control), while a *goal* or *objective* implies a broader value. Except when one or the other term is preferred in a particular discipline, this report does not distinguish between goals and objectives. Some water resource planners believe it is useful to consider a goal as a general societal aim such as the "improvement of the quality of life" and to express an objective in more specific (monetary or other) terms such as "maximization of net benefits." *Policies* are related to the goals and objectives and to the various constraints which restrict development and management within specified bounds.

When various projects are elements of a regional plan (or even when a single project emphasizes different types of values), multiple purposes and objectives may be considered. Water resources planning objectives have changed in both more and less developed countries in response to changing national values and the political process.

A plan that is optimal for the national economic development objective produces maximum net economic benefits (benefits minus costs). Other plans may emphasize environmental quality, nonstructural measures, or other approaches. Since these plans would not generally be the same, *tradeoffs* that increase some values at the expense of others would have to be considered in order to obtain a recommended plan.

5.3 Sequence of Studies for a Single Engineering Project

This subsection assumes that the general location and purpose of the prospective project have already been determined by an earlier screening process or other means of designation. The following describes a typical five-stage sequence of reports, documents, and actions for the project, including the preliminary (or reconnaissance) report, the feasibility report, the contract documents, and activities during construction and operation.

5.3.1 *First Stage: Preliminary (or Reconnaissance) Report*

This consists of office studies, field studies, and the preparation of a report. The report prepared as a result of these studies should answer the following questions:

- Is a feasible project likely?
- What are approximate estimates of capacity and cost?
- What additional studies are needed to confirm feasibility?

The investigation begins with *office studies*, using available information contained in previous reports, maps, and data. Much of this may be available from federal, state, and local governmental agencies. Utilities, private firms, newspapers, libraries and other sources should also be contacted. Basic materials include maps, and photographs (topographic maps, land surveys, tax maps, transportation maps, aerial photographs); geologic and soil surveys and data; climatological data; stream flow and ground water records; water quality and sediment measurements; information on ecological and environmental conditions; and data and forecasts pertinent to the specific purpose of the project (e.g., projection of water supply requirements, or electric power demands; characteristics of existing water supply, or electric generation and transmission systems; etc.).

Office studies may be adequate to make initial determinations of the general arrangements of the project components, the capacity of the project or the services it can provide, and its cost. Better estimates can be made by supplementing office studies by *field reconnaissance and surveys*. This work is needed to confirm the studies, to suggest changes in them, and to obtain detailed information concerning such matters as needed relocations in cases where the available maps are not recent. Topographic surveys, stream measurements, and geological and soils investigations may be needed, but these should be kept to a minimum, consistent with the nature of the preliminary report. The personnel involved in this work are normally engineers and geologists, but they may also include environmentalists and other specialists.

5.3.2 *Second Stage: Feasibility Report*

If the project sponsor determines that additional studies are warranted based on the preliminary report and other considerations, a feasibility report will be prepared. This report should contain enough information to permit a decision on whether or not to implement the project. This implies technical studies more detailed than those required for the preliminary report, financial and economic analyses, and a plan for project implementation. The feasibility report should include the following:

- Descriptions and analyses of the data

- Confirmation of construction feasibility based on additional field and laboratory investigations, studies of project arrangements and individual project features, and analysis of construction methods (sources of construction materials, access to the project site, diversion of water during construction, etc.)

- Final recommendations for arrangement of project works, preliminary plans and other analyses to determine the principal quantities of construction, a reliable cost estimate, and discussions of the design criteria

- Construction schedule showing the timing and costs of project features

- Economic analyses of the project

- Financial analyses projecting the year-by-year costs, revenues, and subsidies for the project

- Plans for financing construction, and for managing the construction and operation of the project

- Institutional and legal requirements

- Assessments of the environmental and social impacts of construction and operation, and other impact studies if required

Depending on the extent of detailed drawings and of analyses needed to confirm construction feasibility and make reliable estimates of project cost, the work in this phase consists of designs in addition to planning studies. Many textbooks, published articles, and manuals of United States and other government agencies are available for guidance.

5.3.3 *Third Stage: Final Design and Preparation of Contract Documents*

Contract documents include plans and specifications which are sufficiently detailed to obtain tenders (bids) from qualified construction and equipment contractors. The plans (drawings) and specifications are based on additional studies of the details of project works, the logistics of construction, other aspects related to temporary and permanent facilities, and the performance of contractors. The contract documents also contain additional information on the responsibilities of the project sponsor and the contractor. Various forms to be completed by the contractor provide information on the contractor's legal status and financial capabilities, set forth the quantities and prices for construction and for equipment, and elaborate on the construction methods proposed by the contractor.

The sponsor and engineers review the tenders made by contractors. A major factor is the prices offered by a contractor, but other factors considered may include the reputation and previous experience of the contractor, the specific working methods proposed to carry out the construction or manufacture of equipment, and in the case of the latter, the operating efficiency of the equipment to be provided. Contractors' tenders are usually ranked after weighing the factors, in order to determine which tenders are in the sponsor's best interest, and awards are made accordingly.

5.3.4 *Fourth Stage: Construction*

Additional detailed drawings needed during construction are prepared by the sponsor's engineers and by the contractors subject to the sponsor's approval. Payments to the contractors are usually made based on measurements of work in progress or completed, in accordance with the terms of the contract documents. Usually, a percentage of each payment is withheld by the sponsor and released only when the work is entirely completed and accepted. Supervision of construction by the sponsor's engineers often includes field layout of major works, approval of contractors' choices of working procedures and materials, interpretation of the plans and specifications, approval of the contractors' drawings needed to supplement the engineers' drawings, inspection of construction activities and of finished work to ensure conformance with plans and specifications, measurement of quantities of construction, and certifications required as a basis for payments to the contractors.

5.3.5 *Fifth Stage: Construction*

The sponsor may employ outside engineers and other consultants to assist in operation for a limited period, train operators, prepare manuals for operation and maintenance, and monitor the performance of the various features (structural, hydrologic, hydraulic, etc.). Studies of operating rules may continue as experience develops.

5.4 Formulation of an Engineering Project

The engineers (or the interdisciplinary team of specialists) who formulate a water resources project define the arrangement of project components, and sufficient details concerning their sizes and functions so that realistic cost estimates can be prepared. Project formulation relates to stages 1 to 3, above; it begins in a rudimentary way in the reconnaissance level work required for the preliminary report, is refined and elaborated in the feasibility report stage, and undergoes additional changes and detailed definition in the preparation of the plans and specifications for the contract documents.

During project formulation, the planner evaluates the available data and conceives a plan to utilize water and related land resources to meet project needs. This work draws on scientific training, experience with other projects of similar type or with similar components, and imagination and judgment to lay out a project that fits the available topographic, geologic, and soils conditions. Account is also taken of information on water volumes and flow rates, nature and magnitude of project products and services that are desired, and existing or potential constraints. Constraints may include legal limitations on water or land quantities or uses; practical limitations on relocations, land purchase, and easements permitted for buildings, roads, railroads, utilities and other human-made features; or obvious unsuitability of a site for certain types of developments (e.g., a type of dam may be unsuitable for certain topographic configurations, geology, or construction material availabilities). In most cases more than one layout is possible. A good planner will eliminate the most unsuitable alternatives while assessing the remaining alternatives fairly and comprehensively. With some sites and service requirements, the planner may be able to proceed directly to the optimal solution. In the more usual case, alternative layouts will need to be prepared and examined for cost, function, construction suitability, and other factors.

The planner may approach a solution for a site starting with the perspective of a water need of a particular type and magnitude (e.g., municipal and industrial water supply) and then consider the possibilities for modifying the project to make it suitable for multipurpose operations (e.g., recreation, hydroelectric power). Or, the planner may from the beginning examine a variety of plans that exploit the site for all the opportunities for multipurpose development.

The formulation of a project as discussed above emphasizes structural details, costs, project services, reliability, safety and other engineering matters. It is necessary, however, to consider the impacts of a project that are not primarily of an engineering or cost nature. If the formulation team is dominated by engineers, it will be necessary to consult with or have formal assessments by other specialists at various stages to ensure that environmental, sociological, institutional, and other factors are adequately taken into account. Otherwise, projects may be proposed that cannot be implemented. At the early stages of planning, impact analysis can be limited to identifying the most obvious problems, but studies at later stages need to be more comprehensive.

As the work of formulation proceeds, the planner gains an improved understanding of site conditions, advantages and disadvantages of alternative project arrangements, and possible opportunities for using the site to produce more or different project services. The planner is, therefore, better able to communicate with the sponsor of the project, and reconsideration of project objectives and purposes, scale, or other aspects may result from such communication.

Many types of planning aids can be used to facilitate the studies discussed in this section. Some of these aids are required routinely. Other aids permit a more comprehensive and interdisciplinary examination of a study area or allow a perspective that may otherwise not be evident. Finally, some of the techniques can assist the planning process by reducing the amount of technical effort required, particularly when repetitive tasks are needed or where the planning process requires a number of iterations. The planning aids may be of the following types:

- Basic data
- Aerial photos, satellites, and remote sensing
- Generalized estimates

- Overlays and other techniques for suitability mapping

- Computerized data banks and displays

5.5 Screening to Identify and Rank Potential Projects

The screening techniques that are appropriate depend on the specific goals of studies, the amount and completeness of information that is already available, and the time and resources that can be expended. In any method, the investigator attempts to ensure that all meritorious projects receive adequate consideration.

The process of screening involves evaluation of all existing and potential projects in a river basin or other defined geographic area for one or more purposes and objectives of water resources development. It may lead to the selection of outstanding projects on which to focus further investigations directed to early construction or to a ranking of all potential projects that appear attractive for a long-term program of development. The studies may also assess the adequacy of the available information for existing and potential projects as a basis for more comprehensive planning.

Screening presupposes that a reasonable amount of information has already been collected on the topography, geology, and hydrology of the study area. If this is not the case, as in many economically underdeveloped regions in the world, time must be allowed for programs to collect such data, by aerial or ground surveys, geological investigations, and stream gagings. The minimum time for this work may be two to five years, depending on the variability of stream flow and other aspects. Early in the screening process, the planner should identify those areas where constraints would prevent the siting of a water resources project. In any region, legislation may protect specific environmental and cultural resources from development. These include wilderness areas, registered historical sites, and known habitats of endangered species. In addition, certain natural, social, and other characteristics may cause areas to be unsuitable for further consideration. Exclusions depend on the type of project and will vary among different regions of a country. Map overlay methods to show restricted areas and computer techniques based upon geographic information systems (GIS) are approaches that may be suitable for these studies.

When studies are made with emphasis on single-purpose development, the screening techniques adopted should accomplish one or more of the following:

- Identify the set of projects within a defined geographic area that satisfy specified minimum site criteria.

- Determine which of the identified projects are sufficiently attractive to be retained for more detailed studies and which should be "screened out." This process may involve one or several stages of assessment and elimination of projects.

- Assess the data for each retained project, for completeness and adequacy, for further evaluations.

- Determine an order of merit of the retained projects, when each project is considered for single-purpose independent operation.

5.5.1 *Site Selection Criteria*

The planner considers the functional requirements of projects and draws on past experience to establish the site selection criteria. In this phase, the planner should review information on existing projects of the type to be inventoried, paying special attention to the characteristics of economical operating projects. The requirements for identifying a reservoir storage site may include a minimum drainage area to ensure adequate inflows of water, a location for dam and reservoir of minimum volume to provide adequate storage and regulation of seasonal inflows, and a location for a spillway of adequate capacity to pass specified flood flows. Criteria can be used to limit the amount of work in a screening investigation. For instance, if all potential sites having at least 200 square kilometres of drainage area are to be identified, changing the criterion to 100 square kilometres will increase the number of sites included by a factor of about 3.

The following is a set of appropriate criteria for natural runoff on-stream catchment reservoirs in the northeastern United States to serve a water supply need of about 1 cubic metre per second.:

- The dam site shall have a drainage area of at least 130 square kilometres.
- The reservoir shall have a live storage adequate to regulate the flows in a 4-year drought cycle.
- The reservoir shall have additional storage to allow for evaporation, seepage, and dead storage (below outlet level).
- The spillway site shall provide for a capacity to pass a peak outflow in cubic metres per second of $175A^{0.5}$, where A is the drainage area in square kilometres. This is very conservative and some leeway may be allowed in this requirement.
- The reservoir shall not be located in areas requiring extensive relocations or where such construction is known to be illegal.

5.5.2 *In-Office Studies*

The office studies evaluate all previous studies of specific sites, and identify additional sites by careful perusal of maps and aerial photographs, following the streams on these maps to discover topographic features that permit dam, reservoir, and spillway construction. Transparent overlays and tables are useful for showing the location and principal features of potential developments and providing space for additional comments based on these and other studies. Because of the large areas to be covered and many sites to be studied, all computation procedures and estimates should be standardized. Maps, photos, and other basic data should be filed for ready reference since time spend searching for such information is wasteful.

The inventory studies are carried out initially using only readily available topographic, geologic, and hydrologic information. This allows basic information to be assembled at minimum engineering cost, and inventory studies can be accomplished in a relatively short period of time. The aerial photographs should be the most recent since available maps may not have been updated to show industrial and residential construction and transportation routes which would interfere with development.

Previous studies are especially important when water resource investigations are to be conducted. In most countries, few new dam sites or reservoir sites will be identified except where new technology has made construction feasible. For instance, the development of large pumps and/or reversible pump-turbines may make a reservoir, previously limited in size by a deficient drainage area, economically feasible. Thus, the deficient flow from a small drainage area on a tributary stream can be augmented by seasonal pump-in from the main stream, with or without generation of seasonal electric energy through discharge back to the main stream. Also, new methods of cutoff construction such as chemical grouting, slurry trench, or drilled concrete caisson piles may now make a dam with a permeable-foundation feasible, where 25 to 50 years ago costs of construction would have been prohibitive.

A thorough investigation should include both existing reservoirs (for possible redevelopment to larger size) and all sites previously studied. A list of reservoirs studied in the past for any purpose should be prepared as a prerequisite to a proper preliminary screening for a basin study.

Generalized hydrologic relationships based on regional studies should be prepared to determine whether individual sites meet the criteria. For example, using data for the existing gaging stations, a map may be prepared with lines of average runoff per square kilometre. Regulation studies may also be made using these data and results plotted as a dimensionless ratio of regulated flow to average flow versus dimensionless ratio of required live storage to average annual runoff volume.

Generalized cost relationships in the form of graphs and nomographs should be prepared if they are not already available. Such relationships can cover structure, fill, excavation, lands and relocations, and other features.

After identifying the sites meeting the criteria for drainage area and having valley topography suitable for a dam and spillway, a rough calculation can be made based on map data of storage versus reservoir elevation, and the dam and spillway arrangement can be tentatively selected. Hydrologic relationships can be used to determine the scale of the project and an abbreviated cost estimate can be made using the cost relationships. This process should permit an approximate ranking of sites using a simple cost parameter. For a reservoir, this parameter may be in terms of cost per cubic metre of storage or per cubic metre per second of water supplied. The parameter can be used to establish cutoff points at which to eliminate poor sites in this early phase of screening. It will generally be found that the unit costs of a reservoir project will be lowest when the site is developed to its maximum hydrologic capacity, as limited by the topography of the site or the level at which excessive relocations are required; this is because the reservoir surface and hence the rate of addition of volume, increases as the dam height increases.

The first screening may result in a large number of identified sites meeting the criteria and having unit costs below cutoff levels. To make the number of sites retained more manageable, more detailed abbreviated cost estimates may be applied to the better sites taking account, in the case of the reservoirs, of costs of water conveyance systems, pumping costs, and other ancillary facilities, and reexamining aerial photographs and other sources of information for relocations and other problems that would increase construction costs. From the list of sites that have been reranked in order of unit cost, the best, perhaps 50% or less, will then be subjected to more intensive study.

5.5.3 *Field Reconnaissance, Adjustment of Cost Estimates, and Reranking Sites*

The field reconnaissance should be made by specialists experienced in project layout and cost estimating, geology, and soils. They can check whether the general layout prepared in the office is reasonable or whether changes are indicated, make a preliminary assessment of the adequacy of foundations for structures, locate materials in the area that are needed for construction, and identify any obvious problems of design and construction. They can determine if there are any serious problems of access and relocation that may not have been evident from maps and other office references. Social and environmental evaluations may be limited due to personnel and time limitations, but problems such as severe social dislocations or obvious environmental impacts should be considered. The value of field reconnaissance in the basin study cannot be overemphasized. It is through field observations that the investigator gains an understanding of the project sites and the entire basin terrain.

As the result of the field reconnaissance work, the cost estimates may be revised, new cost parameters calculated in terms of unit of service or product, and a reordering of projects made.

5.5.4 *Systems of Projects*

The procedures described above for developing an order of merit for single projects may be the basis for systems studies. A typical approach would formulate a schematic plan of existing and potential projects (location, interconnection with the river system and with other projects, hydrologic interrelationships, etc.) for systems studies. The systems studies could include mathematical optimization studies for single or multiple purposes, sometimes specifically referred to as "screening models," or could include other studies of integrated operation leading to a regional or "master" plan.

5.5.5 *Multiple Purpose Projects*

If multiple purposes of development are considered, the outline and explanation presented above is too simple. Identification and assessment of the various purposes and possible trade-offs may take place at various points in the study. If environmental and social considerations are important (especially when multiobjective planning is specified), these aspects cannot be ignored even at the earliest stage of the study and should be evaluated formally when establishing the final ranking of projects. For this work, matrices or tables are often used to show the interactions between development actions and their socioeconomic and environmental impacts, with numerical values applied to indicate the importance of these impacts. Weighing procedures permit estimation of the relative contributions of the projects to the designated purposes and objectives, and to other factors influencing site selection.

5.6 Comparison of Projects Prepared at Different Times by Different Planners

5.6.1 *Review and Adjustment of Project Data Base for Preliminary Comparisons of Alternatives*

The problem discussed in this subsection is how to compare a number of alternative projects with different outputs and other characteristics. Any methodology for this problem should be based on reevaluating key physical relationships, updating costs, and performing other adjustments to permit comparison of the projects in terms suitable for a single-purpose project (e.g., cost per unit of output for water supply) or terms suitable for a multipurpose project (e.g., net benefits or benefit-cost ratio). An example of this approach is the screening study made in 1977 for the government of Jamaica and the World Bank in connection with additional water supplies for Kingston, Jamaica (Goodman and Jezierski 1979). The study involved the review of six major surface water supply schemes previously proposed and three groundwater sources.

The study included review and evaluation of existing reports, development of new data, and field work. Emphasis was placed on checking or establishing fundamental data on population and water demands, hydrology, geology, and hydrogeology. The alternative layouts followed closely the alignments and other engineering features as indicated in the available reports, since the scope of work did not include redesign or new designs for any of the structures. In order to provide a realistic and relatively uniform basis for comparison of the projects, however, the office and field studies were designed to the greatest practical extent to bring the various schemes into a similar focus from a number of important standpoints. These included reliability of construction and operation of facilities, integration with other existing and future projects in the water supply and distribution system, compatibility in the context of a master plan, and safe yield.

In developing comparative cost estimates, all information and basic physical data on sites and structures were obtained from published reports and pertinent backup information. Project components or structures were not redesigned. In order to produce a fair representation of project costs on a consistent level, however, structural dimensions were changed to reflect proper construction procedures. For example, provisions were made for overbreak in tunnels and a flat excavated invert to allow construction. Also, available geological information was utilized to establish firm rock lines and excavation limits. The tunnel section that had been proposed for two of the routes was considered to be inadequate to allow safe and efficient construction for the long lengths between portals, and was increased in diameter. When more adequate preliminary detail was available in a study of one project, it was applied to another project to represent better the quantities of excavation, concrete and reinforcement. Unit prices were increased to reflect inflation since the dates of the original estimates; published indexes were used for this purpose. Costs of mechanical equipment were estimated with the aid of manufacturers' quotations.

As a result of this effort, each scheme was represented for purposes of comparative analysis by an alignment; principal dimensions of diversion structures, tunnels, pipelines, compensation wells, treatment facilities, and other project features; and estimates of construction quantities and total cost and unit cost of water. Contingencies of 15 to 25% were applied to the construction cost, depending on the information available on a given project and the level to which it was studied in the past. Estimates of investment cost also included engineering, supervision and administration costs, and interest during construction. Annual costs included amortization of debt and operation, maintenance, and replacement costs.

5.6.2 *Review and Adjustment of Project Data for Master Planning*

The problem discussed in this subsection is to adjust and augment a data base so that equitable consideration of single multipurpose projects can proceed, in which each project can be analyzed both individually and in a systems context. The preceding section treated this same problem for a more limited case (singe-purpose public water supply). This subsection presents a general comprehensive methodology. It is based partly on studies that led to a recommended master plan for integrated development of the Vardar/Axios Basin in Yugoslavia and Greece prepared for the United Nations (TAMS, 1978). In work prior to these studies, various governmental agencies and consulting firms had prepared reports on individual projects at different times and with different levels of detail. Not all of the elements discussed below were applied to the Vardar/Axios studies.

In the course of investigations of this type, a schematic diagram should be prepared indicating existing and potential projects, the sources of their water supplies, and their interconnections with the river system and other projects. An inventory and examination should be made of principal project features such as layout and sizes of principal project components, operational characteristics such as spillway design floods and mean water yields, adequacy of foundations, estimates of construction costs, and unusual or special construction problems or relocations. The projects studied in a large river basin may vary from a small direct pumping scheme covering a few hundred hectares of irrigated land to large multipurpose projects involving reservoir storage for irrigation, hydropower, municipal and industrial, thermal power plant cooling, and recreation uses. This information, together with additional data processing defines the basic system of projects and the physical and economic data needed for comprehensive systems analysis.

The procedure assumes that all projects with significant potential value (in the basin and outside the basin, but serving its population) have already been identified. It also assumes that at least preliminary studies have already been carried out for each project.

For purposes of alternative system studies, information should preferably be available concerning each project at more than one level of development. Feasibility of stage development should also be investigated. Three levels of development are usually adequate to define trends of cost and benefits. Information for fewer levels of development may be considered due to restrictive topography and geology, hydrologic limitations, unacceptable flooding of large communities, or other reasons.

The information described above should be put into table and perhaps other types of exhibits. Fairly large exhibits are needed to show all the information. Since projects are to be compared, the exhibits should be arranged to show both the information that is available and the information that is lacking, and deficiencies to be overcome if possible. To the extent practicable, the information should be shown in quantitative terms. Where quantitative expressions are not available, descriptive material can be put into tables. Dates for information should be indicated to show where updating of costs will probably be necessary and possibly for other reasons (e.g., environmental and socioeconomic studies have been carried out only in recent years). The tables should be organized so that, for several levels of development of a project, it is clear which items are the same and which are different.

The tables should then be examined to determine what adjustments are needed. All cost estimates should be adjusted to a common basis with suitable indexes such as the *Engineering News-Record* construction indexes that are used in the United States. If there are large differences in percentage allowances for construction contingencies, engineering, and interest during construction, they should be adjusted, unless there are obvious differences in risks or other reasons. In the case of major physical features such as spillways, diversion schemes, and waterways that have a hydrologic and hydraulic basis, criteria should be established for recurrence interval for the hydrologic events, limiting velocities, and so on, and adjustments made to the project features and cost estimates if they are substantially out of line. If hydropower projects have different capacity factors (ratio of average to maximum power) but will be expected to operate in a similar manner, the factors should be adjusted. If there are some obviously poor layouts of project features, their revision should be considered. These measures should not take an inordinate amount of time at this stage of the work; the emphasis should be on adjusting estimates for comparative purposes.

Rough comparisons should then be made among the projects, to eliminate those that obviously should not be considered further. This should be done on the basis of cost per unit of reservoir volume or per cubic metre per second of yield in the case of a flow regulation project, or some other measures of unit cost of output (construction cost or present worth value) or economic indicator (e.g., benefit-cost ratio). Projects should be eliminated at this stage very cautiously, eliminating only those that are obviously inferior; concurrence or, at least, advice of the sponsor's staff should be sought.

Several types of studies should now be undertaken to:

- Adjust projects in accordance with known opportunities for resources development and known user demands.
- Adjust layouts and cost estimates in accordance with information obtained by field examinations; these consider construction conditions, access, relocations, etc.
- Estimate principal features such as reservoir volumes for additional levels of development
- In general, to fill in the missing pieces of data in the inventory tables to the extent feasible.

It is important in comparing and ranking projects that all be compared on an equitable basis. However, this is not always easily done. For instance, some projects may have had more field examination than others, such as drilling or better mapping. Others may have been subjected to a more detailed level of design. Factors should be applied to account for these different levels of study between projects. Usually, the geologic evaluation of a site is the most important consideration or variable affecting project construction costs. All sites considered should be given a uniform geologic evaluation by a geologist knowledgeable of the geology of the region, with a view to reflecting this evaluation in project costs. Much of this work depends on the field examinations, but office map studies and other analyses should also be utilized.

The projects should then be reexamined to rank projects, considering benefits, cost, importance in meeting broad national objectives, and other factors. Systems of projects, including alternative operating rules, can then be formulated using various levels of the better projects, as indicated by this ranking. No standard procedure for such formulation of systems is suitable for all problems. The concurrence or advice of the sponsor's staff should again be sought.

5.7 Comprehensive Regional Planning

In water resources planning, *master planning* is the formulation of a phased development plan to (1) meet the estimated requirements for a single water resource purpose over a specified period of time; or (2) exploit the opportunities for single and multipurpose water resource projects in a defined geographic area over a specific period of time or until all justified projects are completed. The plan can include a single project in various phases or a multiunit system of projects, and can encompass both structural and nonstructural elements. When the studies involve multiunit, multipurpose, and multiobjective planning, and consideration of both structural and nonstructural alternatives, the terms *comprehensive planning* or *integrated planning* are often applied.

Regional plans of this type often include a schedule showing the phased development of programs; sufficient information on the characteristics of each project to indicate clearly general physical arrangements, scale, controlling parameters (such as dam elevation, capacities, etc.); and a schedule of investment costs. They may also include concise statements or tables summarizing contributions to specified planning objectives and project impacts (economic, environmental, social, and others).

These plans are based on a review of previous reports on individual projects; on discussions with planners in governmental agencies and other organizations, and with private individuals; on the results of screening studies; and on topographic, geological, hydrologic, and other information. In many instances, previous studies must be reevaluated and new groupings, stagings, and modifications of physical features must be made to achieve the desired formulations.

Master (or comprehensive, or integrated) planning studies do not include detailed "feasibility" report studies of individual projects which are needed for final authorization and financing of projects. Such studies may already have been completed before or during the master plan studies because of earlier initiatives by various organizations. If so, they should be made consistent with the master plan.

5.7.1 *Outline of a Comprehensive Planning Report for a River Basin*

This section outlines a composition of a report that is a synthesis of various comprehensive planning studies of river basins carried out in the United States and other countries, both industrialized and developing. For a specific project, the outline should be modified to take account of local factors such as: (1) the organization sponsoring the studies and its planning objectives; (2) the planning criteria that may already be established by governmental (regional, national, international) authorities or special institutions(e.g., the World Bank); (3) the economic sectors (industrial, agriculture, etc.) in the region and their existing development; (4) types of needs and opportunities for water resources development; and (5) other factors (legal, economic, environmental, social, etc.) that are important to planning.

A summary section (often referred to as an *Executive Summary*) should be placed at the beginning of the report. This contains a brief description of the studies and presents the principal conclusions and recommendations. It provides an introduction to the remainder of the report by giving an overall perspective of the studies. Its importance is indicated by the fact that it may be the only planning document read by decision makers and policy reviewers who do not have the time or responsibility to examine the planning analyses supporting the recommendations. Information should include location, drainage area, and other principal physical features of the study area; water resources needs and opportunities for municipal and industrial water supply, water quality management, and other project purposes; compact descriptions and/or tables summarizing the single and multipurpose projects with their structural and nonstructural elements constituting the proposed comprehensive plan; and recommendations for further studies if any. The report as a whole includes details on the above and the study methodologies.

Introduction should discuss the study objectives; outline the scope of the studies and report; state the authorization for the work; make reference to the previous reports and studies bearing on the project; and include appropriate acknowledgments of cooperating organizations and individuals.

Planning Principles should discuss the planning objectives (e.g. adequate water supply, economic development, increased employment opportunities, environmental protection and conservation); legal and other constraints relating to water and related land resources; and planning criteria (e.g., benefit-cost, interest rate, water quality standards). The general planning methodology should also be described. The detailed methodologies should be described by means of tables, graphics, other exhibits, and discussions in the chapters that follow.

Study Area and Economic Profile should describe the study area (location, drainage area, political and geographic subdivisions, general topography and vegetation, pattern of streams and other water bodies, important urban centers, etc.). An economic profile should include data on existing conditions and projections for population and employment; manufacturing, commerce, recreation, and other activities with economic impact; and supporting infrastructure such as transportation routes, communications, and water and power distribution.

Water Resources Needs should analyze the current status and projected needs for project purposes (municipal and industrial water supply, water quality management, floodplain management, electric power, etc.). In this sense, the term "needs" comprehends both "basic needs" and reasonable "aspirations." This chapter presents information on existing problems (e.g., floods and droughts), and the new or more intensified problems expected in the future due to economic growth, degradation by wastes, increasing demand for services to meet expectations for a higher standard of living, and other important changes in the river basin.

Water Resources Opportunities should assess the surface water resources (location, precipitation pattern, runoff pattern, floods, low flows, withdrawals, degree of existing flow regulation, opportunities for increased flow regulation); the groundwater resources (location, variations of groundwater surface, withdrawals, estimates of yield, extent of physical connection with surface waters and opportunities for conjunctive use); the existing and potential reservoir sites (location, area and capacity, effect on downstream flows, availability of sites for single and multipurpose development); and the opportunities for nonstructural management (floodplain zoning, water conservation, and other measures).

Plan Alternatives should present information on various plans for single - and multipurpose development, including structural and nonstructural measures that meet (partially or fully) the planning objectives, constraints, and criteria. At this level, the assessment is approximate but should reflect enough study work to enable preliminary comparisons (e.g., site location, range of scale and construction cost, and capacity to provide water, power, and other services so that the extent of meeting needs and rough unit costs can be judged). Plans should be eliminated that cannot be implemented because of gross defects such as excessive unit costs or conflict with extensive existing development. Reconnaissance-level environmental and social assessments may be appropriate for these studies to identify the possible impacts on nonengineering/economic objectives and thus to help indicate the range of choice in comprehensive planning. The involvement of various government agencies, private organizations, and the general public may be required or desirable for establishing and/or reviewing the formulations; for certain countries and types of projects, the public involvement program may be defined by law.

Recommended Plans should describe the proposed plans and should provide information on the analyses leading to their selection. These include project layouts, cost estimates, economic (and perhaps financial) analyses,and environmental and social assessments at the level needed for these studies.

Project Implementation should include a schedule for the implementation of the various projects staged to meet the needs, and the annual capital investments that must be provided. Recommendations should also be included on unresolved problems that should be studied; and on the feasibility reports, applications for licenses and permits, and other documents that will be required before final approval and implementation of the projects. Of particular importance is an analysis of the organization, professional personnel, and outside consultants needed to perform final planning, design, construction, and operation. In developing countries, the issue of sustainability beyond the period of initial operation is very important, and should be addressed in this report.

5.7.2 *Integrated Plan of Single - and Multipurpose Projects to Meet Various Needs in a Specified Geographic Area*

Methodologies are available for water resources planning drawn from systems analysis, operations research, and other academic disciplines which are capable (particularly with mathematical models and computers) of considering the interrelated factors of engineering, cost, and economic benefits for individual projects and highly complex systems of projects.

The following draws on the Executive Summary volume of the report prepared for the United Nations on the integrated development of the Vardar/Axios River Basin in Yugoslavia and Greece (TAMS, 1978). The integrated development of Vardar/Axios Basin includes a system of projects scheduled to meet the needs and aspirations of two countries. It includes recommendations for cost-sharing arrangements. Institutional, managerial, and financial arrangements were not part of the studies. Legal, social and environmental impacts were not fully analyzed but were taken into account in some planning criteria.

The considerations that guided the detailed methodology for formulating the master plan included: economic sector development (principally agricultural, municipal and industrial, and electric power); balanced regional development; engineering and economic feasibility of facilities; and compatibility with existing power and hydraulic systems.

For the formulation of a basin plan and a schedule for implementing projects, the preferences expressed by a Coordinating Directorate composed of representatives of Yugoslavia and Greece (working through a United Nations Project Manager and two Co-Managers representing the individual governments) were followed as closely as practicable. In some cases, adjustments were made to improve reliability with the available water. Priorities of project purposes such as municipal and industrial water supplies, irrigation, and hydroelectric power were taken into account where water was limited and it was necessary to change the size or operation of some projects. In determining whether projects were satisfactory from a hydrologic standpoint, criteria were established in terms of the percentage of time that water requirement targets were met.

In general, the ultimate development of the projects was considered close to the maximum size proposed in the engineering reports made available for the master plan studies by the governments. It was concluded that with some exceptions, there was enough water in the basin to meet the contemplated goals for irrigation and other needs with integrated development.

An essential preliminary step in the planning of the development of the basin was an assessment of the water requirements throughout the basin in the years 1985, 2000, and 2025 as well as an assessment of water available in the basin and of potential hydraulic works.

The master plan was developed in a series of steps, generally proceeding from individual project examination, through subbasin studies, to complete basin simulations. Because of the very large number of projects to be considered and the complexity of their interactions, it was necessary to adopt computerized techniques of analysis. The schematic diagram of project interconnections has been described in subsection 4.6.

The work described above, referred to as "preliminary screening," together with additional data processing, defined the basic system of projects and the physical and economic data needed for comprehensive systems analysis. Economic and financial criteria applying to the systems analysis, and other planning considerations were taken into account in the course of formulating the master plan.

Prior to undertaking the simulation for the entire basin, water balance analyses were carried out for each project at a subbasin level. These subbasin analyses resulted in adjustments to the required capacities of reservoirs and the modification of irrigation projects to be compatible with available water supplies. These investigations were also useful in providing an initial evaluation of the project configurations and interrelationships comprehended by the schematic diagram mentioned above, and led to the evaluation of basin configurations by simulation models. These models accommodated a large number of projects and an enormous quantity of data, and provided measures of performance in hydrologic and economic terms. They were also effective in accounting for the complementarity between projects and purposes (for example, water used in a reservoir for hydropower and for recreation can be released for use in other projects downstream).

The simulation models reproduced the interactions among the elements of the system and described the outcome of operating the system under a given set of inputs and operating assumptions. By successive and systematic runs of the models, the response to the variations in inputs or operating conditions or both were evaluated.

SECTION 6

FEASIBILITY STUDIES AND PROJECT APPRAISALS

6.1 Scope of Feasibility Studies

As discussed in Section 5 which described the sequence of studies and reports for a project, the *feasibility report* provides the basis for an examination by decision makers in a government agency or in an international financial institution, to determine whether a project should be implemented and/or financed. The level of engineering detail for such a report is higher than for a *preliminary report* but lower than for the design and preparation of *contract documents* for construction.

An outline of tasks for planning an urban flood control project will provide a perspective of the complexity of a typical water resource project and an indication of the different professional specialities involved in the studies and preparation of a feasibility report. Some of the activities in the following list overlap (e.g., environmental studies will begin before the structures are finally selected).

- Management and coordination
- Analysis of basic data -- maps, aerial photos, stream flow, etc.
- Determination of needs for flood control
  - -- delineation of area affected by floods
  - -- determination of floodplain characteristics
  - -- forecast of future activities in affected area
  - -- estimates of existing and future flood damages
- Consideration of alternative ways of meeting needs
  - -- upstream reservoir
  - -- local protective works for urban area
  - -- nonstructural measures
- Studies for reservoir
  - -- selection of site
  - -- selection of capacity
  - -- selection of type of dam and spillway
  - -- layout of structures
  - -- analysis of foundations of structures
  - -- development of construction plan
  - -- cost estimates of structures
  - -- layout and cost estimates of access roads, bridges, communication facilities, construction camp, etc.
  - -- identification and estimates of requirements for lands, relocations, easements, etc.
  - -- consideration of reservoir for multipurpose use with pertinent

analyses of layouts, capacities, costs, etc.

- Studies for local protective works--levees, walls, river shaping and paving, interior pumping stations.
- Studies of nonstructural measures--land use controls, flood warning systems, flood proofing, etc.
- Formulation of optimal combination of structural and nonstructural components for flood control project
- Financial analyses
- Economic analyses
- Assessments of environmental impacts--ecological, archeological, historical, geological, air and water quality, land sedimentation and erosion, etc.
- Sociological impact assessment
- Measures to mitigate adverse environmental and social impacts
- Institutional and legal aspects
- Public information and participation programs
- Report preparation

6.2 Financial and Economic Analyses

Financial analyses are needed for both public and private projects. They include the preparation of the following types of documents:

- Estimates of the investment cost and annual cost of the project, in terms of monetary requirements
- Schedule showing the breakdown of the investment cost by years, with separate accounts of expenditures for construction and for the other categories of costs needed to bring the project into operation
- Estimates of portions of investment cost in domestic and foreign funds, especially in the case of developing countries whose foreign currencies are in short supply
- Plan for financing the costs of the project investment, including the sources of funds and the terms of repayment of each category of borrowings
- Estimates of costs; revenues from the sale of water and other services; and required subsidies on a year-by-year basis extending from the completion of construction to the date when the repayment of all borrowings is completed and beyond if appropriate

- Plan for the required annual subsidies, if any, working funds to enable operation to commence, and for financing to meet temporary cash flow requirements

- Additional statements of a financial nature depending on the regulatory and financial institutions involved in the project

Economic analyses are needed, in addition to financial analyses, for most public projects, especially when water resources projects are analyzed at a national level. Some of the elements of the description that follows may be considered by private enterprises, but it is rare that they will be treated as *formally*.

Economic analyses treat all economic costs and benefits. Economic effects of public works may involve beneficial or adverse effects in addition to construction and operating costs and user benefits. Economic feasibility implies that the discounted benefits of constructing and operating the project will exceed the discounted costs over its useful life. Indicators such as the benefit-cost ratio, net benefits, and internal rate of return are used to demonstrate economic feasibility. All costs and benefits that can be accounted for as being attributable to the project should be included in the analyses.

A variety of methods exist for determining benefits of a project. A benefit is not the same as revenue, since the actual or perceived beneficial effects of a project may be greater or less than the revenue to recover project costs. Unlike the services of a private business, many public services are offered without expectation of full or even partial reimbursement of costs. On the other hand, there are many times when prices charged for public services are set equal to costs, but when the benefits in terms of consumer satisfactions are actually greater than revenues. The "Principles and Guidelines" of the U.S. Water Resources Council (1983, p.9) include the following measurement standard for goods and services valued for the "National Economic Development" account: "The general measurement standard of the value of goods and services is defined as the willingness of users to pay for each increment of output from a plan. Such a value would be obtained if the "seller" of the output were able to apply a variable unit price and charge each user an individual price to capture the full value of the output to the user. Since it is not possible in most instances for the planner to measure the actual demand situation, four alternative techniques can be used to obtain an estimate of the total value of the output of the plan: willingness to pay based on actual or simulated market price; change in net income; cost of the most likely alternative; and administratively established values."

For a water supply serving municipal, industrial, or thermal power needs, a minimum measure of benefits may be the cost of an alternative that would provide comparable service in terms of quantity and quality of water that would in fact be utilized in the absence of the water supply project under consideration. For a hydroelectric power project, the benefits may be equivalent to the cost of an alternative power project (usually thermal-electric) providing equivalent power and energy. For an irrigation project, the benefits may be evaluated in terms of increased agricultural income attributable to the water supply. For flood control, the benefits may be determined as the damages prevented by the project. For navigation, the benefits may be the cost savings of waterborne commerce in comparison with alternative modes of transportation. Recreational benefits may be in terms of perceived values based on the type of recreational activity and the money people are willing to spend while reaching and engaging in the activity.

The examples of benefits outlined above are in terms of *direct user benefits*. The *direct costs* are usually related to the investment and annual costs of the financial analyses. In addition, both benefits and costs may be increased for *externalities* due to other effects on the economy that may be caused by the project. External economies include such effects as a reduction in downstream water treatment costs that is external to a plan for flood control and hydropower purposes. A plan may also cause external diseconomies, as when a reservoir stores low flows and reduces the flows downstream that are available to dilute wastwater discharges, thereby increasing the cost of treatment. Externalities are not usually evaluated in a financial analysis but should be included in an economic analysis.

Economic analyses should be based on benefits and costs that are adjusted by *shadow pricing*. Shadow prices, particularly in developing countries, are used when market prices do not indicate the true costs to the national economy. Additional adjustments called *weights* are also used in some countries to express government policy to favor or discourage use of specific resources.

In engineering economy studies involving business decisions, the terms *financial* and *economic* are often used interchangeably. In some fields of public works also, no distinction is made between the two terms. However, whether or not the terms are used interchangeably, the analyst should always make clear which objective is being studied--the financial or the national income (economic) objective.

It is a general rule of economic analysis that costs already committed and for which the sponsor is liable do not enter into a comparison of alternatives or a decision as to whether or not to proceed with a project. This is consistent with the fact that such *sunk costs* would apply to both the "*with*" and "*without*" conditions and therefore cancel out in decision-making considerations. In financial analyses, however, all cash flows, including carryover obligations, may have to be considered. For such analyses, the analyst may include sunk costs with an appropriate footnote to the calculations, or may make two sets of calculations, with and without the sunk costs.

Transfer payments such as taxes and subsidies are not properly included in national income (economic) analyses, since the national income objective is concerned with real income and productivity effects. However, they are properly taken into account in financial analyses and in studies of impacts on regional and group income accounts.

In economic analyses, calculations are made in terms of constant currency units. In practice, the analysis is usually made in terms of prices in effect during the planning phase. This assumes that general inflation rates would have an equal effect on future benefits and costs which, after conversion to constant currency unit values, could be discounted at a specified interest rate. This approach should be modified if different components of the benefits and costs are affected differently by inflation. In financial analyses, an analysis on a year-by-year basis makes it possible to take account of assumed inflation rates for any component of costs, revenues, and subsidies.

The financial and economic analyses are very important elements of the feasibility report. A project is justified from a national economic viewpoint if it has positive net economic benefits, provided that the services of such a project are considered of high enough priority for implementation compared with the use of valuable resources for other purposes. The results of an economic analysis do not, however, provide sufficient information on financial viability during the course of each project's actual construction and operation. Financial analyses are made to determine the needs for financing the project construction and handling the flow of costs, revenues, and subsidies after the project goes into operation.

6.3 Environmental, Sociological, Institutional and Legal Analyses

In modern water resource planning, it has become increasingly important to pay proper attention to the environmental and social impacts of a project, and the institutional and legal structures and constraints. These issues are critical to project acceptance and to its implementability and operation, and must be adequately addressed in the feasibility report.

In the United States, the environmental assessments of a project are made in every stage of planning and for important federal projects, culminate in the preparation of an *environmental impact statement*. The National Environmental Policy Act of 1969 (NEPA) requires that the environmental impact statement (EIS) be prepared by the "responsible official." In practice, such EISs by federal agencies are often based largely on environmental impact assessments (EIA) prepared by state and local governmental agencies, consulting firms, and other entities. The EIS is submitted to the Council on Environmental Quality (CEQ) and is made available to the public. The document does not require formal approval by the CEQ as a prerequisite to project authorization. It is, however, an important relevant information document that can be considered by federal legislators and agency officials in the process of reviewing legislation and specific plans. Nonfederal agencies, public interest groups, or individuals may also influence, delay, or otherwise affect project implementation by raising questions (at public hearings and in the legislative and judicial processes) concerning the adequacy and correctness of the statements.

The following points that must be covered in the EIS are elaborated on in CEQ guidelines (1973 and 1978):

1. A description of the proposed action, a statement of its purposes, and a description of the environment affected

2. The relationship of the proposed action to land use plans, policies, and controls for the affected area

3. The probable impact of the proposed action on the environment

4. Alternatives to the proposed action

5. Any probable adverse environmental effects that cannot be avoided

6. The relationship between local short-term uses of the environment and the maintenance and enhancement of long-term productivity

7. Any irreversible and irretrievable commitments of resources that would be involved in the proposed action should it be implemented

8. An indication of what other interests a consideration of federal policy are thought to offset the adverse environmental effects of the proposed action identified pursuant to paragraphs 3 and 5

Some of the eight points of the EIS may not be self-evident from the list above. Issue 3 covers both primary and secondary effects. The latter term refers also to indirect effects. As noted in CEQ's guidelines (1973, Sec. 1500.8): "Many major Federal actions, in particular those that involve the construction or licensing of infrastructure investments (e.g.,... water resource projects...)stimulate or induce secondary effects in the form of associated investments and changed patterns of social and economic activities. Such secondary effects, through their impacts on existing community facilities and activities, or through changes in natural conditions, may often be even more substantial than the primary effects of the original action itself. For example, the effects of the proposed action on population and growth...should be estimated if expected to be significant...and an assessment made of the effect...upon the resource base, including land use, water, and public services."

In considering alternatives to the proposed action, issue 4, the analysis should contain a "comparative evaluation of the environmental benefits, costs and risks of the proposed action and each reasonable alternative." The terms "comparative" and "reasonable" imply a degree of detail that is less than the full treatment of the recommended plan. In issue 6 concerning trade-offs between "short-term" and "long-term" effects, these terms "do not refer to any fixed time periods, but should be viewed in terms of the environmentally significant consequences of the proposed action." In considering issue 7, CEQ cautions that the term "resources" does not mean only the labor and materials devoted to an action, but also means the natural and cultural resources committed to loss or destruction by the action. Finally, for issue 8, it is stated that agencies that prepare benefit-cost analyses of proposed actions should "attach such analyses, or summaries thereof, to the environmental impact statement, and should clearly indicate the extent to which environmental costs have not been reflected in such analyses."

Social impact assessments have become an integral part of the water resources planning and evaluation process; in the United States, this is particularly since the National Environmental Policy Act of 1969. They are needed for virtually every federal water resources project and for many nonfederal projects. The scope for such assessments has been defined in legislation, rules published by government agencies, and manuals and special reports prepared for the agencies. In many studies, social impacts are assessed together with, or even as part of, the environmental impact assessment.

Social impact assessments can contribute to the planning process in many other ways, such as:

- To assist in handling the difficult methodological problems of assessing benefits and costs which are both monetary and nonmenetary and are thus not directly commensurate.

- To assist in the identification and estimation of water-based needs and the formulation of alternatives

- To improve ability to project the acceptability and costs of alternatives

- To reduce the number of alternatives considered in planning, and to make them more representative

- To assist public involvement programs

- To enhance ability to project conditions both with and without the project

- To complete the assessment of other social effects

- To define human and other non-property-based flood damages for the national economic development account

- To better project national economic development benefits for previously unemployed or underemployed labor

- To project construction phase impact and to suggest means of mitigation

There is also a need for public involvement in various stages of planning, including the feasibility report, and particularly in connection with social impact assessment.

The feasibility report must discuss how the project will be implemented and operated to meet institutional and legal considerations. There must be an organization, in place or proposed, that will manage the implementation of the project including financial management, construction and operation, dealing with beneficiaries, and all of the other functions involved in the management of an enterprise. This involves not only the organizational structure but details concerning personnel, equipment, and other resources needed.

All legal impediments to construction should have been cleared away. These may be related to land and water rights, compensation of those who are relocated or otherwise affected adversely by the project, and other matters of law. This may involve the enactment of new laws as well as the enforcement of existing ones. International agreements may also be involved.

6.4 Project Appraisal Process

Project appraisal is the process by which a reviewing authority determines whether a water resources project meets appropriate criteria for authorization and/or funding, or whether a regional plan meets appropriate standards for proceeding with implementation studies of one or more component projects. The analyses for the United States and other economically advanced countries may differ from appraisals of projects in developing countries that are subject to international lending agencies review.

Project appraisal emphasizes the *results* of planning rather than the *process* of planning, but of course the latter must be carefully considered when appraising recommended plans and confirming the validity of the rejection of alternatives. Planners in national, regional, and local organizations, should formulate their appraisal procedures while *conforming* to their institutional missions and incorporating specific considerations that apply to the conditions in their project and service areas.

In the United States, alternative plans by federal agencies have been formulated in consideration of four tests (Water Resources Council, 1983, p.7):

Completeness is the extent to which a given alternative plan provides and accounts for all necessary investments or other actions to ensure the realization of the planned effects. This may require relating the plan to other types of public or private plans if the other plans are crucial to realization of the contributions to the objectives.

Effectiveness is the extent to which an alternative plan alleviates the specified problems and achieves the specified opportunities.

Efficiency is the extent to which an alternative plan is the most cost-effective means of alleviating the specified problems and realizing the specified opportunities, consistent with protecting the nations's environment.

Acceptability is the workability and viability of the alternative plan with respect to acceptance by state and local entities and the public and compatibility with existing laws, regulations, and public policies.

6.5 Appraisals

This discussion is based largely on the appraisal guidelines of the World Bank in reviewing an application for a loan by a governmental or quasi-governmental organization in a developing country. Until recently, these guidelines, with their nearly exclusive emphasis on the national income objective, were not fully appropriate for project review for countries that may also place stress on other objectives such as environmental quality. Now, however, the World Bank has developed criteria to implement its concern with other impacts. This multiobjective broadening of the World Bank's criteria makes its procedures more generally acceptable than previously.

The following discussion has broad applicability, therefore, to water resources developments and to planning organizations in developing countries. An agency in a developing country submits a loan application in order to fulfill its responsibility to provide water supply, electricity, or other services to a particular area. At the same time, the World Bank is interested in determining whether the project is important to the regional or national economy and to the improvement of the general welfare and standard of living.

The following outlines concerns of importance to the World Bank. (For details on World Bank procedures, see King, 1967, Krombach, 1970, Baum, 1970, and

Baum and Tolbert, 1985).

Creditworthiness. Before any project presented to the World Bank for financing undergoes appraisal, the Bank assesses whether the terms and amounts of the loan (or credit) being applied for are within the limits which the country can reasonably be expected to service, taking into account all existing and future foreign debts. The Bank judges this based on its previous activities within the country and its contacts with the prospective borrower.

Scope of Appraisal. The appraisal of the project itself has usually involved a number of different aspects, including economic, technical, commercial, financial, institutional, organizational, and managerial aspects. More recently, there is an increased interest in the social and environmental impacts.

Economic Aspects. This appraisal determines whether: (1) the sector involved (e.g., agricultural, power, etc.) is a priority for the economic development of the country concerned; and (2) whether the project is of sufficiently high priority in this sector to justify investment in it. The first question should preferably be answered by reference to a study of the entire economy which has produced an overall economic development program including the identification of priority sectors and the requirements that are projected for goods and services in each sector. Often, however, such comprehensive plans either do not exist or are not reliable. Many projects are thus selected not with reference to an overall plan but rather to meet specific identified needs (e.g., to overcome a shortage of electric power), or to take advantage of identified special opportunities (e.g., to produce agricultural crops that have a ready market).

The second question should preferably be answered by reference to a more detailed plan for the specific sector in which the water resource project is placed (e.g., power sector, including thermal and hydroelectric alternatives) in which the projects have been compared in comprehensive economic terms. This implies the evaluation of benefits and costs, adjusted for accounting (shadow) prices if appropriate, the determination of indicators of merit such as the internal rates of return, and the comparison of these indicators with those of other investments in the country having comparable risks. Other economic aspects should also be considered when establishing an order of priority for the various projects. For example, a basic investment in a project with lower economic returns (or possibly no revenues) may set the stage for the development of projects with much more attractive returns. Other factors affecting priorities may include foreign exchange requirements and earnings of the project, and effects of the project in reducing unemployment or in improving health and distribution of income. The analysis also needs to take account of infrastructure costs that are not included as part of the project cost estimates, and also opportunities created by the project for related enterprises. For purposes of economic analysis, the Bank prefers that resources be valued in terms of their opportunity cost to the economy in their best alternative use, and claims that this central concept is applicable to all economic systems, whether market-oriented, centrally planned, or a combination of the two.

Technical Aspects. This appraisal involves a review of the detailed engineering plan for construction and operation of the project. In this connection, the World Bank not only carries out its own appraisal, but requires assurance that a qualified engineering staff has prepared the plan. The scale of the project should be suitable considering the possibilities for physical exploitation of the available site, the time expected for the demands for project services to increase to the project capacity, and the needs to conserve scarce capital. The location and layout of project features are reviewed for adequacy and appropriateness. The design criteria employed for preliminary plans and expected for subsequent detailed designs if the project is approved are also reviewed. The appraisal considers whether the proposed plan is the least cost or otherwise best solution among the alternatives. The construction schedule is analyzed for potential causes of delay. The underlying assumptions for the cost estimates are considered, and the estimates are reviewed to determine that they are complete and that they contain adequate contingencies (for omissions, physical contingencies, and price increases), allowance for interest during construction, and provisions for working capital. The projections of cost during operation of the project should be prepared for various levels of project usage. The Bank has found that a pervasive shorcoming has been to underestimate the cost of implementing projects as well as the time required, and that the cost overruns that ensue can have adverse effects on both the financial and economic viability of projects.

Commercial Aspects. This appraisal includes a review of the arrangements for buying materials and services needed to construct the project. In this respect, the World Bank insists on procedures to obtain best value for money expended, which normally involves competitive bidding, internationally if practicable. Consulting engineers can often be usefully employed to evaluate bids to take account not only of price but also quality, experience and reliability of the supplier, efficiency of the project, terms of delivery and payment, and other factors. The Bank's appraisal extends to the arrangements for obtaining the materials, power, and labor to maintain and operate the project, and the procedures for marketing the goods and services provided by the project. The Bank considers the management of the procurement process to be an important aspect of project implementation, since it can help to ensure the efficient execution of project by acquiring goods and works with the optimal combination of quality, price and delivery time. It can also promote such national goals as the development of local industry, the balanced regional development of industry, or the support of small-scale enterprises. The process should comply with the procurement regulations of any external lending institutions helping to finance the project.

Financial Aspects. This appraisal determines the soundness of the financial plans for both construction and operation phases of the project. The financing plan for construction must cover all the monies involved, the sources from which they will be obtained, and the amounts and terms for repayment of each loan. In addition to loans from an international agency such as the World Bank, monies may be obtained from banks within the country, from surplus funds made available from existing operations, and from governmental appropriations. A financial analysis must also be make of financial liquidity, projecting costs expected during the operation phase, and the revenues and other funds to pay such costs and to repay both foreign exchange and domestic loans. The financial return on the investment is also estimated if the project is revenue earning.

If the loan application is submitted by an ongoing enterprise, various financial statements will be reviewed, including those projected for the future in which the new project is integrated with other operations.

The Bank has found that more attention should be devoted to the system of prices and incentives and the performance of markets. Improvements in policies such as those on pricing, subsidies, and cost recovery, affect project performance and should consider the relationship of the project both to the sector in which it falls and the broader national development objectives. It has also found that a cost recovery policy should have three separate but related objectives: economic efficiency, income distribution, and revenue generation. It recognizes that difficult tradeoffs may be required among these sometimes conflicting objectives, and the poorer the country the more painful the choices may be.

Institutional, Organization, and Managerial Aspects. The World Bank reviews the organizational arrangements for construction and for operation. It wants to be assured that the organization functions in a businesslike manner and, in some projects, it has conditioned its assistance on the creation of an autonomous operating authority insulated from political pressures and rigidities of governmental administrative procedures. The Bank places particular stress on adequate management skills. If such skills are not fully available locally among engineers, accountants, lawyers, and other trained individuals, outside organizations or individuals may be needed, at least during the initial stages of operation and to provide management training to local personnel. Management tasks include the development and administration of rate policies, monitoring financial performance, and setting technical standards for operation. Training programs need to extend to both office and field operations.

The Bank has found (Baum and Tolbert, 1985, p. 582-3) that "there has been a tendency, fostered in part by external lending institutions, to assign responsibility for the management of projects in the public sector to special project implementation units established outside the regular line ministries. Such "enclave" units have helped to insulate project implementation from some of the bureaucratic, staffing, and salary weaknesses of the traditional ministries, thereby contributing in some instances to better implementation. But they have been without lasting institutional benefit, since they have operated under conditions that could not be replicated by the line agencies. Project implementation units should be confined to such special cases as projects that embody innovative or very large-scale activities. Even then, arrangements should be made to reincorporate the units as soon as possible into the agencies that bear permanent responsibility for such activities in accordance with a strategy for strengthening the capacity of those agencies." Baum and Tolbert (1985, p.590) discuss the parastatals and other forms of state-owned enterprise that have proliferated in recent years, their mixed performance in terms of efficiency, deficits, and political interference, and have observed that "given the preponderance of public enterprises in the economies of many developing countries, reforming them has repercussions going far beyond improved project performance."

Social and Environmental Analysis. The World Bank and agencies in the United States and other countries have developed in recent years improved methods to determine the social impacts of projects. The World Bank and other international financial agencies, and national and local government agencies in both economically advanced and developing countries, have developed an increased awareness of the environmental impact of projects and of the need to prepare environmental assessments so that enlightened decisions can be made when projects are rejected or authorized. Although the level of commitment of noneconomic impacts is understandably less in the poorer countries for whom water resource development is needed for survival and attainment of an acceptable standard of living, it is clear that societies are aiming toward balanced development considering "quality of life" as well as "quantity." In this context, quality of life comprehends not only the human environment and the ecological values relating to other forms of life, but also such aspects as aesthetics, cultural, anthropological, and historical values, and the restoration of waters and related land damaged by human activities.

As discussed by Baum and Tolbert (1985, p. 588), "the role of social analysis, which deals with the impact of projects on people, is to consider the suitability of the proposed project design to the people it is intended to serve, to make proposals for improving the "fit" between the two, and to fashion strategies for project implementation that can be expected both to win and hold people's support and to achieve project goals by inducing changes in social attitudes and behavior........A project that runs counter to or ignores the traditions, values, and social organization of the intended beneficiaries, or that is based on objectives which they do not share, has little prospect of success." Furthermore, they state (p.591), that "it is widely recognized that environmental analysis is necessary for a country to ensure the sound management and use of its national resources as an integral part of its strategy for economic growth.....Usually the poor are disproportionately affected by environmental degradation. The objective of environmental management should be to achieve a balance between human demands on the natural resource base and the ability of that resource base to meet these demands on a sustainable basis in the interests of future generations as well as those alive today... Analysis of the tradeoffs between different design features and their environmental impact should be a routine part of project work; the analysis is complicated, however, by the fact that the standard time -discounting methodology gives insufficient weight to environmental costs and benefits because of their long-term nature."

SECTION 7

MODERN PLANNING TOOLS

7.1 Introduction

Many sophisticated planning tools have been developed in the past several decades to improve the formulation and analysis of water resources projects. Some of these tools, such as mathematical models that simulate the operation of water resource systems, are primarily extensions of traditional engineering analyses that have become practical with the advent of powerful digital computers. Such models are utilized regularly and are being continually improved by researchers and practitioners. Other tools have been developed first for industrial or military applications and then studied by researchers in various academic disciplines before being recognized as useful for water resources planning.

The following subsections describe some of the tools that are available both to facilitate conventional water resources planning and to support the broader concepts of integrated water resources planning. All of the categories of planning tools covered in the following subsections are undergoing further development. In general, they will be used increasingly in the future as water resources planning continues to move away from the narrow focus of an individual project serving a specific need.

7.2 Forecasting Models

Forecasting models assist in estimating the need for project services. Furthermore, in order to measure the effects of a project, they can help to estimate future economic/demographic conditions with and without the project. Forecasts should be made for conditions at various points in the future, and from national, regional, and project area standpoints. Projections of population, employment, income, and other parameters may be useful for analyzing social, environmental, and institutional impacts; needs for supporting infrastructure facilities; and for other purposes.

Forecasting models may stress non-monetary objectives and may account for the preferences of the public, experts in technical fields, and political decision makers. This recognizes that few projects can be implemented unless they recognize *nonmarket* impacts and the perceptions of those affected by or interested in the projects.

The conventional engineering approach to forecasting is the extension of historical trends. For example, population changes result from births, deaths, and the difference between inmigration and outmigration. Population projections may be based on a time-series analysis of data for population as a whole or by considering each of the components of the equation. Extensions of historical trends by simple graphical extensions, or even by mathematical curve fitting techniques, do not recognize adequately that social, economic, and other forces change with time.

As discussed by Viessman and Welty (1985), *trend impact analysis* may be employed to add the effects of unexpected events to extrapolated historical trends. The procedure can be initiated by identifying all major events that might significantly affect the trend to be projected, estimating the probability of these events, calculating the impact of each event on the trend, calculating the combined impacts of all events on the trend by letting each event happen at each time step according to its chances of happening, and modifying the extrapolated trend at each time step by the net change occasioned by the impacts.

The Stanford Research Institute (Mitchell et al 1975, 1977) has classified forecasting models as time series and projections; models and simulations; and qualitative and holistic techniques. Trend extrapolation, which has been described above, is based in the analysis of time series. Other approaches with a substantial body of literature and adherents such as expert-opinion methods (panels and Delphi), scenarios and paradigms, decision trees and matrices, and games, are particularly applicable when future conditions may lie within a wide range and are thus highly speculative.

When *expert-opinion panels* are used, experts are brought together in open discussion to reach a consensus judgment concerning the future of a specified trend or project. Panels may be informal, ad hoc, one-time-only groups meeting face to face to hammer out a consensus. Many other variations are possible, including extremely formal, continuing groups which --as in *Delphi panels*--may never meet face to face. The Delphi technique differs from most panel techniques in usually maintaining anonymity of panel members, iteration of results with controlled feedback, and statistical group response. With Delphi, a panel of experts is asked to give their judgment on the future of specified trends or events. Responses are summarized and returned to the panel for reassessment of previous judgments. Several iterations are usually involved. Expertise may be equated with special knowledge about a topic, informed opinions about the attitudes and intents of some population, or both.

Scenarios are literary, numerical, and/or graphic narratives which describe and explore the implications of future sequences of events and states of affairs, given some specified topic and some set of explicity or implicit premises. It is basically an outline of one conceivable state of affairs, given certain assumptions about the present and the course of events in the intervening period. It is important to note that scenarios usually are "portraits of possible futures" rather than predictions of what will come to pass. The development of scenarios requires a large fund of data, information, and ideas pertinent to the topic. It also requires writers who can devise relatively smooth and plausible accounts in rich detail dependent on scattered, disparate, discontinuous individual forecasts.

Paradigms are similar to scenarios. A paradigm is different in that it shows side by side the characteristics and implications of various futures, such as those which might be developed in a scenario. They can be used to analyze various sets of ideas on a comparative basis. A paradigm may have a special structure and functional notation that enables new concepts to be logically derived from a previous part and that provides for systematic cross-tabulation of concepts.

Decision (or issue) trees represent the structure of all possible sequences of decisions and outcomes and provides for cost, value, and probability inputs. Trees are used mainly to evaluate alternatives and determine the sequences of decisions that should be used to pursue planning goals. Probabilities of occurrence and values are assigned to each of the possible outcomes. The optimum decision is usually found by selecting the alternative of highest expected value, but other bases (e.g., minimax) are also possible.

Another use of trees is in relevance trees. This is a systematic decision-making aid in which weighted indexes based on consensus expert judgment are used to indicate how closely related (relevant) given technological capabilities are to specified needs. Needs may be specified generally (e.g. nationally) or at one or more levels of successive detail, with relevance index numbers assigned at each level. The output is a relevance tree diagram, showing the technological capabilities analyzed, together with the names of the levels or sectors for which relevance index numbers have been estimated, and the index numbers themselves.

Decision matrices are conceptually an extension of decision trees. When two basic kinds of factors (e.g., resources versus requirements) are crucial, a two-dimensional decision table is used. When three kinds of factors are crucial, a three-dimensional cube is employed. A variety of quantitative and qualitative procedures are used to specify each interrelationship among all the factors considered.

Games are simulation activities involving two or more decision makers playing assigned roles seeking to achieve role-related objectives in some limiting concept. They facilitate learning about the subtle consequences of actions, the development of scenarios, and the assessment of policy options. Good decision-making games combine the analytical, rational, technical point of view with the intuitive, artistic, "seat-of-the-pants" experience of decision making in the real world.

Through multiple iterations of a particular game, alternative scenarios can be devised for the situation under study (e.g., initial assumptions, timing, roles, etc.). The game may be based on historical or hypothetical case studies. Policymaking in a particular situation usually calls for a unique game to be designed. Ideally, the participants in a game will be those directly involved in the decisions to be made. Several rounds of play may be involved (e.g., one round equals one year). There are three main results:

- Learning of the participants
- Alternative scenarios of development (forecasts of alternative outcomes that incorporate the softer, nonquantifiable variables)
- Evaluation of alternative actions

A field of operations research, called "game theory," deals with competitive situations in a formal, abstract way, and places particular emphasis on the decision-making process of the adversaries. The bulk of the research on game theory has been on problems involving only two adversaries or players (armies, teams, firms, etc.). In this respect, game theory is different from the simulation games described above, which involve an average of 10 to 30 players with different personal and institutional points of view.

Concepts of game theory have been investigated for their applicability to water resources planning problems in which tangible and intangible effects are viewed differently by various interest groups.

7.3 Economic Planning Models

The traditional approach to water resources planning involves a description of the existing economic structure in the region influenced by a project or programme; the identification and analysis of growth forces; and projections of economic growth in terms of population, labor force and employment and personal income. It also projects trends in the principal economic sectors such as agriculture and manufacturing. Projections should be made that facilitate translation into water requirements and other water resources development needs. In most cases, these studies involve the collection and tabulating of extensive amounts of data, and relatively unsophisticated extrapolations based on historical trends with some attention to potential changes in underlying growth forces.

A model based on relatively straight-forward cause-and-effect relationships, and specifically taking account of project impact on population and community services was developed for the U.S. Bureau of Reclamation (Mountain West Research, Inc. 1978). The BREAM model evaluates the consistency of the labor supply projections obtained from analysis of the area's economy. In the event that the supply and demand for labor are not in balance, adjustments are assumed to occur principally by migration, although some change in the number of employed can also be expected. Once equilibrium is achieved in the labor market, no further migration occurs and levels of population, employment, and income are established for each statistical unit (county) in the local impact area. The model then disaggregates the county population projections and allocates them to the communities within each county.

The model accepts user supplied inputs based upon the characteristics of construction workers expected to be needed. The model then analyzes this data, utilizing five interrelated analytical submodels: construction worker, demographic, labor market, economic, and community allocation. Once equilibrium has been established in the local labor market, population, employment, and income are allocated to communities within each county. School age population for each community is also allocated and the estimated number of households is determined. The population is allocated by component of population change, which allows different allocation schemes to be used for natural increase (births minus deaths), retirement migration, employment-related migration, and migration of nonlocal construction workers.

A number of concepts and techniques are available for evaluating the economic impacts of investments in water resource developments. These methods include: econometric models, export/economic base models, multipliers, simulation/dynamic models, input-output models, and comprehensive economic planning models. Some of these methods are more successful than others in capturing the income effects of a project. The methods generally consider the impacts of public investments on the existing economic structure; linkages may, however, occur in both the forward and backward directions.

The methods provide information for improving the estimates of demands for products and services of water resources projects. They are also useful in estimating the direct and indirect economic effects of projects. Such analyses can be used together with the more customary estimates of population and water needs and economic and financial analyses to formulate and justify projects. Evaluations of economic impacts are considered together with other assessments (financial, environmental, social, legal, political, etc.) in the complex process of decision making.

The methods, to a varying extent, recognize that public investments can *create economic and physical conditions that induce additional economic growth.* The Office of Appalachian Studies (OAS) of the Corps of Engineers in its Appalachian Water Resources Survey (U.S. Department of the Army, 1969) developed methods which attempted to estimate the total change of income due to a project. The economic analyses made for the Appalachian region are discussed in subsection 2.3.

Income and employment analyses do not always distinguish between net national accounting and regional accounting, which can include regional transfers. Differentiations are sometimes not made for analyses in developing countries but are usually required by government planning agencies in industrialized countries such as the United States.

The applications of economic growth models to water resources projects are limited, and this is a developing field. Further details and applications are contained in the publications of professional planners and economists. For more advanced treatment of some of the methods, the reader is referred to a comprehensive survey of economy-wide planning models for developing countries sponsored by the World Bank (Blitzer et al. 1975).

An *econometric model* is composed of equations that are used to forecast economic indicators, such as population, employment, income, or capacity of a specific industry that will locate in a specific area. The equations are "best fit" equations that relate a dependent variable to one or more independent variables, by statistical techniques. The equations are derived by *regression* analysis and are studied in terms of their reliability by *correlation* analysis. Their suitability for forecasting depends on the amount and quality of data on which they are based. Furthermore, if the relationships are not expected to hold in the future because of substantial changes anticipated in the structure of the economy, this introduces additional complications. The econometric model may be most useful for short-range forecasts.

The equations are determined by "calibrating" or "fitting" them to historical data. Projections can then be made about the effects of new developments in the region by assessing these effects on the variables in the equations.

A number of studies have applied regression analysis to indicators of economic growth. A study by Cicchetti et al. (1975) estimated the effects on regional economic growth in five states in the southwestern United States of the water resource projects of the U.S. Bureau of Reclamation over the period 1940-1970. The empirical results of their analysis indicated that water investments have an impact on regional economic growth and that the extent of the effect depends on the nature of the investment, the state of the regional economy, and the amount and nature of other investments in the region. Equations were developed that took account not only of the Bureau variables but also of non-Bureau public expenditures for education, health, fire and public services, and highways.

Export-base theory assumes that the economic growth of an area occurs principally as the result of industrial and commercial activities that produce, transfer, and distribute good and services that are exported outside the area itself. A broader use of the concept (Chalmers and Anderson 1977) refers to *basic* activity as activity determined by forces external to the area in which it occurs. The relevant distinction is not the location of the purchaser (as is connotated by the term "exports"), but whether the purchase decision is motivated by forces internal or external to the local economy. Thus, basic activities would include not only activity associated with exported commodities (agriculture, mining, and manufacturing), but would also include tourist-related activity, some federal or state government activities and employment at universities attended largely by nonlocal students. Activities that service basic industries can be categorized as basic if the level of activity is largely determined outside the area. Activities can also be classified as partly basic and partly nonbasic.

The methodology consists of quantitative division of activities into basic (export, exogenous) activities and nonbasic (service, endogenous) activities in terms of their respective employees; estimating future growth of the basic activities and employees; estimating total future employment by applying a ratio of total to basic employment; and estimating total future population by applying a ratio of population to employment. Existing and future income can be computed in a parallel way by applying appropriate unit income per employee in basic and nonbasic activities.

The foregoing employment and income pictures are somewhat oversimplified. Existing ratios of total to basic employment and of population to employment should be adjusted for future conditions if they are expected to change. Further refinements may be made in estimating income effects.

Chalmers and Anderson (1977) assess the impact of a project as the change in basic activity associated directly with the proposed action plus the indirect or induced effects caused by the change in basic activity. The most common method used to estimate the relationship between direct and indirect effects is a simple multiplier approach that uses the ratio of total activity to basic (export) activity and applies this to the change in basic activity associated with the project. The result measures the total employment impact expected, which can then be used to generate estimates of changes in other variables. For assessments they surveyed, simple employment multipliers of this type varied from 1.2 to 3.9.

Lewis and Glover (1982) developed a more advanced "linear programming/economic base" evaluation model to study the regional development impact of a waterway project. This model is based on "location theory" and optimizing the behavior of users of the waterway.

Multipliers are used by themselves and as elements of mathematical models based on input-output and other concepts. For example, when a consumer receives an additional income (Y) of $1.00, he or she will allocate this money to consumption (C) and savings (S). If his or her "marginal propensity to consume" (mpc) is 0.9, the person will spend $0.90 and save $0.10. The $0.90 the consumer spends will be regarded as income by the receivee, who then will proceed to spend $0.81 and save $0.09. This process will continue until total savings equals the original injection of income.

The multiplier (k) is equal to 1/(1-mpc) which for this illustration, is equal to 10. Thus, $1.00 of income has an effect of $10 on the economy. This is an oversimplification. A portion of the new income in the area may "leak" out; if this is 50%, the Δ Y becomes $5. Furthermore, although $5 may be a fair value for the region, the nation will benefit only from the productivity of nationally underemployed resources and not from income transfers, and could be much lower.

The multiplier demonstrates the manner in which a change in investment, working through consumption, will produce a multiplied change in income. In more general terms, the multiplier may be stated as a technique for demonstrating how a change in a component of a time series, by working through another variable, will produce changes in that time series. The multiplier concept was utilized in connection with the previously described BREAM model of the U.S. Bureau of Reclamation, to estimate employment and income multipliers.

Many economic models are concerned largely with the impact of public investment on the existing economic structure. As such, they may not recognize the full potential for increased income throughout a region. This can be conceptually achieved by the assumption of a *multiplier/accelerator* effect. The accelerator concept assumes that the change in income of the beneficiaries of public investment will cause existing private investment to be used more intensively or, more significantly, will cause the demand to rise for new private investment. Public investments may either change the comparative advantages that a region has, or create a means to use an existing comparative advantage by removing inhibiting costs (e.g., due to flooded land). The two aspects of induced investment are: (1) the provision of a source of employment and income now; and (2) the establishment of an institutional framework which will, in the future, be the basis for sustained growth and a more extensive use of economic resources.

Simulation modeling begins with a conceptualization of the system which can be accomplished by means of a diagram of "links" (flow paths) and "nodes" (reservoirs, levels). In the context of a socioeconomic model, the nodes represent population, income and other demographic and economic characteristics, and physical variables with which they may be related. The links represent the relationships between the nodes, which are usually expressed in mathematical terms. "Feedbacks" may also be shown in the representation, due to the cause-and-effect relationships from a given variable back to itself. The exercise of identifying the elements and graphically tracing out the relationship is useful for shedding light on the issues involved and highlighting problems. These models can be used to study the effects of urban-rural migration, interrelationships between changes in the economy and project services, and other important economic effects.

Input-output (I/O) models are widely used by central planning agencies for macroeconomic analyses of national economies. These are impact studies in which economic projections and structural relationships among disaggregated industrial sectors are pursued. Since the publication of the input-output analysis by Leontief in 1936, the development of interindustry economic analysis has been significant in both theory and empirical applications. The concepts of input-output techniques have also been employed for water resources planning applications.

As outlined by Kim et al. (1977) and Kim (1985), there are several alternative I/O models: national, regional, interregional, and international. Depending on the extent of impact to be measured, the model can also be classified into open and closed categories. An open model provides only the direct and indirect impact of a given investment. With a closed model, one can extend the measurement of the impact induced by the increase in consumption expenditures resulting from the increase in an output. Coefficients describe the relationships between sectors. Three regions and 28 subareas were employed in the Appalachian Water Resources Survey. The I/O model was built up from national input-output coefficients and estimates of interregional trade. The national coefficients were disaggregated for Appalachia on the basis of estimates of interregional trade in the Appalachian region for which surveys and statistical models were used.

Another study by Kim et al. (1977) analyzed the economic impact on local and national economies, in terms of output and income resulting from construction expenditures of the McClellan-Kerr Arkansas River Multiple-Purpose Project. The principal elements involved were: (1) construction of an interregional I/O model; (2) conversion of MKARMPP costs into regional final demand sectors; (3) estimates of direct and indirect and induced construction impact of the MKARMPP in terms of output and income; and (4) sensitivity analysis of the model. Basic data required for the model included: (1) regional technical coefficients; (2) trade coefficients; (3) regional household income and expenditure coefficients; and (4) regional final demands.

The direct, indirect, and induced impact per $1000 project cost was estimated to bring $5780 of output or $1851 income on the national economy. Of this amount about one-third of the output and one-half of the income were estimated to be shared by the region around the project. Related studies determined the variation of these quantities with the type of project civil works.

The study outlined above estimated the short-run construction impact of a project. Another study of the same project by Liew and Liew (1982), used I/O analysis to estimate the long-run impact.

Comprehensive planning models may employ a variety of export economic-base, multiplier, input-output, and accelerator concepts. The Upper Licking River (Salyersville-Royalton area in Kentucky) was subjected to a case study by Spindletop Research (1967), which involved development planning and estimates of expansion (total income) benefits. There were five principal features in this model for estimating expansion benefits.

- Identifying preliminary development opportunities available in study area

- Providing development framework areas where development is most likely to occur, and the water-related and other bottlenecks that have hindered or prevented development in the past

- Providing service employment multipliers

- Computation of wage expansion benefits

- Computation of induced investment

7.4 Water Resources Models

7.4.1 *Introduction*

Mathematical models can be used to generate alternatives for the planning process and to compare competing alternatives. The next subsection will briefly describe a number of models that provide solutions based on optimization of a specific objective, usually monetary, such as least cost or maximum net benefits (benefits minus costs). This will be followed by a subsection dealing with the evaluation of alternatives when multiobjectives are considered, in which it is often necessary to consider societal preferences.

The mathematical model has become an essential tool in modern water resources planning and management. The analysis of mathematical models has been greatly facilitated by the availability of powerful electronic computers, principally of the digital type. Such computers often permit the solution of problems that would be otherwise be impossible to analyze, except crudely, by other means. The methodologies in this section focus on planning and management issues such as the allocation of scarce resources (particularly water and money) and the determination of the appropriate scales (sizes) and operation policies of projects that are economically efficient. Engineering problems that have a large engineering design content are not discussed, although they are widely used for analysis and optimization.

7.4.2 *Analysis of Alternatives - Single Objective*

These methodologies seek values of one or more variables (decision variables) corresponding to the minimization or maximization of an *objective function* incorporating these variables. For minimization the function is usually in terms of cost or other scarce resources. For maximization the function may be in terms of net benefits or other economic parameter. The formulations also accomodate limits or *constraints* on water, manpower, land, and other resources and/or project outputs (such as amounts of specified crops.) The constraints may be specified to be greater than or less than specified resources (inputs) and/or outputs. Solutions involve systematic procedures known as *algorithms*.

Linear Programming and its offshoots are probably the most widely used methods of operations research in industry and business and are often applied in certain areas of water resource planning (e.g., agricultural studies). They are suitable for problems in which it is desired to allocate scarce resources among various activities in an optimal manner. The following formulation describes the basic version of linear programming (LP), in which all functions are in linear form. Other formulations that have a structure similar to that of LP but that can handle nonlinear and other special forms of the functions are also amenable to solution.

An objective function shown in the first line below, is to be optimized (maximized or minimized) subject to the various constraints shown by the equations below this function, for all non-negative values of x:

$$Z_x = c_1x_1 + c_2x_2 + \cdots + c_nx_n$$

$$\begin{aligned}
a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n &\leq b_1 \quad (\text{or} \geq b_1, \text{ or} = b_1)\\
a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n &\leq b_2 \quad (\text{or} \geq b_2, \text{ or} = b_2)\\
\vdots \qquad\qquad &\quad \vdots\\
a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n &\leq b_m \quad (\text{or} \geq b_m, \text{ or} = b_m)
\end{aligned}$$

The input data include all the constants (a and c) and amounts of the resources (b) and the values of the variables (x).

Dynamic programming (DP) is a mathematical technique that is often useful for making a sequence of interrelated decisions where nonlinearities in the objective function or constraints are present. It provides a systematic procedure for determining the combination of decisions which maximizes overall effectiveness. There is no standard mathematical formulation for dynamic programming, and general DP computer codes are usually not available. The procedures are not difficult, however, and a computational code can be written for each application. Although there are similarities in the construction of various DP problems, the specific approach and the necessary equations are tailored to suit the actual conditions.

Simulation models are often used to study complex river development systems. A series of linked equations include assumptions concerning the scale (size) of features and operation rules of each project. Flows are routed through the system, based upon historical or synthetic sequences, following specified operating rules, and hydrologic and/or economic results are tracked. Depending on the results from the computer runs, the planner can adjust the scales and operating rules. By a number of iterations, satisfactory selections are established.

Theoretically, the number of combinations of variables may be very large and the computational burden can easily become excessive. The trial-and-error or enumeration procedure is often controlled by a preestablished algorithm, usually of the *search technique* type that optimizes according to some objective such as net benefits. For practical large and complex water resource systems, the approach must be largely experimental since the variables may not be related by smooth mathematical functions or structure. Also, instead of a clear-cut objective function, components of the objective(s) may be reflected in the operating rules for the facilities, in the constraints, or in noneconomic elements of performance (e.g. hydrologic reliability). When an automatic search technique is not practical, the water resource planners examine the results of each computer run and make adjustments of scales and operating rules, based on their experience and judgment.

Linear programming, dynamic programming, and simulation are the most popular optimization tools in water resources planning. Other methods include integer, parameter, chance constraint and stochastic linear programming; nonlinear programming methods, network analyses, queing models, and transportation problems. Flows may be historical, simulated, and subjected to stochastic hydrologic analyses.

7.4.3 *Analysis of Alternatives - Multiobjective*

Subsection 4.6 described the general structure of interrelationships in a river system studied for the United Nations. This provides a good example of an optimizing process based on two objectives - hydrologic reliability and economic performance.

The principal planning considerations that influenced plan formulation and the scheduling of projects were: economic sector development (agricultural, industrial, electric power); balanced regional development; engineering and economic feasibility; and financial implications. These considerations motivated the arrangements of projects, their controlling dimensions, and operating requirements. Thus, to a large extent, the considerations (which were similar to "objectives") were embedded in the procedures that led to the plans that were tested in an overall systems context.

A large simulation model known as MITTAMS (and its extension which encompassed surface/groundwater relationships) was used to confirm and "fine tune" the master plans. The general approach was to prepare a set of inputs for specified project arrangements and operation rules as the basis for a computer run. The run provided output in terms of hydrologic and economic performances of each reservoir and each water-using project. Some 150 reservoirs, projects, and stream locations where quality was monitored, were analyzed in a single run. The results were examined by the planners who made adjustments in the input designed to improve hydrologic reliability and/or economic performance of the projects, and this revised input was the basis for another run. The large number of projects and their complex and often nonlinear relationships made it impractical to develop an algorithm to analyze output automatically and revise the input for successive runs.

Hydrologic reliability was determined as the percentage of time that water quantity targets were met for each project. All runs were made for 1-month intervals and reliability computations for all projects were in terms of percent of months except for irrigation projects, where annual failure was taken to be an inadequate water supply for any month in the irrigation season.

In the definition of reliability above, no account is taken of the magnitude of the shortages. The seriousness of a shortage was reflected in a penalty that reduced benefits, computed by means of a "loss function" defined for each type of water use. Economic indicators valued by the model were benefit-cost ratio, discounted net benefits (benefits minus costs) for 50 years of operation, and internal rate of return (for power and irrigation projects only).

The preceding subsection presented the broad concepts of linear and dynamic programming and referred to other mathematical programming techniques, as applied to problems involving a single objective. These methods are also applicable to multiobjective/multipurpose problems. Objectives considered may include economic objectives from national and/or regional standpoints, or environmental and social objectives. These objectives should be quantitative, but not all need to be expressed in monetary terms.

Any approach involves tradeoffs between two or more objectives, based upon expressions of the preferences of society, usually but not always in mathematical form. Conceptually, the problem involves optimization according to a multidimensional objective function written in terms of the multiobjectives, that does not violate a set of constraints. Strictly speaking, such a function, or *vector*, cannot be optimized but the algorithm selected seeks a "noninferior" solution, also referred to as a "Pareto optimal" or "efficient" solution. This extension of a basic concept of classical economics ensures that, with this solution, no increase may be obtained in any objective without causing a simultaneous decrease in at least one of the other objectives. The non-inferior solution which society considers best is the "preferred", "best", "best compromise", or "optimal" solution to the problem of vector optimization.

Mathematical programming techniques have been classified by Cohon and Marks (1975) and reviewed by Goodman (1984) in the following categories: generating techniques that identify only the noninferior set; techniques that rely on prior articulation of preferences; and techniques that rely on progressive articulation of preferences. Among these techniques are goal programming, multicriterion ranking (ELECTRE), multiattribute utility theory, and the surrogate worth tradeoff method.

There are also a number of approaches that emphasize objectives that are not quantifiable in monetary terms. These include *metrics* that scale the impacts of complex policies, *weighting schemes* that aggregate scores on separate dimensions into a total score for each policy alternative, a *balance sheet* that presents the impacts of a project in summary form and other *discrete dimensions evaluations* that do not have a set of weights or a total score, methods that utilize *public or political evaluations*, and other methods that take nonmarket impacts into account. The *forecasting models*, referred to in subsection 7.2, such as expert-opinion panels, scenarios and paradigms, decision trees and matrices, and games, are also suitable for considering multiobjectives including nonmonetary objectives.

7.5 Environmental and Social Planning Models

7.5.1 *Optimization Models*

Water quality management may represent a suitably important and representative category of problems for discussing the problem of optimization. Applications of linear programming, dynamic programming, and simulation analyses may be considered for the problem of designing the least-cost wastewater treatment system, for which the locations of point sources and the water quality standards in all river reaches are specified. This and other types of water quality management problems include consideration of stream, lake, or estuary dynamics. Models that trace the physical and quality characteristics of such water bodies may be combined with economic optimization models that utilize the operations research techniques discussed in the preceding subsections.

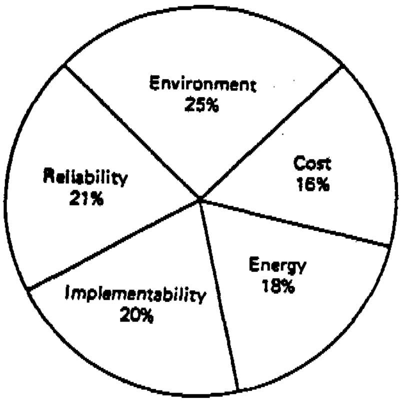
The following is a list of alternative methods in water quality management, which may be considered singly or in combination: (1) remove a portion of the biochemical oxygen demand (BOD) and other pollutants prior to discharge to receiving waters; (2) change the quantity and/or strength of wastewaters by process changes by the producers of waste or by pretreatment; (3) store a portion of treated wastewater and discharge it when the assimilative capacity of the receiving water body is more favorable; (4) use pumping and piping to move wastewaters, either prior to or subsequent to some treatment, to other locations for additional treatment and/or disposal at sites having greater waste assimilative capacities; (5) reduce the cost of treatment by taking advantage of the larger scale of regional treatment plants, even though the costs of wastewater collection may be increased thereby; (6) use flow augmentation from reservoirs to increase dilution and assimilative capacities of receiving waters; (7) use artificial aeration devices to increase assimilative capacity of receiving waters; (8) control pollution from storm water discharges, through storage, treatment, and other measures; (9) control pollutants from nonpoint sources (e.g., agricultural, land, organic wastes from animals, pesticides); (10) land management that affects erosion and sedimentation, dredging and filling operations, etc; (11) control contamination of aquifers from oil and other polluting materials, seepage from land fills and septic tanks, etc.; (12) consider modifications of water body use classifications and water quality standards; (13) develop institutional methods for sharing costs, taxes, effluent charges, etc.

The application of systems analysis (operations research) techniques in water resources planning may be illustrated for a class of problems in the field of water quality management. These problems involve the selection of a set of wastewater treatment plants in a region so that the cost of treatment is minimized while satisfying water quality criteria for receiving waters. This problem has been solved using the methods of linear programming (Loucks et al., 1967), dynamic programming (Liebman and Lynn, 1966), and simulation (Goodman and Dobbins, 1966).

Another approach which involved many alternatives and multiobjectives was utilized by Phillips (1978) to evaluate alternatives in Nassau County, east of New York City. Five objectives were considered; cost, environmental quality, reliability, implementability (as related to institutional and other factors), and energy utilization. The study was carried out in two phases. It was determined that the number of possible alternative diversion and treatment combinations was over 600,0000. In Phase One, a mixed-integer programming screening model was used to reduce the large number of alternatives down to a manageable number based on cost; in this phase environmental quality constraints limited the number of alternatives considered. Phase Two utilized a three-step approach to evaluate further the screened alternatives. Step 1 used a questionnaire to estimate societal preferences for the selected objectives. Step 2 performed a technical evaluation of each alternative based on how well it satisfied each objective. Step 3 combined the results of Steps 1 and 2 to generate a ranking of the final alternatives.

Following the formulation of a least-cost plan in Phase One corresponding to the mixed-integer programming solution, sensitivity analyses were carried out varying the degree of treatment, the replacement of equipment at old plants, and incorporating new areas into the management plan. As a result of these studies, additional plans were formulated and four alternatives were subsequently selected for evaluation in Phase Two.

The results of Phase 2, Step 1, based upon interactions with three groups whose interests span environmental planning to economic growth, provided weights for each of five objectives - cost, environmental impact, reliability of the works, implementability, and energy consumption of the facilities. These are shown together with the structure of the objective function and the multiobjective decision matrix for evaluating alternatives on Figure 7.1.



Objectives	Alternatives 1	2	3	... m
1	$(W_1)V_{11}$	$(W_1)V_{12}$	$(W_1)V_{13}$	$(W_1)V_{1m}$
2	$(W_2)V_{21}$	...	...	...
3	...	...	...	...
4	...	...	...	...
5	...	...	...	$(W_5)V_{5m}$

$$I = \sum_{i=1}^{n} W_i V_{ij}, \text{ where } j \text{ varies from 1 to } m$$

n = number of objectives (five in this case)
m = number of alternatives
W_i = weight of importance the citizen places on objective i (dimensionless)
V_{ij} = relative value of alternative j in fulfilling objective i

Figure 7.1 Multiobjective Decision Matrix
(Source: Phillips, 1978)

7.5.2 *Environmental Impact Assessment Formats*

Subsection 6.3 has described the contents of the Environmental Impact Statement document used in the United States to describe and analyze a proposed project with respect to its environmental effects. This is a rather complex and extensive document which is too involved and expensive for comparing alternatives at any stage before reaching the final feasibility analyses. For most purposes, less comprehensive environmental assessments are adequate and appropriate. In the United States, such assessments often provide input to the more formal environmental impact statement.

The United States Water Resources Council issued a series of Principles and Guidelines in 1983 which included the preparation of a sequence of 10 tables for identifying and evaluating in quantitative and non-quantitative terms the existing environmental conditions, their trends, and changes over time in environmental quality with and without a project. Environmental quality was defined in terms of *attributes* which are the ecological, cultural and aesthetic resources that sustain and enrich human life. Environmental quality *resources* are natural or cultural forms, processes, systems, or other phenomenons that are related to land, water, atmosphere, plants, animals, or historical or cultural objects, sites, buildings, structures or districts and have one or more environmental quality attributes.

Checklists evaluate the "without" and "with" environmental quality in terms of scores that can be used for comparative evaluations of alternatives for one project or for comparing different projects. In the Environmental Evaluation System developed and tested for the U.S. Bureau of Reclamation (Dee et al., 1972), evaluations are in terms of Environmental Impact Units (EIU). A hierarchical structure considers the environmental impacts in four categories - ecology, environmental pollution, aesthetics, and human interest, and assigns a number in the system which does not vary from project to project indicating its relative importance; these Parameter Importance Units (PIU) total 1000. Based upon environmental examinations, a score is assigned to each environmental parameter expressing its environmental quality (EQ) on a scale of 0 to 1, with a higher value indicating better quality. Each alternative is given a total score by assessing each of the environmental parameters as follows:

$$EIU = PIU \times EQ.$$

Matrix analyses are quite commonly used to compare alternatives. One approach was described in the preceding subsection 7.5.1. Another was developed for the U.S. Geological Survey (Leopold, et al., 1971) and was referred to as an "information matrix". The matrix identifies 88 "existing characteristics and conditions of the environment" on a vertical axis and 100 "proposed actions which may cause environmental impact" on the horizontal axis, thus producing a grid with 8800 boxes. Each significant interaction between a proposed action and the environment is identified and their intersection corresponds to a box in the grid. Within this box, a number from 1 to 10 indicates the relative "magnitude" of the impact, and another number from 1 to 10 indicates the "importance" of the impact, with 10 representing the greatest impact and 1 representing the least.

The U.S. Bureau of Reclamation (1979) has developed another method suitable for comparing the environmental quality effects of a project or programme, utilizing a table rating the effects of an alternative in a number of environmental categories related to air, land, and water; biological resources; ecological systems; and historical and archeological resources. Each category is given a "category rank score" ranging from 1 to 4 based upon (a) uniqueness in project area; (b) vulnerability to impact; (c) ease of mitigating impacts; (d) value to regional society and (e) contribution of existing condition to diversity within the category. "Impact statements" for the various alternatives are developed by ranking on a +3 to -3 scale, the impact of an alternative on the specific environmental category being evaluated. The "effect of plan" is obtained for each alternative and environmental category by multiplying the "impact statement" by the "category rank score" (ranging from -12 to +12), and totalling these values.

There have been a number of modern approaches employing public involvement (PI) and techniques of conflict management (CM), designed to consider environmental quality and social objectives in the planning process. As discussed by Delli Priscoli (1989): "Engineers, scientists, and even some social scientists prefer to look at water resources planning and management as primarily analytical. However, more and more of the water professionals' analytical work depends on people-oriented techniques either to relate their activities to outside interests or to build better internal team relationships. Frequently, the major problems that engineers and scientists face are not technical. They are problems of reaching agreement on facts, alternatives, or solutions. Public involvement and conflict management techniques are keys to servicing such needs....Techniques of PI and CM can be viewed along a progression of having knowledge about a decision; being heard before the decision; having an influence on the decision; and, agreeing to the decision. This is really a degree of consensus continuum. Obviously, agreeing to the decision among all professionals and interested parties is not always necessary. Sometimes, only knowledge about a decision is required. The right portion of the continuum, toward negotiation and arbitration, represents those techniques most associated with conflict management. As we move to the left toward public information, traditional public involvement techniques are represented. Actually, CM and PI are different sides to the same coin. Indeed, it is becoming more difficult to differentiate between CM mediation and PI facilitation. Generally, conflict management techniques more explicitly emphasize consensus building and power sharing, while PI focuses on information exchange and discussion. Both PI and CM seek to increase the legitimacy and acceptability of decisions. They are designed to create incentives for reaching middle ground and to move away from polarization. These techniques attempt to increase the probability of implementation. Both emphasize bringing the parties of interest together to build alternatives and agreements around interests and values."

7.5.3 *Social Impact Assessment*

Social impact assessments have become an integral part of the water resources planning and evaluation process in the United States. They are needed for virtually every federal water resources project and for many nonfederal projects. The scope for such assessments has been defined in legislation, rules published by government agencies, and manuals and special reports prepared for the agencies. In many studies, social impacts are assessed together with, or even as part of, the environmental impact assessment. As discussed in other parts of this report, the social impacts of water resources development are increasingly being evaluated for other countries and particularly for the developing countries. Social impact assessments have contributed to the planning process in many other ways, as discussed in subsection 6.3.

A water resources project is more than a physical phenomenon--it is an intervention into a social system. Technology can be applied by a project to increase the resilience of the social system or to mitigate the effects of natural events on that system. Social assessment assists the planning process to profile this dynamic system, project future states with and without the project, and identify and evaluate the impact of the project.

In the United States, social assessments have proved most useful in designing nonstructural flood control alternatives, identification of stress on community infrastructure services and designing measures to mitigate such stress, interpretation of public involvement information, design of relocation measures, improvement of projections, and improvement of techniques for estimating benefits. Twelve generic social science tools, old and new, are increasingly favored by various water resources agencies. These are:

- Institutional analysis
- Policy profiling
- Value mapping
- Social profiling
- Content analysis
- Small group processes techniques
- Human cost accounting
- Community impact assessment
- Ethnographic field analysis
- Questionnaire and nonparametric statistical analysis
- Population projections
- Trends and cross impact analysis

Although many of these tools have long been available, their applicability to water resources projects has been more relevant in recent years. Their application by social scientists from disciplines other than traditional economics has permitted the broadening and improvement of social evaluations.

Institutional analysis, policy profiling, and value mapping are methods, not utilizing a questionnaire, for assessing social acceptability of project proposals. Taken together, the procedures can yield information on implementation outlay costs, on cost-sharing arrangements, and on the special institutional agreements that are necessary for each alternative. Policy profiling is a technique for assessing the opinions of various individuals, groups, and organizations of decisions that affect a project. It is most useful in situations where a small group of professionals must either reach a decision or assess the impacts of decisions on an external political--social environment. Based on common sense and political science principles, the technique simply guides individuals through a systematic thought process, records their perceptions at crucial steps in the process, and produces a net political assessment number that reflects the group's subjective judgment of the feasibility of actions. Among other uses, it has been a quick way to "red-flag" controversial water quality permit problems from among several potential decisions. Value mapping is a generic term for value identification, display, and trade-off analysis. Improved techniques in these areas are the key to understanding relative deprivation perceived by those affected by water projects, facilitating trade-offs, and increasing planning efficiency by focusing on measures of high probable acceptance.

Social profiling has been the most visible social impact assessment activity. Agencies have sought to move beyond traditional census data "dumps", to focus on the social data gathered. Since information on public values is rarely organized in ways that are compatible for water resources planning, much of it has not been fully utilized. The content analysis technique allows planners to routinely and cheaply analyze these data. Simple basic coding is needed in order to produce machine-readable outputs.

Information needed for social assessment is not readily available in standard statistical formats. Much of it must be generated by the planner primarily through various forms of public involvement such as public workshops. Small group techniques offer alternatives to questionnaires for generating value, opinion, and attitude data.

In the drive to quantify social effects, new techniques of human cost accounting have emerged. Based on observations that property-based values are only a partial measure of flood damage prevention, human cost accounting quantifies psychological trauma prevented and behavioral damages prevented. For the first type of damages, victims of flooding are positioned on a value trauma scale, levels of impairment are related to American Medical Association values, and degrees of impairment are translated into dollars paid by the United States Veterans Administration for comparable disabilities. For the second type, descriptions of behavior are examined through questionnaires and translated into economic disruption costs.

Community impact assessment has evolved as a clearly defined subset of more general impact assessment areas. Briefly, it focuses on the influx of construction workers before, during and after peak construction of the water project. The planner estimates the construction worker phasing, translates that into population increase in local communities, and estimates whether this influx will exceed the capacity of basic community services. Estimates depend on a number of subjective locational preferences and subcounty population statistics. Data bases have also been built on surveys of construction workers at actual sites. These data bases, together with before, during, and after case studies, and community impact techniques, provide a guide for planners to make initial estimates and to manage the fear of the "boom-bust" syndrome.

An old social science technique that is frequently used in water resources planning is ethnographic field analysis. In this method, a planner "walks the study area." He or she can sometimes observe seemingly little items that can translate into larger effects (e.g., project stoppages). These techniques are essentially sensing mechanisms to provide "early warning" of the impacts on the social environment. It is difficult to train people in the sensitivity techniques employed in this method.

Questionnaires are the most frequently overused of social science techniques. Since questionnaire data provide only a snapshot, their best use is as a good comparative static picture. Data from questionnaires and other sources are often stated in nominal or ordinal terms. Such data cannot be analyzed by typical engineering methods such as regression analysis. The social scientist employs less familiar statistics, such as contingency table interences, more appropriate to social values data.

In special regions or in cases of subregional data needs, the planners may have to adjust population projections. Although projections may appear unbiased, they are assumption based and value driven. Trend and cross-impact techniques are useful tool to help planners make projections, and computer-assisted packages are available to use these techniques in planning.

With respect to formats, the format described in subsection 7.5.2 for *environmental quality effects* involving "impact statements" was used by the U.S. Bureau of Reclamation, with categories corresponding to various social effects of a project. The other methods presented in the preceding subsection also have their analogs in social impact assessment.

7.5.4 *Environmental Economics*

Many studies have been made of the costs of water quality maintenance and improvement. In the United States, planners are interested in the cost effectiveness of projects in terms of optimizing the cost of construction, operating efficiency, and attainment of standards for wastewater effluent quality and receiving water quality. Costs to achieve reductions in dangerous contaminants are very high and are subject to much study. However, the sponsor of a wastewater treatment plant or the planner of a regional program for wastewater quality management is not required to determine benefit-cost relationships. The benefits of water quality maintenance and enhancement are not fully measurable in economic terms. To some extent, values may be estimated for water-based recreation made possible by improved water quality, cost savings in water treatment due to improve quality at the intake, reductions in damages to structural facilities exposed to water, increased quantity and better quality of fish caught, and other effects. Evaluation of the benefits is very difficult and often becomes quite academic in view of the overall water pollution control policy of the United States, which comprehends both standards for minimum effluent quality and standards for minimum quality of water bodies.

It is clear that most current solutions to problems in water quality management economics will tend to emphasize a minimum-cost plan which will at the same time, be acceptable to the many parties having interests in the water and associated land resources of the project area. Such a plan may aim at a minimum cost from the standpoint of the responsible agency in overall charge or a minimum cost for the individual polluters who must consider wastewater treatment and disposal.

Recently (Passell, 1990), researchers calling themselves "ecological economists" have proposed adding ecological cost to the price of development, saying that traditional economists underestimate the costs of pollution and do not adequately consider society's responsibilities to future generations. Such ideas have special application for countries, such as the developing countries, that depend heavily on their natural resources. These economists propose giving the "sustainability" of natural "life support systems" priority over measured economic growth. Typical values of discount rate, it is said, limit the consideration of the long time frame of environmental resources. For example, the depletion of forests, which is both a short and long term threat to water and related land quality, should according to these economists be considered as affecting the national income accounts.

7.6 Risk and Uncertainty

Projects are planned to meet future (therefore, uncertain) needs, using water and related land resources that are themselves uncertain. Problems of uncertainly have received increased attention from planners as (1) the differences between predicted and actual project outcomes have been recognized; (2) available water and land resources have become scarce and must be used more intensively; and (3) issues of uncertainty have been faced in the review and public involvement process.

Attitudes toward uncertainty vary with the sponsor organization and also with the individual and the type of risk. Members of society may be more willing to accept a higher but known risk (e.g., everyday risk of automobile accident) than the unknown risk of a catastrophic event (e.g., earthquake, great flood, or nuclear incident). Risk probabilities do not fully conform with the value scales perceived by society, which may be "risk neutral" in the case of automobile accidents and "risk averse" with respect to the large and sudden changes in wealth and psychic damage from an earthquake. The planner should recognize that these seemingly irrational attitudes exist, in considering alternative plans and especially in conducting the public involvement process.

The planner's approach may, therefore, reflect not only his or her degree of confidence in the values selected for the study variables but also the sponsor organization's financial strength. A large organization that pools many risks can accept the risk of failure of a project, whereas an organization completely dependent on a single project should be quite "risk averse." Another point to consider is that the consistent use of values of variables having low probabilities of occurrence (i.e., always pessimistic or optimistic), can lead to unreasonable results because the joint probabilities of the values in combination may be inconceivably low.

In the United States, a recent study for the Environmental Protection Agency (reported by Stevens, 1991) by a polling organization found that there were substantial differences between how scientific experts rank risks and how the public perceives risks. As shown by Table 7.1 summarizing these differences, most of the serious hazards assessed are related to water resources.

A number of mathematical approaches have been developed to deal with the problems of risk. They all involve estimating the probabilities of one or more uncertain variables. One approach is to consider the probabilities of alternative events (often arranged in the form of a *decision tree*) such as the failure of a water supply to meet a hydrologic target or the failure of a dam due to a flood, together with the consequences of these events (e.g. losses due to agricultural shortfalls or flood damages). This approach with its many variations is referred to as *Bayesian decision theory* or analysis.

Extensive studies of methodologies for risk and uncertainty analyses have been made in the United States by the U.S. Army Corps of Engineers (Institute for Water Resources, 1990). These studies analyze a variety of techniques for dealing with risk and uncertainty in the planning process, and deal with environmental issues, institutionalized uncertainty, project design, and specific problems and approaches in major types of water resources developments. These include municipal, industrial and agricultural water supply; flood control;

Table 7.1 Ranking Of Risks By Experts And The Public
(Source: Stevens, 1991)

EXPERTS RANK RISKS	*THE PUBLIC PERCEIVES RISKS*
Relatively High-Risk Ecological Problems:	Ranked as very serious risks by at least 20 percent of people polled, in descending order:
Habitat alteration and destruction (soil erosion, deforestation, etc.)	• Hazardous waste sites (in use).
Species extinction and overall loss of biological diversity.	• Hazardous waste sites (abandoned).
Stratospheric ozone depletion.	• Worker exposure to toxic chemicals.
Global climate change (greenhouse warming).	• Destruction of protective ozone layer.
Relatively High Risks to Human Health:	• Radiation from nuclear power plant accident.
Outdoor air pollutants.	• Industrial accidents releasing pollutants into air, water and soil.
Worker exposure to chemicals in industry and agriculture.	• Radiation from radioactive wastes.
Air pollution indoors.	• Underground storage tanks leaking gasoline and other substances.
Pollutants in drinking water.	• Pesticides harming farmers, farm workers and consumers who work with them.
Relatively Medium-Risk Ecological Problems:	• Pesticide residue on foods eaten by humans.
Herbicides and pesticides.	• The greenhouse warming effect.
Pollution of surface water.	• Nonhazardous wastes, like trash disposal.
Acid deposition (acid rain, etc.).	• Radiation from X-rays.
Airborne toxic substances.	
Relatively Low-Risk Ecological Problems:	
Oil spills.	
Groundwater pollution (hazardous wastes, underground tanks, etc.).	
Escape of radioactive materials.	
Acid Runoff to surface waters.	
Thermal pollution.	

hydropower; navigation, and commercial fishing. Related studies treat the subject of dam safety risk analysis which presents particular difficulties because typical methods of analysis are deficient for the low-probability/high consequences situation for dam failure.

The issue has arisen as to how threatened climate changes should be accounted for in the planning, design and operation of water resource systems. A number of mathematical models have been formulated to project the probability of climatic changes and the consequence of such changes. Fiering and Rogers (1990) have proposed an approach based on Bayesian theory, that considers explicit options for a "standard project" event such as the "design flood" along with estimates of the probabilities of their occurrence, and *estimates of the consequences of being wrong*. Such an approach would consider a large number of alternative general circulation models associated with climate scenarios.

Another approach to *risk analysis*, involving *Monte Carlo* methods, sets the values of key variables in the form of probability distributions. Results are then obtained in terms of various numerical values of B/C or other economic indicator, each paired with a probability estimate. Strictly speaking, whenever it is possible to estimate a probability distribution for each variable, there are no *uncertainties*. Risk analysis can include probability distributions for variables that have known distributions (e.g., stream flows) and also distributions for variables that are basically uncertain (e.g., interest rate, inflation, construction contingencies, etc.), but for which judgment may be used to set optimistic, pessimistic, and most likely values or to establish variability in other ways. The availability of economic results corresponding to sensitivity and risk analysis approaches assists the decision maker to make a more rational evaluation of options.

When the variables of parameters affecting the potential outcome of a project are described in terms of probability distributions, the outcome is also expressed in a form that permits more rational consideration of the project by planners and decision makers. For example, suppose that the risk analysis for a project produces the following estimates of the outcome:

- 90% probability that the B/C will be greater than 1.0
- 80% probability that the B/C will be greater than 1.5
- 70% probability that the B/C will be greater than 2.5

Say that a B/C of 1.0 just meets the minimum standard for project implementation, while a B/C of 1.5 is good and a B/C of 2.5 is very attractive. Although the probability of a good or very attractive B/C is high, an inexperienced and underfinanced sponsor may be unwilling to accept the 10% possibility that the project will fail. A sponsor that is already involved in many successful projects may, however, consider the risk of failure to be acceptable when compared to the likelihood of very desirable outcomes.

A method of risk analysis based on work by Taylor et al. (1979) requires a minimum of subjective estimation. It was recommended by the investigators after examination of the beta, triangular, adjusted triangular, Weibull, and normal distributions. It is based on selecting three estimates for each project benefit and cost: a most likely, an optimistic, and a pessimistic.

The "optimistic" estimate is the maximum benefit value (or minimum cost value) that can result from a particular benefit type (i.e., flood control) which can be obtained only if unusually good luck is experienced and everything "goes right"; call this *a*. The "pessimistic" estimate is the minimum benefit (or maximum cost) that will result only if unusually bad luck is experienced; call this *c*. The "most likely" estimate is the normal benefit or cost value which should be expected to occur most often if the activity could be repeated many times under similar circumstances; call this *b*. The three estimates (*a*,*b*,*c*) define a triangular distribution. Symmetry is not required. A probability density function may be derived for each benefit, cost, or other parameter from the triangular distribution.

These distributions and density functions are developed for each uncertain parameter entering into the analysis. Random numbers are generated (hence the term Monte Carlo simulation) which are employed together with these density functions to obtain one value for each of the uncertain parameters, and these are assumed to apply when deriving one value of a benefit/cost ratio or other index of physical or economic performance. The selection and application of random numbers is repeated a number of times to obtain many values of the B/C or other index. These values may be analyzed to provide estimates of project performance vs. probability.

This approach has also been studied by the World Bank (Reutlinger 1970, Bouliquen 1970) with other types of distributions.

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