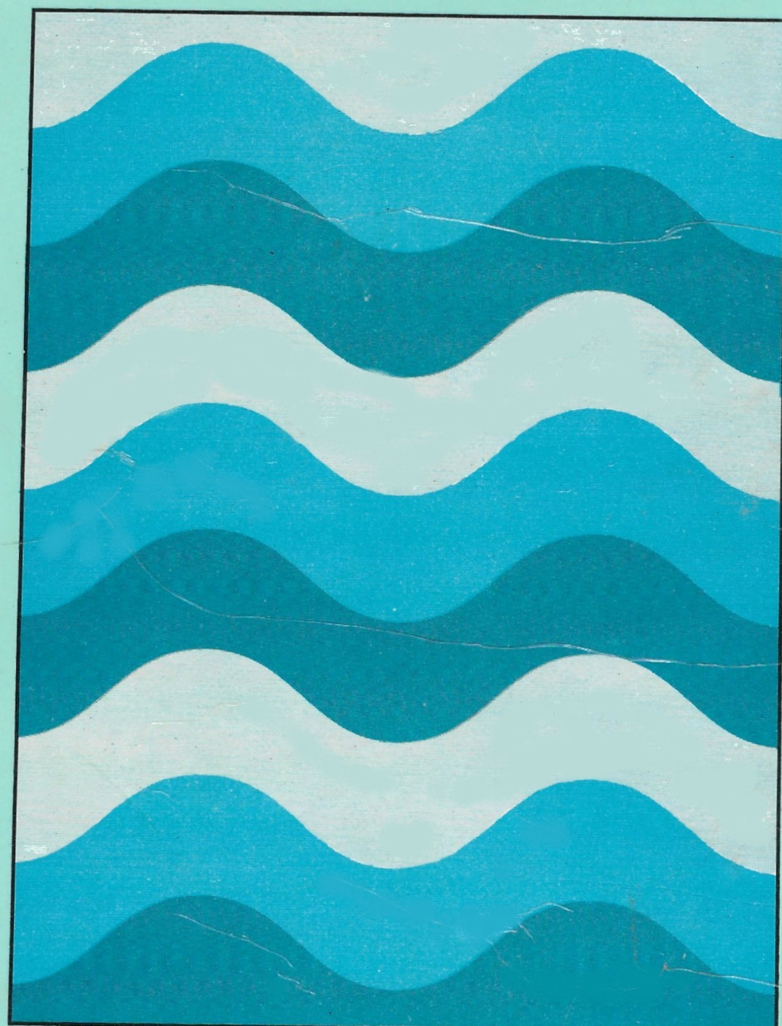
ENVIRONMENTALLY-SOUND WATER MANAGEMENT



Edited by

N. C. Thanh and Asit K. Biswas

Environmentally-sound Water Management

Edited by
N. C. THANH
ASIT K. BISWAS

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Foreword

In the last two decades, much has been written about environmentally-sound development. More recently the term sustainable development was coined. While everyone agrees on the need for development that sustains and is sustainable, experience shows that translating the term from a concept into everyday, operational priorities remains a very difficult task.

Clearly, development must be environmentally sound to ensure that development process does not destroy the resource base upon which future growth depends. This is a fundamental tenet of development. Some 16 years ago, during the World Food Conference in Rome, I called this approach 'development without destruction'. More recently, such seminal reports as UNEP's *Environmental Perspectives to the Year 2000 and Beyond,* the *World Conservation Strategy* and *Our Common Future* have sharpened our understanding of environmentally sound and sustainable development.

Environmental costs of development will only be minimized when development decisions are guided by ample knowledge and information. When development decisions were made—say some 40 years ago—decision-makers were not fully aware of the long-term environmental and social impacts of their decisions. Not surprisingly, decades later we are still paying the price of some earlier decisions, in terms of destruction of the natural resource base and environmental degradation.

Now, with our knowledge base substantially enhanced, we must learn from our past mistakes, and avoid making the same errors again. Environmental considerations need to be integrated rationally and efficiently in natural resources planning and development, thereby minimizing and halting the destruction of our planet's resource base.

We have made reasonable success in intergrating environmental considerations at the project level and some success at the sector level. Unfortunately, we have not succeeded in designing means of integrating environmental concerns effectively at the national plan and policy levels, except in very general terms. Currently, in spite of the rhetoric, appropriate operational methodology for such integration simply does not exist. Unquestionably, increased attention must be paid to improving our knowledge on how to integrate properly environmental concerns at the national plan and policy levels. Water resources development is no exception to this general state of affairs.

Water is the lifeblood of all development. Not surprisingly, all the major ancient civilizations developed on the banks of major rivers like the Nile, Indus, Tigris and Euphrates. Water was considered to be an important element in most early religious and classical texts.

The role of water in the development of developing countries is no less important today than in ages past. The food and energy crises that most developing countries face today will not be solved on a long-term, sustainable basis without efficient water management policies. Environmentally-sound water management is an absolute necessity if the ravages of floods and droughts are to be significantly reduced. The prolonged tragic droughts in Africa and floods in many parts of the world have sadly confirmed this fact. And the threat of climate change and global warming makes sustainable water management policies imperative, particularly given long lead times in resource planning.

Water development projects, like any other type of resource development, have both positive and negative impacts. The primary task facing planners and managers is to maximize the positive impacts of such development and minimize the negative ones. Recent discussions of these impacts have concentrated primarily on the negative impacts. What needs to be better understood are positive impacts of sustainable water management. Simply put, unless positive aspects *significantly* exceed negative impacts, development projects should not be built.

Let us consider the case of the Aswan High Dam in Egypt, which is included in this book as a case study. Among the many adverse environmental impacts attributed to this dam are salinity growth, increases in schistosomiasis, erosion of the Nile Delta and loss of some of the Mediterranean fishing grounds. But what is worth noting is that even after the construction of the Aswan High Dam, availability of per capita arable land now in Egypt is still around 0.07 ha, the lowest of any country in Africa. There is no argument: the dam's contributions to substantially increasing food production and hydropower generation have made an enormous difference to the quality of life of the Egyptian people. Thus, the real question is not whether the Aswan High Dam should have been constructed, but rather what steps should have been taken to anticipate and address the adverse environmental impacts, and to ensure they were reduced to an acceptable minimum. And in this particular case the adverse impacts were all anticipated and plans set for addressing them but international political situations delayed the implementation. So the overall cost of the negative impacts and of their redressing skyrocketed like any other cost in the world today.

What is thus necessary is a *balanced* environment–development philosophy, within which environmentally-sound water development could occur.

I am pleased that Dr N. C. Thanh (Director of Asia Division, CEFIGRE) and Professor Asit K. Biswas (President of the International Water Resources Association) have now prepared a study examining and elaborating such a balanced environment–development perspective. It is the first book that I know which evaluates environmentally-sound water management, and deals in an integrated manner with the issues related to water development in developing countries. This book fills a long-standing need in this area, and is a welcome addition to the growing body of literature on environmentally-sound and sustainable development.

MOSTAFA KAMAL TOLBA
Executive Director
United Nations Environment
Programme, Nairobi,
Kenya

Preface

Throughout human history, water has always been considered to be an important requirement for human welfare and economic development. The role of water became even more important during the past two decades for a variety of reasons. First, severe droughts in many parts of the world, and especially in Africa, contributed to a major food crisis. In Africa, per capita food production declined steadily during this period as population increased far more rapidly than agricultural production. Increases in agricultural production are only possible through further expansion of cropped areas and increases in agricultural yields. Both of these are only possible provided reliable sources of water are available.

Secondly, prices of fossil fuels, especially oil, increased steadily from 1973. This focused the attention of many governments to another major source of energy, i.e. hydroelectric power, which is not only a renewable source of energy but is generated without any consumption of water. Thus, the possibility of developing major sources of water that could be used to expand irrigated areas and simultaneously generate hydroelectric power, became an attractive proposition to many countries.

Thirdly, the United Nations convened a world Water Conference in Mar del Plata, Argentina, in March 1977, at a high decision-making level. This conference, the first of its kind ever held in the area of water, sensitized the world community on the importance of water for development, especially for developing countries. The conference unanimously agreed on an Action Plan. An important component of the Mar del Plata Action Plan was to declare the 1980s as the International Water Supply and Sanitation Decade. This declaration heightened the importance of availability of clean water to every citizen of the world.

Another issue worth noting is that as the interest in water development in developing countries accelerated during the last two decades, so did the concern with the environmental impacts of development projects. As the decade of the 70s progressed, the interrelationship between environment and development came into sharper focus and its importance became increasingly clear to policy-makers and the general public. It was gradually accepted that environment and development are two sides of the same coin. Much of the credit for clarification of this concept as well as its acceptance by developing countries must go personally to Dr Mostafa Kamal Tolba, Executive Director of the United Nations Environment Programme, who made it one of his priority areas. As a result of such efforts, environmental concerns are now being incorporated to the extent possible into development projects of most developing countries, and water resources development is no exception.

All development projects have environmental, economic and social consequences, some beneficial and others adverse. In the nineties, the main challenge facing the water resources profession is how to maximize all the positive impacts of any water development present, planned or already operational, and minimize the adverse impacts. It is now evident that water resources projects can be better planned and managed to ensure more reliable water availability and efficient water use in the agricultural sector, mitigate flood damage, and control water pollution, and simultaneously reduce adverse environmental and social impacts such as prevention of development of waterlogging and salinity, reduction in the spread of water-borne diseases and proper resettlement of displaced people. Environmentally-sound water management should be able to address and resolve all these issues simultaneously.

While no sane person will currently question the importance and desirability of environmentally-sound water management, it is really a sad commentary on our present status that a book on this important subject simply does not exist. In order to fill this critical gap, International Training Centre for Water Resources Management (CEFIGRE) in Sophia Antipolis, France, undertook to develop this text in close collaboration with and support of the United Nations Environment Programme (UNEP) and International Water Resources Association (IWRA). The present book is a direct result of this effort. While the main objective of this book is to promote environmentally-sound water management in developing countries, we are confident that the water professionals in other countries will find it useful as well. CEFIGRE, UNEP and IWRA plan to use this book as the basic text for a series of training courses on environmentally-sound water management for developing countries.

The editors wish to express their most sincere appreciation to

Dr Mostafa Kamal Tolba, Executive Director of the UNEP, for his constant encouragement to develop this book. In spite of his numerous international commitments, Dr Tolba kindly agreed to write a Foreword to the book, for which we are truly grateful. We also wish to acknowledge the support we have received from Dr J. Balek, Dr H. El-Habr and the late Dr L. David (all from UNEP) and our colleagues from CEFIGRE. Without such support, this book would not have been possible.

N. C. Thanh
Director, Asia Division,
International Training Centre for
Water Resources Management
(CEFIGRE), Bangkok, Thailand

Asit K. Biswas
President, International Water
Resources Association,
Oxford, England

List of Contributors

N. C. Thanh
CEFIGRE, France/Thailand

D. M. Tam
Cowater International, Canada

Asit K. Biswas
International Water Resourses Association,
Oxford, England

Janusz Kindler
Institute of Environmental Engineering,
Warsaw Technical University, Warsaw, Poland

Wanchai Ghooprasert
Provincial Waterworks Authority, Thailand

M. B. Pescod
Department of Civil Engineering,
University of Newcastle upon Tyne,
United Kingdom

R. Mackay
Department of Civil Engineering,
University of Newcastle upon Tyne,
United Kingdom

Mahmoud Abu Zeid
Water Research Centre, and
International Water Resources Association,
Cairo, Egypt

CHAPTER 1

Water Systems and the Environment

N. C. THANH and D. M. TAM

FUNDAMENTALS OF ECOLOGY: HUMANS IN THEIR ECOSYSTEM

The word 'ecology' is derived from the Greek *oikos*, meaning 'house' or 'place to live'. Ecology is the study of interrelationships between living organisms and their environment. It is concerned with the biology of groups of organisms and with functional processes in the entire environment which include the air, soil, freshwater bodies and the seas.

Ecosystem is a unit comprising organisms and processes. Its state can vary. It can be as small as a pond, or as large as a lake, a forest, or even larger such as a catchment area of a large river. Generally an ecosystem consists of (i) *inorganic substances* such as water and carbon dioxide; (ii) *organic compounds* such as proteins, carbohydrates and fats; (iii) *climatic regime* such as temperature, wind and precipitation; (iv) *producers* (mainly green plants) which are able to build their bodies using simple inorganic elements; (v) *consumers* (humans and animals) which are not able to use simple elements but must consume organic compounds of other organisms to build their bodies; and (vi) *microconsumers* or *decomposers*, chiefly bacteria and fungi, which break down complex compounds into simple elements that plants can absorb. The first three groups constitute the *non-living* (*abiotic*) *components*, whereas the last three constitute the *living organisms* (*biomass*). Each of the three living organism groups have distinct general functions in the ecosystem: *production*, *consumption* and *decomposition*, respectively. All three must exist together in a stable ecosystem, and all three must live in harmony with the three abiotic component groups. For instance, without the decomposers organic matter will accumulate in dead bodies which plants cannot use, and so no new life can start.

In order to understand the importance of environmental conservation and mitigation of potential adverse impacts on the environment, the following main characteristics of a stable, healthy ecosystem should be noted:

- No organism can live by itself but rather each depends on others for survival. In turn, each of the living organisms plays a useful role in the ecosystem; all species constitute the wholeness of the biosphere. For this reason, one organism will affect the future of others.
- There are mechanisms within individual organisms and in the ecosystem for self-maintenance and self-regulation, and this makes an ecosystem stable. Examples in the ecosystem are numerous: the balance among grasses, rabbits and wolves, or among plankton, herbivorous fish and carnivorous fish. This mechanism (*homeostasis*) develops only after long periods of adjustments. It may have limitations beyond which the system may collapse. After that, it may take some time to recover, if it can ever recover, or the process could be irreversible.
- For the various elements necessary for each organism to grow and reproduce, the single element closest to the critical minimum will be a factor limiting the growth and reproduction of that organism. If everything else is plentiful in water, but light is limited (e.g. by turbidity) then light could be the limiting factor for algae; all other elements may not be useful. This is the *Liebig's Law of the Minimum*.
- Each organism has its lower and upper limits of tolerance for living conditions, such as for temperature. Also, 'too much of good things' will become harmful. This is the *Shelford's Law of Tolerance*.

Stated simply, as such these principles do not reveal all the intricate features in the ecosystem. However, these (and others) are important governing rules which should be carefully considered and applied to human activities that may affect the environment.

The Hydrological Cycle

The hydrological cycle is basically the circulation of water within and around the earth as water is converted from one form to another and transported from one place to another. The driving forces of the hydrological cycle are the sun's energy and the earth's gravity. Most active phenomena occur in the oceans, where each year about 453,000 km^3 of water evaporates to the atmosphere. Water vapour in the atmosphere condenses and precipitates on the surface in various forms such as rain, snow, sleet and hail. About 90 per cent of the 453,000 km^3 of water returns each year to the oceans; the remaining 41,000 km^3/year precipitates on land together with 72,000 km^3/year of water evaporated from land masses and falls back. Water then follows three different paths, namely infiltration or percolation, evaporation or evapo-transpiration, and runoff.

Infiltration/Percolation. A major portion of precipitates infiltrates below the surface and into pores and fractures of geological formations called aquifers. Underground water eventually discharges to surface waters through springs or groundwater outflows in rivers or lakes.

Evapo-transpiration. Through evaporation from the earth's surface and evapo-transpiration from plants, water constantly returns to the atmosphere as vapour, which then circulates around the earth and precipitates again. While evaporation is an important process in the hydrological cycle, plants magnify the effect greatly by transpiring considerable masses of water. In addition, their root systems accelerate the upward movement of water against the force of gravity. In this way, transpiration by vegetation vaporizes large quantities of water: a hectare of forest in temperate climates can evaporate 20–50 tonnes of water per day (Ramade 1981). The combined effect of evapo-transpiration is thus an important factor in the hydrological cycle of land-based ecosystems. In tropical forests, such as those in the Congo and Amazon basins, the majority of rainwater originates from evapo-transpiration; only 20 per cent comes from the seas.

Runoff. About 20 per cent of precipitation reaches springs, lakes and rivers. A major part of surface flows is in sparsely populated areas such as the Amazon River Basin, leaving only 9000 km^3/year for human use. Eventually 41,000 km^3/year of surface water on land returns to the oceans to complete the hydrological cycle. While the movement through some parts of the hydrological cycle may be relatively rapid (for instance, water vapour on the average remains in the atmosphere for 10 days), water moves very slowly underground. Complete recycling of groundwater may be measured in thousands of years. This fact is seldom understood by groundwater users who 'mine' these 'fossil aquifer' at a rate much higher than the replenishment rate (see section 'Excessive water withdrawal and its impact' below).

About 97.3 per cent of the earth's water is in the oceans and bodies of saline water. Of the remaining 2.7 per cent, which is freshwater, 2.1 per cent is tied up in the polar ice caps and in glaciers, leaving only 0.6 per cent to circulate. Groundwater and soil moisture constitutes 22.4 per cent of the global freshwater, but two-thirds of the groundwater reserve lies below 800 metres depth and is beyond human capacity to exploit. For all of their livelihood purposes, humans must depend upon the remaining approximately 0.2 per cent found in freshwater lakes, rivers and up to 800 metres in the ground. Contrary to popular belief, the amounts of freshwater in lakes and rivers are very small, constituting about 0.009 per cent and 0.0001 per cent, respectively, of the world's total water. Moreover, the distribution of these tiny portions are grossly uneven. For example, nearly 50 per cent of Africa's total surface water resources are in the Congo River basin, and Lake Baikal alone contains 10 per cent of the total freshwater stock of the whole planet! Coupled with all abuse created together with the population growth and the increase in per capita water demand, water crisis is a reality.

Even though the major rivers of the world have very large discharges, the amount of water contained in these rivers at any given time is small. For instance, if all the water of all rivers of the world could be pooled together at any given time, the resulting lake would still be smaller than Lake Ontario. Thus, in water resources development planning and design, the dynamic flow over time is a more important factor than the static holding volume.

From the above, we can see that understanding our ecosystem and the hydrological cycle is the essential beginning of water resources development planning. Humans should not disrupt the orderly functions of the hydrological cycle, or of hydrogeochemical cycles in general. It should be noted that the hydrological cycle is only an integral part of hydrogeochemical cycles, in which water, air and soil are interrelated. Human activities have caused profound effects on the hydrogeochemical cycles. The most sensitive components to these effects are the atmosphere, the living biomass (mostly forests) and ground and surface freshwaters (Stumm 1986).

WATER USES

Figure 1 indicates that global water use during the period 1950–80 increased by more than three-fold, mainly because of the fast increase in per capita water use. During the same period, world's population increased by 80 per cent only, which shows the degree of stress humans have put on the environment.

Agricultural Use

Agriculture is the largest user of water, accounting for nearly three-quarters of the total global consumption. Large portions of water used are lost through evapo-transpiration and seepage. Accordingly, more water must be provided onto the fields than what is required by the crops. Often more than half the water withdrawn for irrigation does not reach the field. Approximately one-third of the agricultural production comes from the 18 per cent of the world's cropland that is irrigated. It is estimated that by 1990, the total area irrigated in the world will be some 273 million hectares, of which 119 million

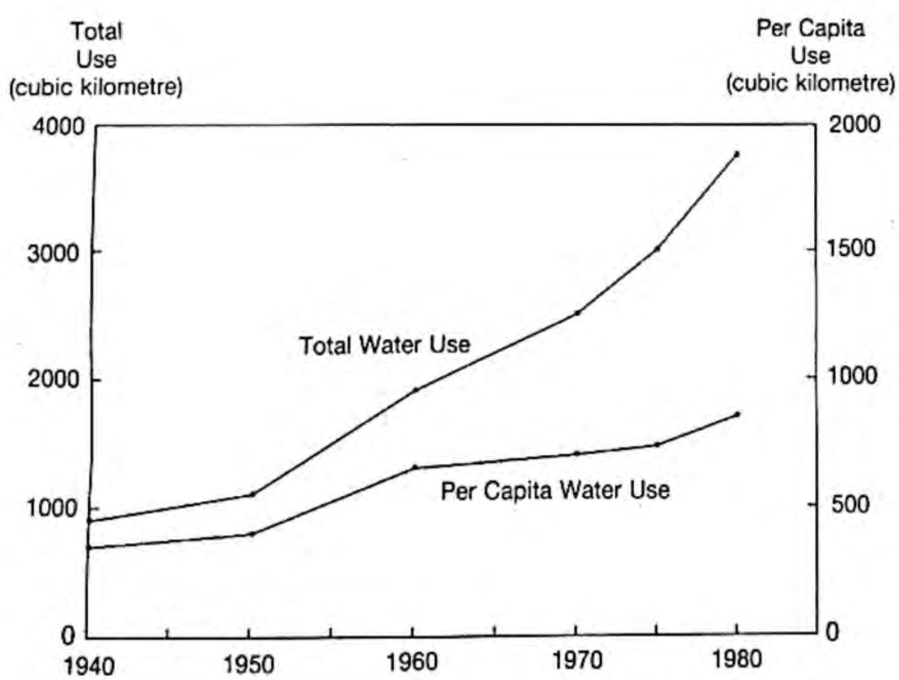

FIGURE 1. World water use, total and per capita, 1940–80

(Source : USSR Committee for International Hydrological Decade and Worldwatch Institute) hectares will be in developing countries. By the turn of the century, the volume of irrigation will be increased by an estimated rate of 25–30 per cent over the 1980's level.

Industrial Use

Industry is the second major user of water, accounting for about a quarter of total water used worldwide. The largest industrial water users are power plants (both nuclear and fossil-fuel) since large quantities of water is used for producing steam to drive turbo-generators and for cooling. However, only a small portion (2 per cent in the USA) of water withdrawn is consumed. The volume of water withdrawn by these plants are of less concern than the discharge of heated water back to the environment.

Of the remaining water withdrawals for industry, two-thirds go to just five industries: primary metals, chemical products, petroleum refining, pulp and paper manufacturing, and food processing. Developing countries use about 20–40 m^3/person-year as compared with 2300 m^3/person-year in the USA.

The relation between industrial and agricultural uses varies from one country to another. For example, in the USA agricultural and industrial uses are somewhat similar, in Canada industrial water use is significantly higher than that in the USA, but in India agriculture probably accounts for 90 per cent of total water use.

Domestic and Recreational Use

This use accounts for only 6 per cent of the total water demand, but has the greatest influence on human health. Whether we are healthy or sick depends on the quality and quantity of water that we drink and use, or that we come into contact with for bathing, washing clothes, cooking and cleaning utensils.

Hydroelectric Power Generation

During the period 1925–70, hydropower grew steadily at a rate of 6.5 per cent per year. The growth rate is expected to decline to about 3.75 per cent a year during 1970–2000. Hydroelectric power currently accounts for 70 to nearly 100 per cent of all electricity generated in Brazil, Canada (where electricity is called simply *hydro*), Morocco, Norway and Sri Lanka. In general, hydropower potential in many developing countries is still much under-developed: while these countries possess 50 per cent of the world's hydropower resources, they have exploited only 10 per cent of their potential.

WATER RESOURCES DEVELOPMENT AND THE ENVIRONMENT

Water resources development activities are not new in human history. As early as 3000 BC the Egyptians had developed intricate water networks, especially for irrigation systems. In China, the Huang He (Yellow River) has been used for irrigation for nearly 2500 years, and the origins of the Grand Canal date back to the same period. Water resources development activities along the Tigris, Euphrates and the Indus Rivers also date back thousands of years. However, only during the last 4–5 decades both the magnitude and number of water projects have increased significantly, with concomitant impact on the environment. The various aspects of environmental impacts will be discussed in the following sections.

Environmental Inventory

The environmental inventory consists of physical components present in the ecosystem of a project area that need to be assessed both qualitatively and quantitatively. Table 1 (adapted from Roser 1976) serves as a checklist of those components in an environmental inventory that should be considered in planning water resources development projects. The actual list would depend on specific site conditions.

Environmental Parameters

Environmental parameters (also called 'attributes') are variables that can be quantified or clearly described and that represent or measure the characteristics of the environment. In short, they serve as 'yardsticks' of the environmental inventory listed above. For example, as shown in Table 2 (adapted from Jain *et al.* 1981; Rau and Wooten 1980), 21 parameters can be used to describe the characteristics of the water resources components listed in Table 1.

AREAS OF ENVIRONMENTAL IMPACTS

Although any environment impact could be either beneficial or adverse, in environmental analysis, impacts are historically considered only to be of adverse type caused by our developmental activities. Impacts can be generally categorized as primary, secondary or tertiary. *Primary impacts* are those caused directly by project inputs such as loss of forests, changing of a river regime due to the construc-

TABLE 1. Environmental inventory

Topographic and scenic components	*Vegetation resources*
Basic geology	Virgin timber stands
Prominent elevations	Rare timber remnants
Caves and sinkholes	Reforestation activities
Cliffs and outcroppings	National forests
Stone and mineral collection areas	Orchards
Ore outcroppings	Nurseries
Agricultural activities	Game inhabited areas
Soil conservation activities	Important habitats
	Endangered plant species
Climatic regime	*Historical and cultural resources*
Rainfall	Historical structures
Temperature	Museums
Wind	Temples and shrines
Evaporation	Cemeteries
Humidity	Traditional cottage industries
Solar irradiation	*Wildlife resources*
Potential for natural disasters, e.g. flashfloods	Biological diversity
	Animals
	Fish
Water resources	Birds
Drainage patterns	Breeding grounds
Significant streams	Sanctuaries
Groundwater	Endangered species
Lakes and ponds	*Recreational facilities*
Beaches	Hunting areas
Wetlands	Water-related activities
Dams and reservoirs	Camp sites, picnic grounds
Canals and locks	Resorts, tourist accommodations

tion of a dam. As such, primary impacts can be attributed directly to a project activity. They are usually easy to measure. *Secondary impacts* are those caused by project outputs such as water flow regulation and channelization. In other words, they are indirectly attributed to the project activity. If one of the project outputs is availability of irrigation water, secondary impacts could be the effects on the fertility of the irrigated soil. Secondary impacts could be more severe than primary impacts and, unfortunately, often more difficult to predict and measure. Secondary impacts in turn may lead to tertiary impacts.

It should be noted that the distinction between primary, secondary

TABLE 2. Environmental parameters

Water	*Land*
1. Aquifer safe yield	38. Soil types
2. Flow variations	39. Soil composition: nutrients and trace elements
3. Chlorides	40. Soil physical characteristics: bulk density, permeability, etc.
4. Oil and grease	41. Soil stability
5. Suspended solids	42. Natural hazards; seismicity, floods
6. Acidity/alkalinity/pH	43. Salinity intrusion
7. BOD and/or COD	*Socio-cultural environment*
8. Dissolved oxygen	44. Infrastructures and basic services: water supply, sanitation, health care, school, etc.
9. Nutrients	45. Housing conditions
10. Trace elements, e.g. Mn, Mg, Bo, Se	46. Socio-cultural and ethnic characteristics
11. Pesticides	47. Community life; community organization, self-help activities, places to meet, festivals
12. Heavy metals	48. Religions
13. Other toxic substances, e.g. PCBs	49. Demographic characteristics
14. Faecal coliforms	50. Women's role in household and in development
15. Faecal streptococci	*Economic environment*
16. Temperature	51. Labour and wages structures
17. Radioactivity	52. Industrial outputs
18. Aesthetics: colour, odour, taste	53. Total and unit yields of agricultural and fishery products
Air	54. Income: level, source and distribution
19. Particulates	55. Land tenure and value
20. Sulphur oxides	56. Landownership
21. Hydrocarbons	*People*
22. Nitrogen oxide	57. Health indices, e.g. life expectancy
23. Carbon monoxide	58. Nutritional status
24. Photochemical oxidants	59. Eating habits
25. Hazardous chemicals, e.g. lead	60. Hygiene practices
26. Odours	61. Health status: diarrhoeas, parasitic diseases, other infectious diseases, e.g. tuberculosis
27. Visibility	62. Settlement and migration patterns
Noise	
28. Noise levels	
29. Physiological effects	
30. Psychological effects	
31. Communication effects	
32. Performance effects	
33. Social behaviour effects	
Flora/Fauna	
34. Species checklist/counts	
35. Species diversity	
36. Growth rate	
37. Migration patterns	

and tertiary impacts could often be arbitrary. In the ecosystem, impacts are usually complex and one impact may lead to another, resulting in chain-actions (e.g. deforestation could contribute to increased reservoir siltation which could lead to a loss in downstream fishery, causing malnutrition which in turn may increase sickness) and a major impact may often be due to a combination of factors. The causal linkages between impacts may not be direct or clear-cut. Various types of water-related activities can cause beneficial or adverse impacts on the environment. These activities may include land clearance, construction, water impoundment, water channelization, flood land alteration and changes in land-use patterns.

Impacts could also be conceptually divided into two broad categories: short-term and long-term. Short-term impacts occur during the planning, construction and immediate post-construction phases. Longer-term impacts stem from the presence of large man-made lakes, development of perennial irrigation instead of seasonal irrigation, alteration in the ecosystem of the area, and the changing socio-economic situation.

SHORT-TERM ENVIRONMENTAL IMPACTS

Many adverse impacts—such as noise, soil disturbance, air pollution, disruption of transport—are inevitable results of activities during the construction phase. These are usually tolerable. However, major short-term social and environmental impacts are often caused by the large workforce at the construction site. Water resources development projects requiring major construction create new employment opportunities, and so new workers of different categories move into the areas near construction sites in large numbers. If these projects are undertaken in remote, undeveloped regions, they lack suitable housing, sanitation and other facilities. Construction of such supporting infrastructure invariably have environmental implications. Even when they are not in remote regions, host communities are seldom able to absorb large numbers of immigrant workers without encountering serious environmental and social problems.

In developing countries labour-intensive technology is often used to construct large structures, which means that a large number of unskilled and uneducated labourers arrive at construction sites in search of employment. The construction of large water development projects often lasts over a decade, and the daily labour force engaged fluctuates greatly. Under these difficult circumstances and in view of inadequate medical assistance in most developing countries, it is impossible to provide appropriate medical and sanitation facilities to most of the workers.

The presence of large numbers of workers in unhygienic, dilapidated quarters is conducive to the prevalence of disease: tuberculosis, viral hepatitis, meningitis, etc. Furthermore, in some countries like Pakistan, groups of labourers exist who travel all over the country working from one construction site to another. Such movements tend to increase disease transmission rate.

LONG-TERM ENVIRONMENTAL IMPACTS

Physical Impacts

Impacts on Water Quality. Water quality is a very important consideration for all water development projects as it affects all aspects of water use—for humans, for animals, for crops, and even for industry. With regard to water quality in reservoirs and lakes, an understanding of stratification and its effects are essential.

In temperate climates, reservoirs as well as natural lakes are subject to a seasonal cycle of changes in terms of thermal stratification. In the *fall overturn* the warmer top layer (*epilimnion*) become cooler or at least as cool as the bottom layer (*hypolimnion*). As a result, the water of the reservoir mixes thoroughly, and dissolved oxygen and nutrients in the epilimnion and hypolimnion are interchanged. In the *spring overturn*, as the temperature of the epilimnion rises from 0 to 4 °C at which water becomes heaviest, it sinks to the bottom, taking with it dissolved oxygen. Displaced bottom waters rise to the surface bringing with it nutrients deposited on the bottom back to the surface. These biannual mixing processes reduce the extent of thermal stratification and contribute to the maintenance of higher water quality.

By contrast, since the surface temperature of reservoirs in tropical and sub-tropical climates seldom (if ever) falls below 4 °C, thermal stratification becomes a stable year-round phenomenon. Consequently, the hypolimnion is consantly depleted of its dissolved oxygen while nutrients are not recycled. This problem is especially serious for deep reservoirs. Thus, while the same physical structure yields benefits under temperature conditions, it may create serious problems in hot climates. This is an example showing that a knowledge of specific tropical conditions as different from what has been well-understood in temperate climates is vital. Attempts to improve reservoir water quality by releasing hypolimnion water which has a low temperature and little or no dissolved oxygen could adversely affect the ecosystem of the downstream areas. Impoundment of water over long periods enhances settling of suspended solids, hence water quality may be improved in terms of turbidity. However, the deposition of mineral and organic matter may cause problems by silt accumulation and the depletion of dissolved oxygen in the water. The problem of siltation has sometimes been underestimated in large projects, requiring costly remedial measures (Sundborg and Rapp 1986; Wu 1986).

Water below a spillway may become supersaturated with nitrogen as a result of turbulences. Nitrogen contents of 130 per cent have been recorded (normal saturation is considered to be 100 per cent); while the mortality threshold for some fish species appears to be about 120 per cent (ICOLD 1980).

In arid zones the waters often have high salt content. With high evaporation and low precipitation regime, the salinity in impounded water may eventually become exceedingly high.

The nutrient level in water often increase significantly owing to decaying matter in the flooded land and leaching from the ashes of burned vegetation. This may engender eutrophication as indicated by abundant algal growth, higher turbidity, lower dissolved oxygen, and aesthetic problems. Flooding of tropical forest (instead of cutting trees which are removed as timber or fuelwood) may also produce hydrogen sulphide in impounded water, which imparts aesthetic problems for human consumption, causes toxicity to fish and corrodes metal parts (such as turbines) that come into contac with the water. Studies in Surinam have shown that the cost of turbine repairs corroded by hydrogen sulphide as a result of forest flooding exceeds the expense of deforestation (ICOLD 1985).

Impacts on Groundwater. Irrigation projects may have impacts on groundwater in various ways (Verma 1987). Especially in arid regions, more irrigation water than is needed for evapo-transpiration must be applied to soil to avoid accumulation of salts in the root zone. As a result, groundwater is easily contaminated by fertilizers and pesticides percolating from irrigation water. Considering that there are about 225,000,000 irrigated hectares in the world, groundwater contamination by irrigation projects could be indeed extensive. Irrigation schemes in Punjab, Pakistan, have in their first 10 years of operation, raised the water table 7 to 9 metres above the long-term level.

Large water storage may raise the groundwater level which contacts permeable and polluted beds, thus affecting the quality of groundwater. Once the groundwater table is within several centimetres from the surface, water begins to move upwards by capillary action, pulled by the dry air and soil above. As water reaches the surface and evaporates, a deposit of salts is left behind. Agricultural, industrial and human settlement, development around the new water project area may exacerbate the problem of water quality deterioration.

Impacts on Soil. On the global scale, 46 per cent of the earth's surface affected by soil degradation hazards can be directly related to water. These hazards are roughly estimated as: erosion, 22 per cent; waterlogging and flood damage, 8 per cent; salinity and alkalinity, 5 per cent; and frost, 11 per cent (Biswas 1978). Building a dam over a river deprives the downstream land of nutrients normally brought by the river in the form of silt. Since the Aswan High Dam was built over the Nile, the loss of the nitrogenous components of the silt trapped in the reservoir has been equivalent to 13,000 tonnes of lime nitrate per year. As the Nile no longer carries much silt, its delta some 1000 km away has been eroded, because the soil carried out is no longer replaced by silt brought from upstream. There is still another secondary impact on soil loss. Before the Aswan Dam there was a thriving small-scale industry making bricks from the silt dredged from the canals. In the absence of such silt, these industries started to use the top soil near the canals to make bricks, thus contributing further to the problem of loss of productive soil (Biswas 1978). Egyptian researchers have succeeded in making bricks out of sand, but it took considerable time to persuade the construction industry to switch from silt to sand bricks. On the positive side, however, a decrease in silt loads has reduced the cost of dredging canals.

Soon after the construction of a dam, water is stored to build up water level in the reservoir. This deprives the downstream area of a constant supply of freshwater without which saltwater could intrude into low-land or estuarine areas. Later on as the reservoir fills up, the annual release of water from the reservoir may be lower than that in the pre-construction period, because of higher water loss through evaporation from the reservoir. Thus, freshwater flow to downstream regions is not only substantially cut off during construction but gets reduced *forever*. Saltwater intrusion into low-land areas could become worse with time. This problem has been encountered in the Srinakarin Dam of Thailand where unexpected successive periods of droughts after construction made the reservoir build-up time much longer than expected. Salinity from the Gulf of Siam wiped out some of the richest farmland in the country and destroyed coconut plantations and lychee orchards in coastline Samut Songkhram Province (Tuntawiroon 1985). The affected plantation farmers had to leave their native province to look for other jobs.

Degradation of soil fertility by waterlogging and salinity development is a common, but one of the most serious, impact of irrigation. Increase in irrigation without proper drainage facilities usually leads to increase in soil salinization and alkalization as water evaporates, leaving behind salt particles on top soil layers, causing damage to the vegetation growing on this soil and imparting imbalance in the ecosystem. This problem is more acute if groundwater is used extensively for irrigation, especially when the groundwater has a high dissolved solids content. This occurred in Pakistan during the 1960s when 24,280 hectares of fertile cropland in the country was lost every year (Biswas 1980). Salinization is undoubtedly one of the major environmental impacts of irrigation. Soil salinization and soil erosion due to irrigation practices are becoming serious problems throughout Canada's agricultural areas, particularly in the dry prairie environment (Pearse *et al.* 1985). It is estimated that between 1985 and 2000 the irrigated land area of the world will double, and the problems of salinization and alkalization will increase proportionately. Waterlogging occurs when the water level in field becomes so high that crop yields are substantially reduced. Improper farming and irrigation techniques following the abundant availability of water from the Lake Nasser have caused waterlogging and salinization of previously fertile land. However, extensive tile drainage is now being practised in Egypt to keep waterlogging and salinization under control. It is estimated that about 10 million hectares in India, or one quarter of the total irrigated area in 1978–9, are affected by waterlogging and salinization (Michael 1987). More than 70 per cent of 30 million hectares ot irrigated land in Egypt, Iran, Iraq and Pakistan are affected from these problems. It was estimated that over 2 million hectares of agricultural land were severely affected by waterlogging and salinization in Pakistan alone (Phantumvanit 1979).

As much as half the world's irrigation schemes suffer in some degree from waterlogging, salinization and alkalization. Globally waterlogging and salinization are reducing the fertility of some 1 million to 1.5 million hectares of fertile soil annually. Large areas being affected by these problems include the Helmud Valley in Afghanistan, the North Plain in China, the Punjab and Indus Valley in the Indian subcontinent, Mexcali Valley in Mexico, Imperial Valley in California, the Euphrates and Tigris basins in Syria and Iraq, the San Joaquin Valley in California, and Central Soviet Asia (Biswas 1978).

Increased irrigation efficiency, which conserves water, may still create problems (Water Quality Committee 1986). For example, with increased irrigation less water and therefore less salts in water will be added to the soil, but the absolute concentration (not the mass) of salts in the soil water of the root zone could be increased.

Seepage from irrigation channels is a common problem, and it often raises the water table in the area along the channel. A study of major irrigation schemes in Pakistan showed that seepage from unlined canals raised the water table by 7–9 metres within the first 10 years of operation (El-Hinnawi and Hashmi 1987).

Earthquakes. It has been proven that earthquakes can be induced by large reservoirs. The main earthquake in 1966 in Greece had its epicentre under the reservoir of the Kremasta Dam. Likewise, the 1967 Koyna Dam disaster in the Indian peninsula was caused by an earthquake whose epicentre was located at the dam itself (Biswas 1978). Extensive study during the filling of the Kariba Dam in Zimbabwe indicated that the earthquakes at Kremasta and Kariba dams did not occur by chance (ICOLD 1980). Seismic activity under the Kariba reservoir was strikingly parallel to the rise in water level over the five-year filling period, and the main earthquake occurred when water reached the top level for the first time. At Talbingo in Australia, only one minor earthquake was detected in the 13 years before the reservoir was filled, but 100 tremors were recorded during the first 15 months the reservoir was being filled. The strongest tremor occurred just when the water reached its top level. All the foci were shallow, just near the dam. Mild seismographic activities were persistently recorded in the basin after Lake Kariba had been built (Obeng 1978a). Similarly, minor seismic disturbances were experienced near the Sholiyar and Parambi Kulam Dams in India; this region did not have any recorded seismic disturbance before the project implementation (Varshney 1984).

Groundwater Mining. Excessive groundwater withdrawal may cause serious long-term environmental and social problems. Groundwater has been exploited extensively because of its simplicity and low cost. As explained above, apparent abundance of groundwater could be a result of accumulation over centuries and annual replenishment through rainfall could be minimal. Often groundwater cannot be considered as a renewable resource. The phenomenon of excessive groundwater pumping and subsequent lowering of the water table appears to be worsening around the world.

Effects on Climate. New microclimates are usually created by new large reservoirs. A change in the rainfall pattern has been observed around Lake Volta in Ghana, the peak having shifted from October to July/August. Evaporation from reservoirs in arid zones is very high, especially when the daytime temperature is high. During the night, if there is no wind, cool temperature thickens the vapour over the reservoir surface, creating fog banks. This fog remains on the reservoir parameter, causing some changes in temperature. The High Aswan Dam, by more than doubling the Lake Nasser's surface, has increased the total annual evaporation from 6 km to 10 km. The total annual loss due to evaporation is about 11 per cent of the lake water content. These changes of climate will ultimately affect humans and their activities such as cultivation.

Biological Impacts

Impacts on Living Organisms. The direct impact of dams and reservoirs would be the flooding of reservoir area, killing animals and plants in this area. Depending on local ecological conditions, dam/reservoir projects may be irreversibly destructive to wildlife. Unfortunately, wildlife management in many developing countries is still inadequate. It takes time and much resource to establish a full inventory of the wildlife in a specific region. Due to pressing schedule and lack of resources, baseline studies during the project planning stage often consist of superficial listing of the fauna and flora in the project area, with the result that species may be wiped out before their existence is ever known.

Furthermore, in developing countries direct destruction of natural flora and fauna may be only the beginning. Water development projects will open new roads and navigation channels into areas that so far have not been accessible. Coupled with the population increase due to migration from other areas, which increases cultivation and illegal hunting and logging, the wild ecosystem in and around the project area is in danger of destruction.

In dam/reservoir projects, much expectation has been placed on fishery in reservoirs. However, results may be disappointing without careful planning and design. For reservoirs to be stocked with fish, due to the combined effects of (i) stable stratification under tropical conditions as explained above, (ii) eutrophication, (iii) hydrogen sulphide toxicity, and (iv) siltation, the fish yield may be much less than expected. Experience seems to indicate that alterations in fish species composition are unavoidable. There is evidence that some fish species were lost and others reduced in number during the early period when the Lake Kainji was formed on the River Niger in Nigeria (Obeng 1978a). Surveys on the Nam Pong Reservoir in Thailand indicated that impoundment had severe impact on catfish but favoured murrels (Chatarupavanich 1979).

Ladders built to facilitate the movement of migratory fish to their breeding grounds do not always work. Where dams are more than 30 to 40 metres high, fish cannot move up the ladders without fatally delaying their migration.

There often occurs a reduction in fish production downstream of dams because the structures trap nutrients in their reservoirs. Downstream fishery was reduced by about 50 per cent after the construction of the Kainji Dam in Nigeria (Obeng 1978a). In Southeast Asia, natural fishery in the fields flooded by the river annual overflows constitutes an important low-cost protein source in the local people's diet. Thus, there may be profound and damaging effects of dam/reservoir projects on this type of fishery, but dam implementing agencies rarely consider mitigating this impact.

Damages on living organisms may extend far beyond the project area. Before the Aswan High Dam was built on the Nile, the river overflowed its banks every year between July and October as a result of summer rains in Ethiopia. The floods distributed silt, at a rate or 100–150 million tonnes per year, from the fertile basalt lava of Ethiopia over the Nile valley and delta. This supply of silt was one of the principal foundations of the civilization flourishing since early times along the Nile. The nutrients carried by floods also encouraged the growth of algae and fish off the Mediterranean coast as far away as Lebanon. Algae may be numbered as high as 2,400,000 cells/L during the flood season as compared with 35,000 cells/L during the dry season (Falkenmark and Lindh 1976). These algae provide food for, among other marine organisms, sardines whose catches were 18,000 tonnes a year. The Aswan High Dam traps 88–89 per cent of the silt as sediment in its reservoir, now releasing only 2 million tonnes of silt a year (Sundborg and Rapp 1986). The silt deposited yearly in Lake Nasser is equivalent to 13,000 tonnes of calcium nitrate fertilizer (Worthington 1977). By 1969, the sardine catches had fallen to a mere 500 tonnes a year. Meanwhile, the fish production in Lake Nasser also reduced when the dam was closed, then recovered to the normal level about 10 years later. However, it should be noted that as the fish yield in the lake continued its upward trend, the total fish catch in Egypt increased.

Increase in nutrient level in water may cause blooms of aquatic weeds, the most troublesome being the water hyacinth *Eihhornia crassipes*, the water lettuce *Pistia stratiotes*, and the water fern *Salvinia auriculata.* These weeds cause deoxygenation and eutrophication, impede transportation, increase water losses, harbour disease vectors, and suffocate aquatic organisms. The growth of aquatic weeds in newly formed reservoirs in hydroelectric projects in Africa is serious and spectacular (Obeng 1978a). In Surinam, aquatic weeds infested more than 50 per cent of the Brokopondo Reservoir within two years it was filled (Biswas 1978). Within three years after the Congo River was dammed, aquatic weeds spread throughout 1600 km of the river. The weeds absorb nutrients in water and when they die, the nutrients are locked up in sediments in the reservoir. Loss of water caused by weeds is due to two reasons. First, more water is required to compensate for reduced flow caused by the weeds. Second, owing to the large biomass weight per unit area and the high metabolic rate, the evapo-transpiration rate of aquatic weeds is very high. Once established, it is difficult, if not impossible, to eradicate the weeds. The Egyptian Government has spread massive quantities of herbicides—with unknown ecological consequences—on its canal systems, only with the hope of containing the weeds and reducing their effects to manageable proportions.

Impacts on Health: Water-related Diseases. Water resources development projects are closely linked to water-related diseases. These infections are caused by agents that have close relations with water, and are not new in the regions they exist. For example, schistosomiasis was known during the Pharaonic times as calcified schistosoma eggs were found in mummies dating back to 1250 BC, and the method (still practised) of removing the guinea worm from the patient's wound was described by Hippocrates. Under natural conditions, the agents of these diseases are contained by seasonal variations of water availability and by limited contact between humans and water. Water resources development projects promote year-round favourable habitat for these agents, increasing the prevalence of their infections and spreading them to areas never infested before. Year-round abundance of water also means increased contact between humans and parasites/vectors, and this not only increases case number but the severity of the disease (parasite load per patient). Large water resources development projects in Africa (such as Lake Kariba in Zambia/Zimbabwe, Lake Volta in Ghana, Lake Kainji in Nigeria, and Lake Nasser in Egypt) have almost invariably led to considerable increases in the incidence of water-based infections and those caused by water-related insect vectors (Hughes and Hunter 1971; Milligan and Thomas 1986; Obeng 1978b). In the northeast of Thailand, the liver-fluke *Opisthorchis viverrini*, which infects 60–80 per cent of the population in many provinces (Harinasuta 1975), has been of concern in water development projects in the region. In one survey, it was found that the rate of liver-fluke infection in irrigated areas of the Nam Pong Project (Ubolratana Dam) was 42.4 per cent, whereas in non-irrigated villages within the irrigation areas the infection rates varied from 8.8 to 18.6 per cent (Mekong Committee 1979).

Among diseases spread by water development projects, schistosomiasis (also called bilharziasis, after Dr Theodor Bilharz, a German physician who first identified the parasite) deserves attention. It is caused by three species of the flatworm genus *Schistosoma* whose life cycle depends on freshwater snails. People get infected when they come into contact with water bodies containing the parasites released from snails. They, in turn, spread the disease by contaminating water with their excreta or urine containing schistosoma eggs. The eggs hatch in water to release larvae which must, within 24 hours, find a suitable snail as an intermediate host, or they will die. The disease is of concern in water development projects in Sub-Sahara Africa, Arabian Peninsula, the Nile Valley, Iran, a part of the Middle East, Brazil, Venezuela, the lesser Antilles and Puerto Rico, China, Japan the Philippines and (in a small focus) Indochina. The number and its victims is currently estimated to be 200 million. After Lake Volta was formed, an explosive growth of the water lettuce *Pistia stratiotes* formed an ideal habitat for snails which are hosts of schistosome larvae. The schistosome parasites were present among people who had arrived from infested areas, and these parasites started infesting the local snail population. Soon, outbreaks of the disease were observed in the new townships along the lake. The rate of infection increased steadily, and within two years nearly all children were affected. In Egypt, a scheme for perennial irrigation of four areas led to an increase, within 3 years, of the percentage of the population infected with schistosomiasis in all four areas from 2–11 per cent to 44–75 per cent. The life expectancy of the men and women living in infested areas is 27 and 25 years, respectively. The estimates for the increase in schistosomiasis cases due to the Aswan High Dam are between 2.6 to 6 million.

Transmitted by anopheline mosquitoes, malaria, whose victims in the world number 200 million, is also often associated with water development projects. The Sarda Canal Project was started in 1920 in India with a plan to irrigate nearly 3 million hectares. The work was almost abandoned in 1929 as the labour force suffered heavily from malaria; in one team as much as 90 per cent succumbed (Waddy 1975). The process of clearing vegetation from water encouraged sunlight breeding mosquito vectors of malaria. The Gezira Irrigation Project with the help of the Sennar Dam irrigated nearly half a million of hectares of semi-arid savanna south of Khartoum, Sudan. At first the irrigated land was almost exclusively planted with cotton. This allowed simple but effective mosquito control by drying out irrigation ditches once a week—the time required for the life cycle of mosquitoes from eggs to adults. But gradually other crops were also grown, and the periodic drying out of the land was abandoned. Consequently, malaria begun to spread and infected more than half the population in some villages (Donaldson 1978).

Other major diseases associated with water development projects include:

Bancroftian filariasis, which currently affects 250 million people. Transmitted by the bite of several species of mosquitoes, the parasite (*Wuchereria bancrofti*) lives in the lymphatics and causes the most characteristic symptom of elephantiasis, i.e. a massive overgrowth of the skin and subcutaneous tissues on the legs and scrotums, resulting in grotesque deformity and handicap.

African trypanosomiasis, a fatal infection whose victims total nearly 35 million. It is caused by two parasites of the genus *Trypanosoma* and transmitted by the tse-tse flies which breed in fast-flowing water. The parasite invades the patient's central nervous system, causing disturbed cerebral functions such as sleepiness (the disease being called 'sleeping sickness').

Onchocerciasis, which is caused by the worm *Onchocerca volvulus* and transmitted by the biting fly *Simulium* which breed in fast-flowing streams. The parasite itself normally causes no symptoms, but its larvae can enter the patient's eye, often leading to blindness. In Africa blindness is most commonly found near rivers in which the *Simulium* flies breed, hence the name 'river blindness'. The large dams in Africa have led to new exposures to onchocerciasis, especially during the construction stage as the velocity of the river is increased by narrowing the channel or by diverting it around the site. After construction (as in the case of the Volta Dam) breeding usually stops in the reservoir but may continue in the catchment area and spread the disease. For the Volta Dam Project, a 20-year international campaign involving several agencies and costing $120 million is underway to fight against river blindness, just one of the three major diseases spread by the dam project (Donaldson 1978). Although the programme led to an initial reduction of black fly populations, this reduction was achieved only temporarily. As the black fly is capable of wind-assisted dispersal over large areas, the area treated with insecticides is constantly invaded by flies from other areas.

When the project area attracts migration of people from other areas, these people may introduce new strains of locally endemic diseases or new diseases not normally found in the project area. On the other hand, newcomers may easily succumb to a disease that is indigenous in the project area. The eruption of malaria during the construction of the Panama Canal is a classical example.

An increase in water supply means an increase in resultant wastewater discharge. If the absorptive capacity of the soil is exceeded and without a wastewater collection system, open channels or pools of wastewater on the ground will serve as breeding sites for a number of diseases such as filariasis, haemorrhagic fever, intestinal parasites, etc.

Socio-Economic Impacts

Impacts on the Economy. Many of the impacts on the economy are derived from the impacts presented above. And they can even be quantified in monetary terms, such as the costs of reduction in fishery catches or of reduced soil fertility. Examples of impacts on the economy are:

- Loss of timber forest or low-lying farmland due to flooding, clearance, construction, or salinity erosion. Newly cleared land on higher grounds for compensation may not be as fertile as lost land.
- The deposition of silt upstream reduces the agricultural and/or fishery yields as well as natural biological productivity of the downstream areas.
- A development project attracts migration from other areas because it promises job opportunities or better basic services. Without long-term development planning, the project area will be burdened with an excessive population to feed, employ and house, leading to new socio-economic problems such as increase in living costs, unemployment, the development of slums, deterioration of public health, etc.

Without appropriate planning and management, potential benefits may not materialize. Fishery benefits of a dam/reservoir project may be substantial, but fish population management and suitable technology (methods and gear) used in catching fish are often ignored. Fishery on a deep and large reservoir is entirely different in many respects, from fishery on rivers that the local people are used to. Another problem in getting full economic benefit relates to distribution of benefits. Unequal distribution of a project's benefits has been a common problem in developing countries, when one group of people stand to benefit at the cost of another group. For instance, the total fish yield from a reservoir may increase but this yield is harvested by a small number of people. Furthermore, as has been experienced in Thailand (Harinasuta 1975), increase in fish production does not necessarily ensure increased income for fisherman, since most of the increased income may actually go to middlemen.

Impacts on Archaeological Sites. Before the Srinakarin Dam in Thailand was built, ecological surveys were conducted at the project area as part of an environmental impact assessment. The investigators found archaeological artifacts of the Hoabinhian age (named after Hoabinh Province in Vietnam where artifacts indicated a distinct prehistoric civilization age). The investigators (McGarry *et al.* 1972) recommended that this Hoabinhian area at the project area be excavated, any archaeological material found be moved to the National Museum, and during construction the workforce be alerted to the importance of the archaeological value of the area and report any sighting. Unfortunately, no significant follow-up was taken. The Thai Fine Arts Department was hampered by its vast area of responsibility and constrained by the lack of trained personnel. Consequently, the department was not able to render its full service to the investigation and excavation before construction (Phantumvanit 1979).

Before the Aswan Dam was built, the Abu-Simbell Temple located in the area to be flooded was successfully relocated to new site. This work, which was sponsored by Unesco, has been considered as a fine example of the preservation of archaeological treasures (ICOLD 1985). Another good example can be found in the Maduru Oya Project completed in 1985 in Sri Lanka. An ancient land and irrigation system was discovered under the surface when site clearing began. Archaeological investigations determined that some of the works were about 1600 years old, and of an extremely advanced technical quality. The Maduru Oya Dam was moved a distance upstream from its originally planned location to preserve the examples of early irrigation works.

Impacts on Socio-Cultural Structures. Water resources development projects may cause extensive upheaval on the socio-cultural structures of the project areas. The most well-known impact would be disruption of local people's livelihood in the area and their resettlement to a new area. In this regard, experience in developing countries has been a dismay. It is common to undertake a difficult and costly task of resettling tens of thousands of people for a single water resources development project. The Sanmen Gorge Project in China required relocation of 300,000 people who were unwilling to leave, and so created a number of problems (Wu 1986). The Pa Mong Project in Laos required resettlement of up to 460,000 people, or 16 per cent of the country's population. The total resettlement cost was estimated to be US$ 626 million (1975 value), according to Phantumvanit (1979). Approximately 100,000 people had to be relocated because of the Aswan High Dam.

Socio-economic impacts are complex and interrelated. Worse, many of them are intangible and easily cause controversies. Projections are difficult and good intentions may not give intended results due to peculiar and unpredictable human behaviour. In many African and Asian societies local people like to cling by all means to the land they are farming, to their deep-seated culture, their means of living, the food they are familiar with, etc. They will ignore all promises of a more civilized life. Local people, especially minorities, may have traditional social structures that outsiders (i.e. foreigners serving as project planners and designers) are entirely ignorant of.

In many cases, water development works are built in remote areas where ethnic minorities are not well understood or even acquainted. This was the situation in Quae Yai-Quae Noi Basin in Thailand, an ara of several major multipurpose projects and was inhabited by ethnic groups such as the Karen, Mon, and Lao (Phantumvanit 1979). It will be difficult to relocate people with their special cultural characteristics to a new environment. As to the people who have to leave their land, the experience is traumatic. When the Bennett Dam in Canada was built, the lifestyle of the local Indians and Metis was badly disrupted, and their social dislocation was serious. The situation was finally rectified at significant economic cost (Biswas 1980).

Quite often the work of resettlement has proceeded improperly, exacerbating the sufferings of relocated people. The Kariba Dam on the Zambesi displaced approximately 57,000 Tonga tribesmen, who suffered cultural shocks when moved to communities totally different from their own. An unsatisfactory settler/host relationship developed and led to a drawn-out conflict over land tenure. Being settled in a drier region, they had problems with planting and harvesting timings. They also faced severe food shortage as they could no longer catch fish and rodents (as they did when they lived on river banks) while land clearing did not progress as scheduled. And, ironically, they even suffered from water shortage (Obeng 1978a). But their hardship did not end there: in an effort to save the settlers from famine, the government had to send in food, and the food distribution centres became the transmission sites for trypanosomiasis (Milligan and Thomas 1986).

In another case, to build the Volta Dam in Ghana 78,000 people together with 973,000 animals in over 700 villages and towns had to be resettled. This was a nightmare since affected people previously living in small communities with different ethnic backgrounds, languages, traditions, religions, and social values and cultures, now had to live together in 52 locations (Biswas 1978). The complex emotional relationships between the different groups were not fully understood. Many of those being resettled near the newly formed reservoir were not fishermen, but had various occupations such as farming and trading, thus found themselves in entirely unknown hazards (Donaldson 1978). The impact of the change was terrible. Many people found it very hard to break altogether from their ancestral roots by leaving their gods, shrines and graves of ancestors. The adverse health that many relocated people experienced was not due solely to the new environment. Life disruption itself had harmful effects.

Despite the fact that socio-cultural impacts are complex in nature, they should be assessed to the extent possible. In the past, emphasis in project planning was biased towards physical planning. Gradually socio-cultural aspects were introduced into the planning process. International agencies, such as the World Bank, have insisted that the relocated people should be no worse off, and preferably better off, with the project. All resettlement costs, such as employment creation and compensation expenses, have to be incorporated in the project analysis. Detailed resettlement plans are essential before any project is to be appraised for assistance by the World Bank (Goodland 1986). While headquarters of agencies have a good intention, it may take time for local project personnel to seriously adopt the new policy direction.

CONCLUSION

This chapter is not meant to be negative towards development. It simply draws lessons from the past, so that what has happened will not be repeated in the future projects, and so that humans will have a good life.

All water resources development projects have environmental and social implications which are usually long-term, widespread and sometimes even irreversible. The real question is whether those changes are acceptable. It is not always easy to answer this question. One has to accept the hard fact that adverse impacts do happen, and very seriously. Perhaps the most well-known example of 'narrow-minded technology' is the Aswan High Dam. But still this does not mean that this dam should have never been built. It has doubled Egypt's electricity generating capacity, helped prevent disastrous floods, improved river navigation, created a vast potential fishery in the reservoir that has more than compensated for the sardine loss in the Mediterranean, and attracted more tourism. While the total construction cost of the dam (including subsidiary projects and electric power lines) was Egyptian Pounds 450 million, the annual return on full operation was 225 million (140 million from agricultural production, 100 million from hydropower, 10 million from flood protection, and 5 million from navigation). Dams and irrigation canals provide a lot of benefits, and more of them will be built. The question is how to avoid problems on our ecosystem which is so complex and still largely not understood.

While considering negative impacts, we should not ignore greater positive benefits, the real reason for development projects. Technology does exist to achieve the concept of balanced environment development. On the one hand, more water, food and other commodities have to be supplied to each person in an ever expanding population. On the other hand, the area of cultivable land is reducing and water is becoming scarcer each day. This necessitates a need for striking a balance between the environment and development.

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CHAPTER 2

Objectives and Concepts of Environmentally-sound Water Management

ASIT K. BISWAS

INTRODUCTION

Development in all fields during the past 3 to 4 decades has been significant, and water resources is no exception. For example, the number of dams throughout the world which have created large reservoirs having capacities higher than 100 million m^3, increased from a total of 1777 in 1951 to 2357 in 1985. During this period, major water projects were generally considered to be essential for further progress of developing countries in terms of simultaneously enhancing agricultural production and increasing hydroelectric power generation. This type of thinking was highlighted by Pandit Jawaharlal Nehru, the first Prime Minister of India, who termed the large dam at Bhakra as one of the 'temples of modern India'.

There is no doubt that for developing countries, which are all located in the tropical and sub-tropical regions with erratic rainfall patterns, efficient control and management of water has to be an essential requirement for their continued development. Without proper water management, self-sufficiency in food and energy will continue to be a mirage for most of these countries.

Scarcity of water and reliability of its supply are major constraints for agricultural development of arid and semi-arid countries. In most developing countries, many of all available sources of water which can be economically used have already been developed or are currently in the process of development. In some countries, such as Egypt or Jordan, there are already no new major sources of water that can be developed.

While the average amount of water available to each country remains constant, the demand for water is going up steadily for two important reasons. First, population in developing countries is increasing steadily. The world population in mid-1990 was estimated at 5.29 billion, which is nearly twice what it was only four decades ago in 1950. It is estimated that by the year 2000 the world population is likely to cross 6 billion. Currently, over three-quarters of the world population live in developing countries, and it is in these countries that 90 per cent of the projected population growth will occur. To provide the needs of this expanding population, more and more water will be required for domestic purposes, agriculture, industry, and hydropower generation.

Secondly, past experiences indicate that as the standard of living improves, the demand for water increases as well.

Thus, the major challenge facing water planners and managers in the 1990s is that while the physical availability of water in any country is fixed, its demand in all developing countries will continue to increase steadily in the foreseeable future. Accordingly, the problem is how to balance demand and supply of water under these difficult conditions since, unlike oil, water cannot be easily exported from a water-surplus country to a water-deficient country due to a combination of economic, political and environmental reasons. There is really only one solution, that is, to manage the available water resources in each country in an efficient and environmentally-sound manner.

ENVIRONMENTALLY-SOUND WATER MANAGEMENT

With the increasing awareness of environmental issues during the past two decades, there has been a growing concern about the adverse social and environmental impacts of water development projects in many developing countries. As discussed in Chapter 1, projects that have been intended to stimulate economic growth or provide more food have sometimes had adverse effects on agricultural lands, forests or fisheries, and on local communities. Doubts have been raised as to whether the goals that are being sought in water development programmes can be achieved without serious disruption of the environment or severe social impacts.

The matter of environment and development became an issue of increasing international concern in the mid-1960s. At that time the prevailing view seemed to be that environmental disruption was an inevitable price to be paid for economic progress. Since then, however, this position has been increasingly challenged in several fora organized by various United Nations bodies, in the scholarly literature and elsewhere. There is growing consensus today that, given certain preconditions, *both* economic development and environmental management can be pursued simultaneously (Tolba 1982). Arguments supporting this shift in viewpoint have focused predominantly on the water resources scene. It is here perhaps that the apparent conflict has been particularly sharp but also where the attempts to find an accommodation have been most sustained.

This chapter attempts to address the issue of the manner in which the philosophy underlying environmentally-sound water management can be encouraged and facilitated on an even wider scale. It takes the view that the key to reconciling the apparent conflict between development and environment lies in the incorporation of three critical elements in planning and policy making:

1. recognition of the concepts of sustainable development and resilience;
2. the adoption of a comprehensive viewpoint; and
3. the pursuit of higher levels of efficiency.

Any attempt to develop water resources results in some modification of the environment. Sometimes the impact is confirmed mainly in the river region, aquifer or lake itself, as in an alteration in the normal flow or the quality of the water body. In other instances the effects are much more widespread and may result in considerable alterations in land resources, forests or fisheries. Beyond this, water development may have major impacts on human settlements and economic activities. The seriousness of these impacts depends upon the ability of the various physical, natural and human systems to absorb them, as well as human perceptions about them (Biswas 1984).

To a significant extent the environmental impacts of water management are beneficial, particularly when they open up new avenues for economic development or social improvement without serious impairment of the resource base or the ecological system. The creation of a reservoir, for example, may provide additional habitat for the raising of fish or new opportunities for water-based recreation. Often, however, environmental consequences are adverse, varying in the degree of their intensity and social acceptability.

It should be clear from Chapter 1 that environment has a wide variety of meanings and that environmental disruption can take many forms. In some instances water projects may even result in the destruction of the resource on which they depend. It is also apparent that severe damage may be sustained by other resources or by activities in addition to those directly related to water development. At the same time experience across the world indicates that many of the problems of reconciling development and environment result from a failure to consider them simultaneously. Thus, in many countries there are ministries of industry and development which work in isolation from ministries of the environment. Often, too, the latter may be isolated from ministries dealing with various resources. Such separation clearly militates against the adoption of a holistic view. In addition, there is typically little attention given to possibilities for improving efficiency in the use of capital on the one hand and the use of water on the other. An overemphasis on construction alternatives has deflected attention from such options as demand management, which would not only reduce capital requirements but also be environmentally less disruptive. Various commissions and authors have observed that there is enormous waste in water supply systems, notably those involved in urban water supply and irrigation. They have also drawn attention to advantages of pricing mechanisms and which reflect the true costs of supply and the value of water in use.

Recognition of these disadvantages and deficiencies has led to increasing pressure for the specific inclusion of environmental effects as a consideration in water resources planning and policy making.

Environmentally-sound water management implies that:

1. development be controlled in such a way as to ensure that the resource itself is maintained and that adverse effects on other resources are considered and where possible ameliorated;
2. options for future development are not foreclosed; and
3. efficiency in water use and in the use of capital are key criteria in strategy selection.

Recognizing these ideas is one thing; translating them into action is another. What needs to be done beyond the preparation of handbooks, staging of training programmes and conducting of planning experiments? More specifically, what is required to foster the adoption of the three elements noted above in planning and policy making are: namely, the recognition of concepts of environmentally-sound development and resilience, the incorporation of a more comprehensive perspective and the pursuit of higher levels of efficiency.

None of the elements is entirely new, All have been introduced in varying degrees across the world. An examination of a number of themes of contemporary water management which incorporate one or more of the three elements will follow next.

THEMES OF CONTEMPORARY WATER MANAGEMENT

There have been some important changes in the approach to water management in various parts of the world during the past 30 years or so. Seven sets of concepts or themes may be identified, as follows:

1. the adoption of a comprehensive viewpoint;
2. the promotion of a search for the widest possible range of choice;
3. the recognition of water as an economic good;
4. the use of the river basin as a unit of area in various phases of water management;
5. the involvement of the public in planning and policy making;
6. the consideration of environmental impacts; and
7. the assessment of social impacts.

Comprehensive Viewpoint

The adoption of a comprehensive viewpoint implies the recognition of several important concepts in water management. One is that there are numerous potential uses of a given resource and that each has some effect on all the others. Occasionally, the pursuit of one may preclude several others, as in the use of a stream for the disposal of toxic wastes. Optimal use of the stream can only be attained if all the potential uses are considered simultaneously and a combination is chosen that conforms to a selected criterion, such as the maximum net economic return or the preservation of a particular ecological web.

A second concept is that use can sometimes be enhanced if several purposes are pursued simultaneously, that is, in a multiple purpose project. There are numerous possibilities, such as in hydroelectric power generation, flood control and irrigation development, as illustrated by the Columbia River scheme or in the development of the Tennessee Valley in the USA.

A third idea is that of the interrelationship of water development with the development of other resources. Water schemes often have effects upon land resources, as in erosion or the flooding of agricultural land. Similarly, land use practices can influence both runoff and water quality. Removal of vegetation or the introduction of irrigation are illustrations. Obviously the pursuit of particular goals in water development may impair the attainment of objectives in the management of other resources and vice versa. It makes sense, therefore, to identify such interrelationships and seek accommodation of effects in water planning.

Fourthly, a comprehensive viewpoint may imply the integration of water planning with overall economic and social planning. This is especially important when water is scarce and is vital to an economy, as in Egypt or Jordan, or when water development is costly and may account for a large proportion of capital investment in a country. This is particularly true in developing countries; but it has become increasingly so in a number of industrially advanced ones as well, notably the United Kingdom.

Finally, the adoption of a comprehensive viewpoint has implied a recognition that water resources management requires inputs from a wide range of disciplines. Today the engineering profession is joined increasingly by specialists from such disciplines as economics, law, geography, sociology, biology and even psychology. A measure of the sophistication that water planning has reached may well be the number of disciplines that have been called upon to make concrete contributions to it.

The adoption of a more comprehensive viewpoint has been accomplished through a variety of modifications to existing institutions. These include the integration of *purposes* of management (such as provision of water supply, improvement of water quality, flood control, water-based recreation, etc.). Initially each purpose is undertaken independently, usually with separate legislation and administrative agencies. Eventually conflicts appear and economies of integration also become apparent. Larger, more comprehensive water agencies are then established. Increasingly today, the tendency is to link water development with other resource development, and, even more, to environmental management. The omnibus ministry of natural resources or ministry of the environment has become a widespread feature in North America, Western Europe and several other parts of the world.

A similar process of integration may be envisioned with respect to specific functions of water management, such as data collection,

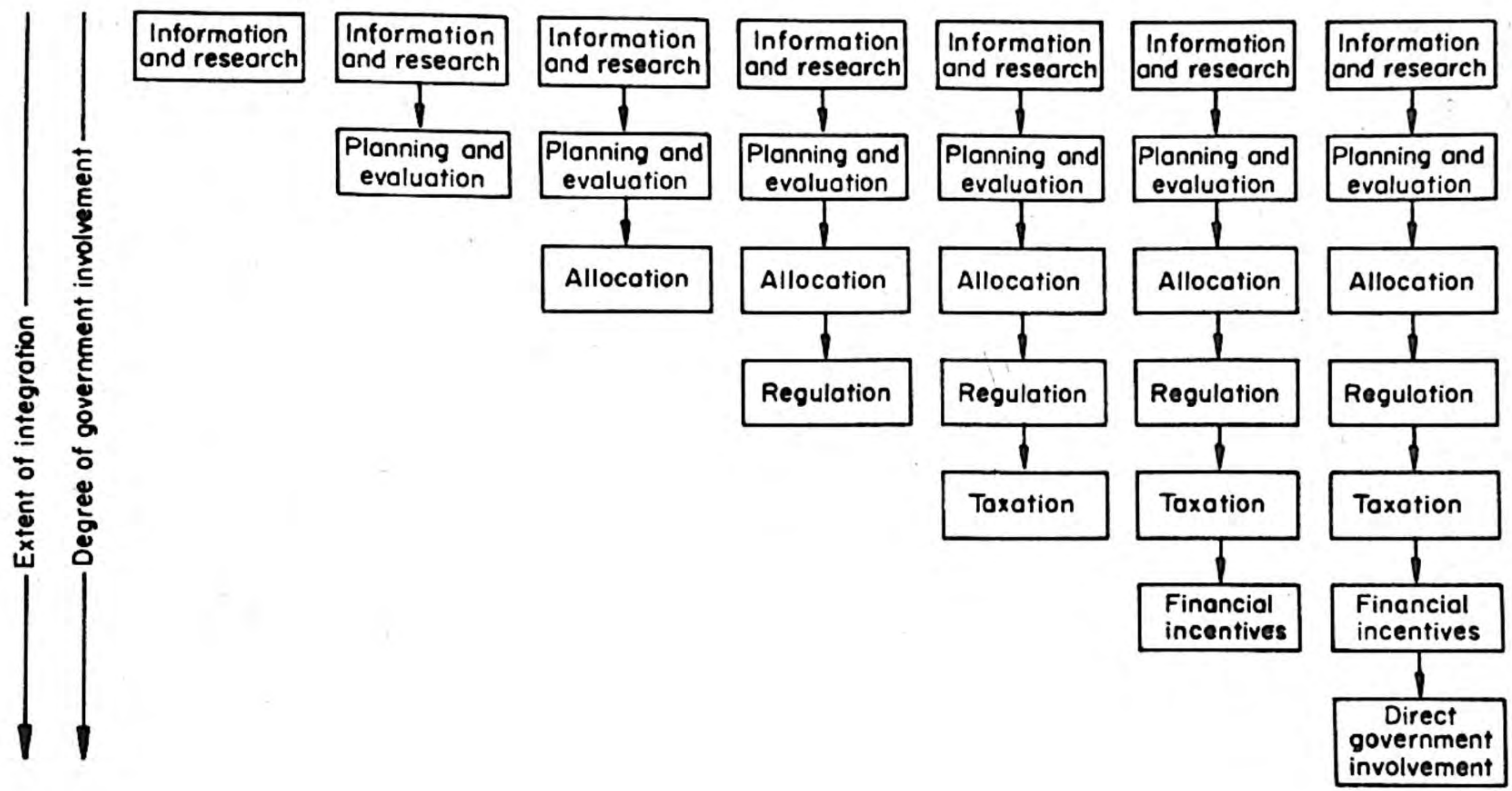

FIGURE 1. Integration of functions

research, regulation and development. As depicted in Fig. 1, there is a gradual increase in the scale and sophistication of functions. With respect to data, for example, the initial focus is upon the supply side; but it slowly expands to embrace the demand side and various economic, social and environmental considerations as well. It may be noticed that as the scale of management grows there is a growing tendency for government involvement to increase, reflecting in large measure the need to reconcile conflicts, provide public goods and to link water management to overall economic and social development.

Range of Choice

Theoretically there are several possible ways in which a given water problem might be dealt with or a water-related service provided. White (1964) and Smith and Handmer (1984) have shown, for example, that there may be as many as a dozen different strategies for reducing flood losses as shown in Table 1. An impending water shortage in a city might be accommodated in at least nine alternative ways (Table 2). Experience in North America, Europe and elsewhere has shown, however, that only a limited range of such options is typically considered by water managers and that this may lead to suboptimal choices, as reflected in higher economic costs, significant social losses or major environmental damages.

In several countries there is now a conscious attempt to canvass as wide a range of options as possible and to review the implications of adopting each of them. In the case of flood losses, for example, land use regulation and structural adjustments are considered together with various construction alternatives. Where water quality is at issue, incentives as well as penalties are now taken into account. Moreover, there are attempts to deal with the causes as well as the symptoms of pollution problems as shown in Table 3.

Water as an Economic Good

There has been mounting pressure from economists and others in recent years for water to be treated like any other natural resource, such as forests, fisheries or minerals: that is, to regard it as an economic good which can be traded in the market. Fees, it is argued, should be charged by the owner (generally the government) for its use and the price of services provided by its development should satisfactorily reflect the cost of supplying them. Marginal

TABLE 1. Classification of flood adjustments: structural/non-structural mode of implementation and the theoretical effect on losses

	Governmental[a]/Engineering[b]	*Institutional[c]*	*Individual*	*Effect on losses*
Structural	Dams Levees Diversions and channel improvements Retarding basins			Prevent losses
Non-structural		Acquisition Non-regulatory measures: fiscal and financial incentives, infrastructure provisions Regulations: zoning, sub-division and building regulations Information and education Forecasts, warning systems, emergency plans Salvage	House raising Small levees Other flood proofing local warning systems Response to warning Salvage	Modify losses
		State and national emergency services Insurance Relief		Redistribute loss
Do nothing				Accept loss

[a] Government measures are those requiring a central authority to make and enforce regulations, to administer financial incentives/disincentives and to finance, construct and maintain major works. In the last case involvement may be through an agency regulating private enterprise.

[b] Engineering refers to the construction of major public works.

[c] Institutional measures are those requiring the direct involvement of government authorities through, for example, land use regulations, or their indirect involvement as guardians of the public interest, for instance by controlling the insurance industry.

TABLE 2. Alternatives for meeting increasing demands

Goals	*Approaches*	*Techniques*
Bear shortage or pollution		
Use available supply	Storage	Reservoirs Storm catchment
	Transport	Aqueducts Ground pumpage Motive transport
Increase overall supply	Precipitation inducement	Cloud seeding
	Increase and capture snow and ice-melt	
Improve water quality	Treat influent	Freshwater purification Desalination
	Treat effluent	Advanced waste treatment
Change water use	Reduce use or alter demands	Price curbs, metering Use restrictions
	Curb waste	Evapo-transpiration reduction Seepage reduction
	Alter distribution	Dual supply lines Direct pipelines Bottled water

TABLE 3. Opportunities for applying institutional instruments for water pollution control

Production–consumption stage	*Policy instruments*
Input mix	Use charges, taxes, pricing, raw material specification, subsidies/grants
Production	Land use zoning, taxes, subsidies/grants, process specification
Product output	Product specification, taxes
Product use	Taxes, pricing, subsidies/grants
Pollutant discharge	Collective treatment, (user charges) emission standards subsidies/grants, dilution rights/transferable discharge permits, withhold discharge during periods of low flow
Environment (ambient water)	Ambient standards, mixing zones specification

costs rather than average costs should be used as the basis for pricing such services. Economists also argue that water should be allocated among competing users or uses on the basis of the economic value derived, that is, the value in use. The higher the value, the more the user will be willing to pay. Finally, they suggest, the scope and scale of water projects should be determined through a comparison of benefits and costs. Such an evaluation would weigh the gains and losses of various scales of development and and various combinations of uses. Optimum scales and combinations would be those which produced the largest net benefits.

Recognition of such concepts has taken a variety of forms in water resources planning. Cost–benefit analysis and its more sophisticated derivations are now used by water agencies all over the world. There is an extensive literature describing its conceptual underpinnings and its potential applications. There are several handbooks that show how to use the technique.

In addition to introducing and refining cost–benefit analysis, economists have helped to improve water demand forecasting. At one time, estimates of future demands were based on little more than straight-line extrapolations of recent water use. No account was taken of such factors as the elasticity of demand or changes in technology or product mix. Research on such matters has materially helped improve forecasting techniques.

River Basin as an Unit of Area

The river basin has become increasingly accepted as a unit for water resources management. The rationale stems from the concept of a river as an organic entity, so that interference with or modification of any part of it will be felt elsewhere in the system. Engineers and geographers in particular have espoused the idea. Economists have recognized it, since it is an attractive way of internalizing externalities.

The extent to which the river basin has been adopted as a unit, however, has varied considerably. In England and Wales, France and India it is now used as the unit for all phases of water management in the country as a whole. In some countries it is employed for the management of water in specific regions, such as in the Tennessee Valley in the USA or in the Conservation Authorities in Ontario in Canada. Its most extensive use has been as a basis for the collection of data on water quantity and quality. Increasingly, however, it is being employed as the unit for water resources planning. Worldwide, examples can be found, as also manuals describing principles and setting out data requirements and procedures.

Public Involvement

Thirty years ago there was little attempt in most countries to consult the public on goals and strategies in water planning. The same was true in many of them even a decade ago. Generally, it was believed that planners and politicians could accurately gauge what the public wanted and how it would react to what was provided. Where public consultation did take place it was almost always at the end of the planning process. Mounting pressure, on grounds both of ethics and pragmatism, however, has resulted in a major shift towards a more direct role for the public in shaping options and in making decisions.

Public involvement, of course, can take a wide variety of forms as shown in Table 4. In some cases it amounts to little more than tokenism, with plans submitted for public approval, sometimes through the ballot box or in the public hearing at the end of the process. Sometimes there is no dialogue at all. Increasingly, however, a more productive role has been created in which a wider range of perspectives and talents can be called upon. The task force and the workshop are illustrative. Particular progress in this respect has been made in Canada, New Zealand and the USA. Attempts

TABLE 4. Strategies for public involvement

1. Public opinion polls and other surveys	Increasing time commitment and value of feedback ↓
2. Referenda	
3. The ballot box	
4. Letters to editors or public officials	
5. Public hearing of inquiries	
6. Advocacy planning	
7. Representations of pressure groups	
8. Public meetings	
9. Workshops or seminars	
10. Protests and demonstrations	
11. Court actions	
12. Task forces	

are now being made in several developing countries, especially in Asia, to involve water users directly in water management process. In Pakistan it has now become a legal requirement.

Environmental Impacts

The assessment of the impacts of water development projects on the environment has come to be recognized as an integral part of planning. Until about 15 years ago there was little or no public concern about such matters and professionals in the water industry saw no reason to be worried about anything other than the manner in which environmental modification would affect the efficient operation of facilities. Today, however, water management agencies almost everywhere are highly conscious of the need to identify and evaluate the impact of projects on physical phenomena and on ecological systems. In some countries environmental impact assessment is now an elaborate process, often involving research and considerable interaction with various interest groups within the public. In some cases guidelines are provided as to what should be taken into account and how various impacts should be measured. Properly done, impact assessment involves a wide range of disciplines and a wide spectrum of interests (Biswas 1990; Biswas and Qu 1986).

Social Impacts

Over the past 30 years attention in the evaluation of water resources plans has gradually shifted from technical considerations to economic and environmental factors. More recently it has begun to embrace social impacts as well. Questions are being posed, for example, as to how far given schemes will disrupt traditional lifestyles, create ghost towns once construction is completed or set in motion a train of native land claims or a movement for a new political structure. Such questions have particular relevance in northern North America where clashes between quite different sets of cultural values are inevitable. Similar concerns have begun to arise in other areas too, notably in New Zealand where Maoris' lands and other rights might be involved, in Australia where there is growing pressure for the recognition of aboriginal rights, and in Narmada Valley in India.

Several responses have been made. One has been to highlight social effects in environmental impact assessments relating to water development projects. Another has been to foster the preparation of broadly based strategic plans for regions which are presently sparsely inhabited but which may come under considerable pressure for development in the future.

Each of the themes has resulted in a variety of institutional responses. Sometimes this has been expressed in wholesale restructuring of water management legislation, policies and administrative apparatus, as occurred in England and Wales in 1963 and in France in 1964. More often it has fostered institutional changes with respect to a particular water use or a particular water management purpose, such as reduction of damages from floods or droughts, as was the case in the USA, or Canada. A brief indication of some of the responses is provided in Table 5.

Experience in the adoption of the various concepts has varied considerably from one country to another. This has reflected the fact that problems vary both in their nature and severity from place to place. It has also reflected differences in political culture. In some countries there is an almost built-in penchant for change; in others there is an overpowering respect for the traditional way of doing things. Besides this, some countries are spurred into innovation by necessity while others can afford the luxury of biding their time.

It is possible to discern, therefore, a spectrum of adoption. Some countries have introduced several of the ideas with great enthusiasm. In contrast, there are a number where management today is just about the same as it was 30 years ago—or even longer. This is not necessarily bad. It may well be that the style adopted is appropriate to the physical, economic and cultural circumstances. Approaches tend to reflect stages of institutional evolution. One might expect, for example, that a country that has reached a high level of economic development, such as the USA, France or the UK, would tend to place high pressure on its water resources and would develop fairly sophisticated laws, policies and administrative arrangements to deal with the problems that have emerged. In many instances this would be likely to result in an increasing degree of government involvement. Such a situation might contrast vividly with that in certain Third World countries, such as Sierra Leone or Tanzania, where legal codes are simple, policies cover fewer issues and administrative arrangements tend to deal with single issues rather than a broad spectrum of problems in a coordinated manner. What is said about water institutions may also characterize institutions dealing with environmental management.

TABLE 5. Contemporary concepts in water management and associated institutional responses

Concepts	*Institutional responses*	*Illustrations*
1. Broadening perspective		
a) Coordinated water management	Omnibus national water agencies	India, Jordan, Israel, Hungary, Egypt, Sudan, Zambia, Zimbabwe
b) Links with environmental management	Ministers of environment with water resources branches	Canada, UK, France
c) Links with economic and social policy	Planning commissions or coordinating bodies	Israel, Hungary, France, India
d) Broadening range of professions	Professionals from disciplines beyond engineering, including law, economics, biology, geography	Canada, USA, UK
2. Expanding the range of choice	Policies to improve water use efficiency, such as recycling, wastewater renovation, planting of drought resistant crops	USA, UK, Israel, India, Egypt, Jordan
	Policies to supplement construction options such as flood insurance, land use control, flood plain mapping	USA, Canada, UK
3. Water as an economic good	Charges for resource use: water withdrawal charges, prices to reflect real costs	UK, France, Canada, New South Wales, South Australia, Zimbabwe, Israel
	Allocations to reflect values in use, metering	Fylde; UK; Denver, USA; Nairobi, Kenya
4. The river basin as a unit for management	River basin planning	USA, Canada, UK, France, India, Hungary
	River basin management	TVA (USA), RWA's (UK), ABF's (France), DVC (India), Gennossenschaften (FR Germany)
5. Public involvement	*Ad hoc*, usually at end of process, narrow range of methods	Most countries

TABLE 5. *Continued*

Concepts	*Institutional responses*	*Illustrations*
	Continuous, often	USA, Canada, UK, France required by law, using wide range of methods
6. Environmental protection as key element in water management	Specific legislation or clauses in water legislation	USA, Canada, UK, India
	Environmental impact assessment	USA, Canada, France, UK, New Zealand, FR Germany, India
7. Protection of minority rights and redress of social losses	Social impact assessment	Canada, New Zealand, USA, UK
	Settlement of native land claims	Canada, USA, New Zealand
	Institution of compensation measures	Canada, USA, New Zealand

CONSTRAINTS TO ENVIRONMENTALLY-SOUND MANAGEMENT

A voluminous literature exists at present which considers at least some aspects of environmentally-sound water development. In recent years it has generally been assumed, at least implicitly, that adequate knowledge is available on how to plan, design and manage water resources systems in order that environmental disruptions could be reduced to a minimum, and whatever residual disruptions occur would be considered acceptable to society as a whole. The real problem was thought to be not the lack of knowledge but appropriate application of the knowledge available to solve the problems. This 'application gap' was often considered to be the real problem, especially in most developing countries.

A comprehensive and critical analysis of existing literature on environmental aspects of water development indicates that there are many constraints which limit the potential application of available knowledge by water professionals and decision-makers in developing countries. On the basis of this analysis, the following four major constraints can be identified:

1. incomplete framework for analysis;
2. lack of appropriate methodology;
3. inadequacy of knowledge; and
4. institutional constraints.

It should be noted that the four major constraints identified are not independent. On the contrary, they are often closely interrelated.

Incomplete Framework for Analysis

The framework currently used for analysing and considering various environmental impacts associated with water development projects is overwhelmingly biased towards assessing only the negative impacts. Realistically, any reasonable water development project will have discernible impacts on rural development, environment and health, though the magnitude and extent of these impacts will vary from one project to another. Indeed, the very fact that any given project has been approved for implementation indicates that decision-makers expect it to have certain positive impacts on society; otherwise there would be no reason to waste scarce resources.

To a certain extent the emphasis on the negative impacts of projects and programmes is not difficult to explain. In the 1960s analyses of water development projects considered primarily technical and economic factors; environmental and social issues were generally ignored. Concerned with the adverse impacts of many development projects on society and the environment, a movement gradually developed to protect and preserve the environment. Environmental protection became an important political issue in the late 1960s, at least in many developed countries, through the activities of environmental pressure groups and non-governmental organizations.

This attitude to and perception of environmental protection was reflected in the United Nations Conference on the Human Environment held in Stockholm in 1972. An analysis of the Stockholm Action Plan that was finally approved by all the member countries of the United Nations would clearly indicate its negative approach to environmental management—stop all pollution stemming from any development activity, stop exhausting non-renewable resources, and stop using renewable resources faster than their replacement (Biswas and Biswas 1982). The emphasis was thus primarily on the adverse impacts of development.

Not surprisingly, environmental impact analysis, which was made mandatory in many developed countries in the late 1960s and early 1970s, was mainly concerned with the identification and amelioration of negative impacts; positive impacts were generally not considered. Because of this beginning, the term 'impact' has continued to have negative connotations.

So far as large-scale water development projects were concerned, another event of this period worth noting is the publication of a series of articles by Claire Sterling in the popular media on the adverse social and environmental impacts of the newly built Aswan High Dam in Egypt. She concentrated only on serious negative impacts of the Aswan High Dam, such as the loss of the Mediterranean fishery, an increase in schistosomiasis, salinity development, a reduction in the fertility of the Nile Valley through the absence of silt deposition, and coastal erosion of the Nile Delta. These articles, published at the peak of the environmental movement and in a 'small is beautiful' era, made the Aswan dam a *cause célèbre*. In retrospect such articles both helped and hindered later water development projects in terms of environmental issues.

They helped in the sense that social and environmental impacts of water development, which were generally a neglected subject around that time, became issues receiving due consideration. By drawing attention to these issues it was made clear to the engineering profession, which dominated and still dominates the water development field, that there are other important dimensions in addition to the techno-economic ones in which society is interested. Accordingly, increasingly more environmental and social impact analyses of water development projects have been carried out during the past decade. However, the emphasis has continued to be on the identification of only the negative impacts of water development and ways to ameliorate them.

Numerous examples can be provided for this all-pervasive bias. Only two examples will be cited here, one generic and the other case-specific.

On a conceptual basis, every time the health implications of irrigation projects are reviewed, the main consideration has been the presence of vector-borne diseases such as schistosomiasis and malaria. Irrespective of whether the increase in the prevalence of such water-borne diseases was due to water projects or not—an issue that will be discussed later—such an approach is not only biased but also somewhat simplistic and erroneous.

Viewed in any fashion, ırrigation is an integral part of rural development. As the project develops, agricultural production increases as well. With a better per capita food availability and a more diversified crop production, food and nutrition levels increase. The situation is further improved by increased livestock holding and development of inland fisheries in the reservoirs. An increase in the availability of animal protein is an important factor to consider in many irrigated agricultural projects, but has unfortunately been mostly neglected. For example, the mid-term evaluation of the Bhima Command Area Development Project in Maharashtra, India, clearly indicates the impact of increased livestock holding, even amongst landless labourers, on the nutritional status of the people (Biswas 1987).

In addition to improved food and nutrition, the health status of the rural people is further advanced by improvements in education, health facilities, the status of women, and general advances in the overall quality of life. This is shown diagrammatically in Fig. 2. At present, instead of considering the overall health situation in project areas, only the negative impacts are being accentuated.

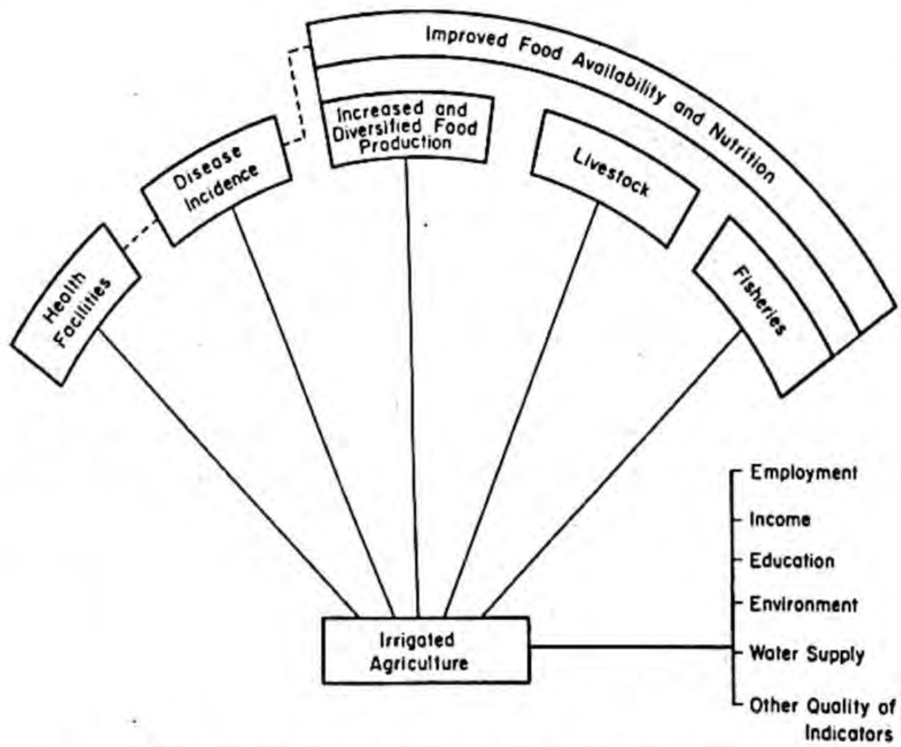

FIGURE 2. Pathways of interrelationships between irrigated agriculture and health

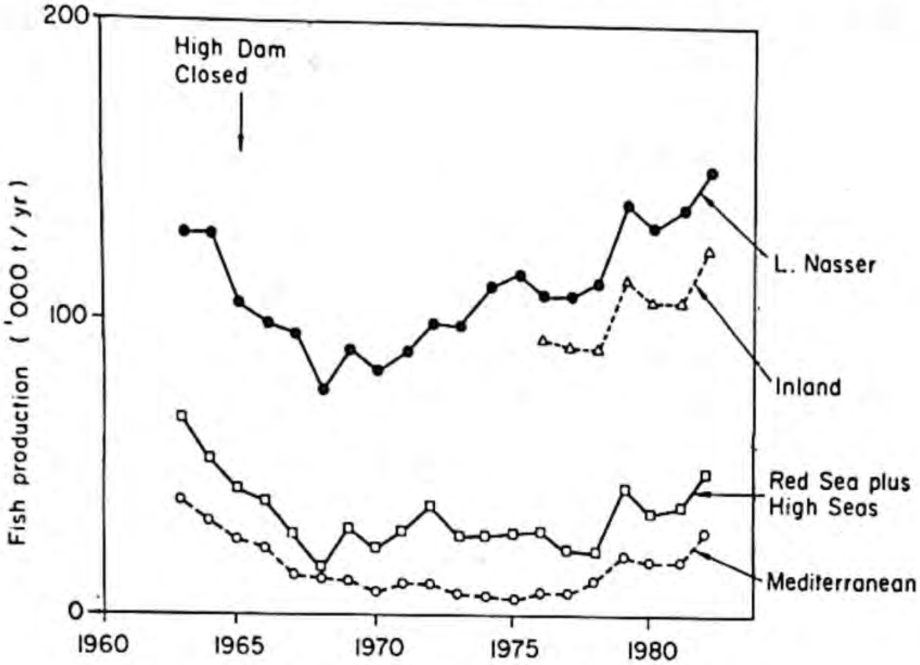

FIGURE 3. Total fish production, 1963–82

The case-specific example is the overall impact of the Aswan High Dam on fish production in Egypt. Starting from the time of Claire Sterling, much has been written on the decline of the fish catch in the Eastern Mediterranean due to the dam. On the basis of data available in FAO databanks, fish production in Egypt in the High Dam Lake, the Mediterranean and other areas was analysed for the period 1963–82. This is shown in Fig. 3, which indicates that fish production in the Mediterranean started to decline around 1963. The production of fish reached a minimum in 1975, but since then catches have been rising steadily. If the 'new' fish production system in the High Dam Lake is considered, total catches have always been significantly higher than at any time in the Mediterranean. Fish production started to decline in the High Dam Lake around the time of the closing of the dam, but it has now not only recovered but is higher than the initial production. The combined fish production in the Mediterranean and the High Dam Lake has been significantly higher than production from the Mediterranean alone before the Aswan Dam was built. Accordingly, the overall impact of the Aswan Dam on fish production in Egypt has been overwhelmingly positive, and not negative as most environmental literature suggests.

The beneficiaries, however, are not the same. Admittedly Mediterranean fishermen who did not wish to be relocated to the

High Dam Lake area have suffered serious economic hardships.

What is thus needed is a balanced framework for analysis which will identify both positive and negative impacts. The next step should then be how to maximize the positive impacts and minimize the negative ones. A framework that considers only the negative impacts and ignores the positive ones is both incomplete and counterproductive.

Lack of Appropriate Methodology

A review of the processes currently used by developing countries to incorporate environmental issues in water management indicates that the methodologies available at present do not appear to satisfy the special requirements of those countries. While the environmental impact assessment (EIA) process was made mandatory in several industrialized countries, its actual use so far in developing countries has been somewhat slow. The reason for this slow acceptance is the lack of an operational methodology that can be successfully applied in developing countries with limited expertise, resources, data and time. The EIA methodologies that are being used in industrialized countries are not directly transferable to developing countries for various socio-economic and institutional reasons. Even in those developing countries where multilateral and bilateral aid agencies have carried out fairly comprehensive environmental impact analyses of water development projects, primarily with foreign experts and consultants, their overall effect in developing countries appears to have been generally minor. This is because such EIAs were carried out primarily to satisfy the internal requirements of the bilateral donor countries and multilateral funding agencies, and generally not at the behest of the developing countries in which the projects were located. Not surprisingly, the involvement and interest of developing countries in such external analyses have been minimal and somewhat superficial.

It is clear that complex, lengthy, expensive and time-consuming EIAs as practised in developed countries are not the right tool to assess the impacts of water development projects in developing countries. Under certain conditions complex EIAs may even prove to be detrimental, and they may hinder than enlighten the overall process of water development. As already pointed out, what is urgently necessary is the integration of EIAs into a broader multi-objective decision-making framework and the development of an operationally-sound methodology that is flexible and at the same time can be carried out within the limited costs, time frame and expertise available in developing countries.

Even though the United Nations agencies have put much effort into trying to develop such operational methodologies for developing countries, it has to be admitted that the process has been, for the most part, a failure. The guidelines prepared for various subjects are often elementary, and are of no use to any operational agency. Conceptually, as argued by UNEP's Regional Office in Bangkok, the EIA is only a 'pre-project' activity, which means that project impacts, even though analysed and identified properly, are not likely to change radically. Without any follow-up monitoring and implementation activities, the usefulness of EIA is reduced significantly and can at best be of marginal value. It becomes primarily a paper exercise to satisfy legal and institutional requirements and not a tool for effective impact management.

It is now clear that nearly all of what is now available in the area of EIA is of limited use for operational purposes in developing countries. What is necessary is to develop some guidelines which can actually be used by professionals for water management in planning and managing projects.

Lack of Adequate Knowledge

There are many areas where adequate technical knowledge may not exist for getting reliable answers. Equally, there are areas where 'conventional' knowledge can at best be dubious and at worst totally erroneous.

There are many areas where not only our knowledge is limited but we are also not even asking the right questions. For example, if the problem of vector-borne diseases is considered, probably the two most widespread and important are malaria and schistosomiasis. However, if we ask a simple question like to what extent a water development project *per se* may increase the incidence of malaria or schistosomiasis, there are no straightforward answers. The problem is further complicated by the case-specific nature of the answers.

In case of malaria, an exhaustive study by the Indian Malaria Research Centre indicates that the resurgence of the disease occurred independently of the green revolution. There is, however, no doubt that irrigation, agricultural practices, rice cultivation and migration of agricultural labour have all had an important bearing on mosquito vector fauna and malaria transmission (Sharma 1987). The linkages are not clear, and there is no evidence to indicate a one-to-one relationship between irrigation development and additional malarial incidences.

There are other complex issues that need to be considered for malaria. A study of two villages in the Kano plains of Kenya, one a newly established village within the 800-hectare Ahero rice irrigation scheme and another an older village nearby in a non-irrigated area with traditional mixed agriculture, showed remarkable differences in terms of differing mosquito species. In the new village 65 per cent of mosquito bites were from the *Anopheles gambiae* complex (principal vectors of malaria in tropical Africa), 28 per cent were of *Mansonia* species (vectors of lymphatic filariasis and Rift Valley fever), and 5 per cent were of *Culex quinquefasciatus* variety (another vector of lymphatic filariasis). In contrast, 99 per cent of the mosquitoes in the older village belonged to *Mansonia* species and less than 1 per cent *Anopheles gambiae*. Thus irrigation can change the transmission patterns of mosquito-borne diseases. This is an especially important consideration for tropical Africa where most of the global total of more than one million deaths due to malaria now occur (Biswas 1986).

There is also the issue of stratification. The evaluation of the Bhima command area development indicates that malaria appears to be attacking women more than men (Biswas 1987). How widespread this stratification is, either in India or elsewhere, is unknown since this type of question is not being asked at present, let alone being answered.

If schistosomiasis is considered, there is no doubt that the presence of an irrigation system in a developing country with extended shorelines of reservoirs and banks of canals contributes to a more favourable habitat for snails when compared to the pre-construction period. It will naturally have a tendency to increase the incidence of schistosomiasis. While no one would argue with this simple and acceptable fact, the question concerning the extent to which irrigation practices *per se* contribute to the increase in the incidence of schistosomiasis is more difficult, if not impossible, to answer at the present state of knowledge.

A perusal of the literature available will indicate a plethora of statements and so-called 'facts and figures' on the increase in schistosomiasis and other vector-borne diseases caused by the construction of irrigation systems. While it is accepted that such general statements had an important role to play in the late 1960s and the 1970s to sensitize engineers, decision-makers and general public to the importance of considering vector-borne diseases, very little progress has been made in the 1980s to give water planners and administrators the specific information they need to improve the planning and management processes.

One of the major problems with respect to the incidence of vector-borne diseases resulting from irrigation projects stems from the lack of an adequate number of scientifically rigorous studies. It is a subject that is replete with poor and conflicting information, repetition of data that have seldom been critically examined, and elucidation of personal biases. International organizations have to a certain extent contributed to this situation, albeit not deliberately. For example, the WHO's statement that globally some 200 million people are infected with schistosomiasis has remained remarkably constant since at least 1969. UNEP has incorrectly stated in the past that schistosomiasis has been completely eradicated in China. FAO publications have erroneously mentioned that water development significantly increases onchocerciasis, whereas all the evidence available indicates the opposite. The FAO (1987) has repeated examples of increases in schistosomiasis from water development projects based on poor and somewhat dubious data first published in 1978. A major problem in this area is uncritical acceptance and repetition of published information, irrespective of its quality. As these data get published time and time again, they gradually gain 'respectability'.

The second problem is the absence of data on pre-project conditions in terms of environment- and health-related factors. Even now, when some baseline surveys are being carried out on pre-project conditions, environmental and health issues receive virtually no attention. Without knowledge of pre-project conditions it is not possible to say with any degree of certainty whether vector-borne diseases have increased or decreased over time in a particular project area.

The third problem arises from the fact that objective and comprehensive evaluation of irrigation projects, including the incidence of vector-borne diseases, is never carried out at regular intervals. Accordingly, very little data exist on the basis of which realistic conclusions can be drawn. There are a few studies available on the incidence of vector-borne diseases in the project area, but they are seldom scientific or rigorous. Control samples are seldom taken. Equally little account is taken of the health status of people who migrate into the project area due to the expanding economic opportunities, even though some of the people migrating to a project area may already have been infected by vector-borne diseases.

In addition to these complex problems, there are three important issues that should be noted in any discussion of the implications of water development on the environment. First, the impacts of water development on environmental health are many. Some of these impacts are direct and comparatively easy to identify and to predict in advance. Others could be indirect and project-specific and thus often prove to be difficult to foresee and even more difficult to quantify. Most water resources projects produce a mixture of these two types of impacts. As is to be expected, it is less difficult as a general rule to predict and control primary impacts than secondary and tertiary impacts. Thus for impact analysis of any medium to large-sized irrigation project a substantial number of specific and interrelated factors have to be analysed, both concurrently and sequentially, in a coordinated manner within an overall framework, by a variety of professionals, based often on incomplete or unreliable data. Considering the methodological limitations that are inherent in such impact analysis, it is a difficult task under the best of circumstances.

Secondly, environmental impacts of projects, both direct and indirect, are never confined within the project boundary. Many of the impacts occur far from the project area. Accordingly, it is not possible to define a precise geographical boundary which could be said to contain all the impacts.

Thirdly, the time dimension of the impacts is another complicating factor. Certain impacts can be immediate, and thus can be identified during the implementation phase or soon thereafter. Other impacts, however, could be slow to develop, and thus may not be visible in the early stages. For example, some unanticipated changes in the ecosystem and the environment could take more than a decade of operation of a project before they begin to appear. For many impacts it is not possible to forecast the timing of their occurrence with any degree of reliability. A typical case is salinity development in irrigated areas, which could take 15–25 years in certain projects, but in others the problem may appear within 2–3 years, depending on physical conditions, drainage facilities, operation and maintenance procedures, and management practices. The time dimension also makes direct comparison of the impacts of different water development projects a difficult process.

Institutional Constraints

As pointed out earlier, a sectoral approach to water development is a major institutional constraint in all developed and developing countries, and this has an important bearing on the sustainability of projects. Medium to large-scale water development projects not only change the environment, but also have other substantial impacts on social well-being, among which are employment, education, health facilities, communication, energy availability, domestic water supply and the status of women. These impacts take place through a series of interconnected pathways which are both direct and indirect and are not always easy to identify or predict. They may also vary substantially in terms of both their nature and magnitude from one project to another. Unfortunately, a holistic approach to land and water management that considers all these issues is rare though attempts are now being made along these lines in a limited fashion in a few countries.

There are many reasons for this situation, but one of the most important is the division of responsibilities between the various ministries that look after various water-related issues. For example, the Ministry of Irrigation or Water Resources is responsible for irrigation development, the Ministry of Agriculture for agriculture-related issues, the Ministry of Health for health promotion, the Ministry of Environment for environmental matters, the Ministry of Education for schools, the Ministry of Rural Development for rural issues, and so on. Because of long-standing rivalries, the coordination and cooperation between the various ministries leave much to be desired. And yet in any large-scale water development project all these issues must be integrated within the project area. While it is easy to point out this necessity, how this integration can be effected in reality in the field is a very complex and daunting task. It has to be admitted that there are not many success stories.

CONSTRAINTS TO ACHIEVING ENVIRONMENTALLY-SOUND WATER MANAGEMENT

There are many constraints which are inhibiting environmentally-sound water management in most developing countries. The importance of individual constraints could vary from one country to another, and sometimes even from project to project within the same country. Often the constraints are closely interrelated: one contributing to the other and vice versa. Among the main constraints are the following:

- Debts and financial deterioration in developing countries, which means lack of funds or substantial delays in allocating funds for essential requirements such as operation and maintenance of irrigation and drainage projects, deterioration in data collection activities, etc.
- Lack of appropriate and consistent policies for water development for both large- and small-scale projects.
- Serious delays in completing water projects after major investments like dams and other hydraulic structures and main secondary canals are completed. Significant delays in field canal construction and land levelling mean large areas which should be irrigated are not. Potential benefits are thus not being realized.
- Absence or inadequacy of monitoring, evaluation and feedbacks at both national and international levels.
- Lack of proper policies on cost recovery and water priciing or, if policies exist, absence of their implementation.
- Lack of professional and technical manpower and training facilities.
- Lack of beneficiary participation in planning, implementation and operation of projects.
- Lack of knowledge, and absence of appropriate research to develop new technologies and approaches, and absence of incentives to adopt them.
- General institutional weaknesses and lack of coordination between various ministries such as water, agriculture, environment, planning, etc.
- Lack of donor coordination resulting in differing approaches and methodologies, and thus conflicting advice.
- Inappropriate project development by donor agencies, e.g. irrigation development without drainage, supporting projects which should not have been supported.

CONCLUSION

Without environmentally-sound water management, it will not be possible for developing countries to achieve self-sufficiency in food and energy. During the past four decades, water development projects in terms of expansion of irrigation accounted for a major part of the increase in agricultural production necessary to meet the demand of an increasing population. Increases in agricultural yields resulting from introduction of irrigation was the main factor for enhancing total food production. Thus, by the mid-1980s, 36 per cent of the total global crop production came from less than 15 per cent of the land that was irrigated. This clearly indicates the importance of water development for the future survival and welfare of mankind.

The current global situation in terms of expansion of water control projects is a matter of some concern for a variety of reasons. For example, during the two decades between 1960 and 1980, the average rate of expansion of irrigated areas was 2.1 per cent. This rate declined by nearly 50 per cent during 1982 to 1987, when the average rate of expansion in developing countries was reduced to only 1.1 per cent. This compares with a population growth rate of 3.1 per cent per year in these countries. One important implication of this situation has to be that water must be used more efficiently than in the past if the standard of living in developing countries is to improve. Efficient use of water is simply not possible, unless it is managed in an environmentally-sound manner. Thus, environmentally-sound water management is an essential requirement for future development of developing countries, and will become an even more important consideration in the future than it was in the past.

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CHAPTER 3

Planning and Decision-Making Framework

JANUSZ KINDLER

INTRODUCTION

The first two chapters of this book have been concerned with interactions between water systems and the environment, potential impacts of water projects, and the general principles of environmentally-sound water resources management. The emphasis has mainly been on interactions and principles. Although this is important for better understanding of water resources management, the use of this knowledge is ultimately necessary in one of the many possible situations when some water-related decision is to be made. This decision might be, for example, the choice of a water resources development strategy, physical location of an environmentally difficult water project, drought control or water use adjustment policy. This chapter deals with planning and decision-making in the area of water resources management, with special emphasis on random and unknown elements involved in these processes.

The usual structure of the planning process for water resources management is shown in Fig. 1. Whatever be the decision to be taken, one has to begin with the identification of the problem at hand and definition of the study objectives. Next, necessary input data must be collected, interpreted and processed for further analysis. In general three blocks of different data are required, describing: (1) water supply conditions (quantity, quality, variability); (2) water demand, water quality control and flood control tasks (quantity, quality, reliability); and (3) potential alternatives for balancing demand with supply, for water quality control and flood control (structural and non-structural measures). To proceed further, a good deal of thought must be given to the criteria which are to be used for evaluation of the planning or decision alternatives. Providing this is done, the proper analysis may begin. First, relatively simple methods are used to identify unfeasible for clearly dominatir g alternatives. Having somehow reduced the alternatives available to a limited number, one can then proceed to build and analyse much more accurate and closer-to-reality representations of the problem that needs to be investigated. The degree of sophistication of analytical methods applied at this stage will always depend on the available input data, the nature of a given problem, the character of the decision to be made and the type of expertise that may be available.

At this stage of analysis (Fig. 1) mathematical models of various complexity are often used. It was noted at the IAHS Symposium on Scientific Basis for Water Resources Management, held in 1985 in Jerusalem, that some of the most important deficiencies in modelling 'have been caused by an overenthusiasm to model, with insufficient attention and effort devoted to understanding the physical, economic and societal world which was to be captured in these models'. Moreover, model imperfections and limitations in coping with the random, unknown, imprecise and non-quantifiable factors should be recognized. This is why critical examination of modelling results is a very important consideration. Providing this is done, whatever decisions that need to be taken in a given context can be made with the assistance of the models.

In this chapter, mostly planning decisions, either of a long-term or a short-term nature, are discussed. The long-term decisions are usually of a strategic character—long lead-times are necessary for implementation of major water resources programmes. On the other hand, short-term decisions are of a tactical nature. However, as discussed elsewhere in this book, short-term decisions must be made within the long-term framework. Many times there is simply no time to wait for implementation of the long-term measures. Water authorities must react to changing situations by introducing new water use policies, adding some physical facilities to increase the reliability and capacity of the systems, changing operation rules of storage reservoirs, and other appropriate measures. In all types of planning efforts, assumptions concerning future management rules (operational aspects) should be made explicit and taken into account.

Since this book is concerned with large-scale water management, this chapter examines the notion of regional development. The development of a region means socio-economic and cultural moderni-

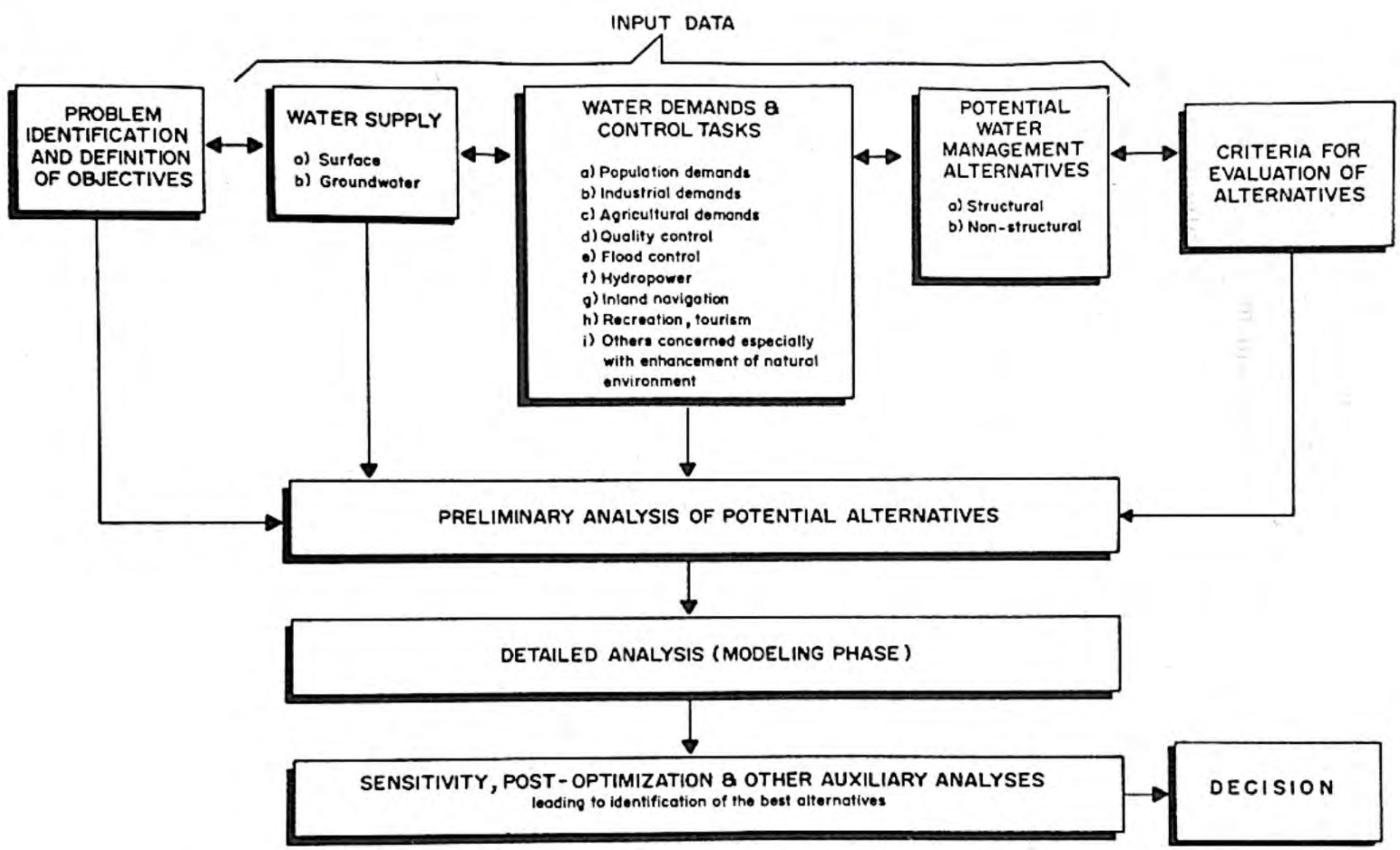

FIGURE 1. General scheme of water resources planning

zation involving structural shifts in activity and associated societal organization from a lower to a higher stage of society (Hamilton 1978). While water resources development may have significant impact on regional growth, which may even be constrained by the absence of an adequate and reliable water supply system, it should be noted that water projects should always be viewed as some of the several essential ingredients necessary for ensuring sustainable regional development. It is important to underline at this point the intensely regional nature of water resources management. There could be no global water management, although there is a global hydrological cycle which may be affected by human activities undertaken in individual regions of the world. The balancing of water supply and water demand occurs within smaller geographical or political regions.

A river basin is the most advisable spatial unit for water resources development planning. River basin boundaries usually do not coincide with the boundaries of regions delineated for economic and social planning purposes. Sometimes river basins may be shared by two or more countries. Such issues will undoubtedly complicate the water planning process. However, the fact still remains that river basins are conceptually the ideal units for water planning and management. Sometimes it may not be an easy task, but there are always some ways of integrating the regional development plans with water resources planning. Careful analysis of the institutional and decision-making structures prevailing in a given region could provide the most valuable hints in accomplishing this task.

Recognizing the structure and the overall nature of the planning process is still far from knowing how to make this process compatible with the principles of the environmentally-sound water management. In this chapter, possible ways of achieving this objective are reviewed under the general framework of systems analysis. This framework, however, cannot be made operational without appropriate institutional arrangements capable of adequate handling of the uncertain and unanticipated events. These challenging issues are examined first, before outlining step-by-step some details of systems analysis and its potential applications for environmentally-sound water resources planning and decision making.

THE INSTITUTIONAL ARRANGEMENTS

Although the importance of institutional arrangements for water resources management has been recognized by many, the term 'institution' is used in a variety of ways and for many different contexts. One of the most complete definitions of this term is given by Fox (1976), who explains that it refers

> . . . either to an entity; an organization or an individual, or a rule, a law, regulation, or established custom. An institutional arrangement is defined as an interrelated set of entities and rules that serve to organize societies' activities so as to achieve social goals. Each nation has an institutional arrangement for managing water resources. This arrangement establishes the conditions under which water resources can be developed and used and provides organizations and individuals with certain resources and authorities to carry out the prescribed tasks. . . .

The institutional arrangements for water resources management have widely varying capabilities and limitations. Hence, these arrangements are not alternatives that can be compared in the abstract with a view to selecting the single 'best' institution. What will work best in a given basin depends not only upon its problem and its physical and economic characteristics but also on the general management milieu that is prevalent in the country. Further, in any particular situation, there should be an explicit need for a new institutional arrangement to accomplish specific objectives, before the best form of such an arrangement could properly be considered. If the existing agencies are carrying out their tasks successfully, one may consider how their performances can be further improved, but as a general rule it could be counterproductive to supersede or replace a reasonably functioning institution. Most often, however, major effort is required to devise and establish new institutions that could be strong enough to bring about unified and environmentally-sound development of the entire river basin.

Experience across the world indicates that most of the problems of reconciling water resources development and environmental quality result from a failure to consider them simultaneously in an integrative fashion from the very beginning of the project formulation process. Separation of the institutions that deal with water resources development and the environment, as well as inadequate coordination between the appropriate agencies concerned, clearly militate against the adoption of a more holistic view of water resources planning and management.

There are two principal trends in the institutional arrangements for water management, although they never appear in their pure form (O'Riordan 1985). One is towards centralization in an attempt to internalize the effects of decisions. The establishment of national water authorities responsible for managing both water quantity and water quality typifies such a shift. In such a case, public involvement and inputs originating from local initiatives tend to be reduced. Moreover, the information barrier typical for all large, centralized institutions could affect the overall quality of the decision-making process. Indeed, centralized water authorities are usually well informed about structural alternatives for water management such as storage reservoirs, interbasin water transfers, etc., but they often have much less information about the options available to individual water users for adjustment of their water demands. This deflects attention from the demand management alternatives which usually may reduce capital requirements and also could be environmentally less disruptive.

A second trend is towards decentralization, but in this case water authority must be equipped with some instructions to influence and coordinate the action of each and all independent water users. The extent to which water pricing schemes can be realistically used for this purpose is at least debatable, especially in developing countries. What other instruments that could efficiently be used is far from being clear. There is the problem of devising effecive market mechanisms which would conserve water and divert it from low- to high-value uses, where and when it may be socially desirable.

But centralization and decentralization should not be seen as two mutually exclusive options. Some of the most efficient management schemes feature strong national water authority collaborating with decentralized and, to a large extent, autonomous, regional (river basin) agencies. Catchment Authorities of New Zealand provide a good example in this respect (NZCAA 1987). They were set up in 1941 by the Soil Conservation and Rivers Control Act of Parliament to control flooding and erosion. In 1967, the Water Soil Conservation Act vested in them Regional Water Board responsibilities for the control of allocation, use and quality of water.

In New Zealand, catchment authority is a special purpose regional body which administers the water and land resources in one or more major catchments. A 'catchment' is an area of natural drainage by a river or stream, which contains a complex array of interlinked and interdependent resources and activities, irrespective of political or administrative boundaries. It is recognized that soil, water and vegetation resources cannot be managed in isolation from one another. In New Zealand, 20 catchment authorities have been established on this basis. There are four types of catchment authorities: Catchment Boards (13) which consist of a majority of directly elected representatives from the regions. Catchment Commissions (4) which consist of a majority of local representatives nominated by the constituent county, borough or municipal councils of the region, regional governments (2) of two major urban areas of New Zealand, and the Waikato Valley Authority in recognition for the hydroelectric development of the Waikato River. Work done at the regional level is overseen by the National Water and Soil Conservation Authority—the parent body of catchment authorities. The National Authority makes the policies that the catchment authorities carry out and allocates government funds for some work. It has 13 members from organizations such as the Catchment Authorities Association, the Municipal and Counties Associations, Federated Farmers, Manufacturers' Federation, and the Land Drainage and River Boards Association. However, to what extent the New Zealand experience can be successfully transferred to developing countries, or even to other developed countries, remains a subject of considerable conjecture. More about different institutional alternatives is discussed later.

It is important that institutional arrangements are capable of motivating all parties involved in water management decisions towards their effective implementation. There are situations where administrative structure seems to be ideal, laws and rules look perfect, but things do not work as expected. This often is caused by the lack of adequate motivating mechanisms. This difficulty has been most evident where authorities have relied chiefly upon regulatory process to achieve policy objectives. The environmentally-sound management of water resources should rely more on sequential decision-making, learning feedbacks and experimentation, that on detailed and usually inflexible policy schemes. Furthermore, for a variety of reasons, regulatory processes in most developing countries are not functioning properly.

To summarize, it is important that institutions charged with water resources planning and management are not too narrowly concerned only with the physical aspects of water management. They should be sensitive to changes in human preferences, habits, desires, aspirations and management abilities. The river basins, which are coherent hydrological units relevant to all water resources planning, design and operation, should be seen in such a context.

UNCERTAINTY AND RISK

Water resources are developed and managed under conditions of uncertainty, which arise from the underlying variability of geophysical processes. The natural stochasticity of these processes may be described by probability distributions, providing there is enough historical data. Furthermore, on the basis of recent experiences in many sub-Saharan countries, there is considerable scientific uncertainty as to the proper tasks of time series data that is necessary to define hydrological processes such as rainfall and runoff with some degree of reliability (Biswas 1988a). There are other sources of uncertainty which need to be considered because future is generally unpredictable with respect to economic events. For example, if the life period of a large dam like the Aswan is 500 years, there is a good possibility that accelerating human activities could change the hydrological regime on the basis of which a dam may have been constructed. The sources and degrees of uncertainty differ among various aspects of water resources planning and management programmes; they also differ in time. It is thus necessary to analyse various possible adjustments in these programmes, including evaluation of the related costs, to cope with the probable and the unforeseen events.

In water resources planning particularly important is uncertainty concerning future goals and the long-term availability of technical and non-technical means by which these goals could be achieved. These are highly uncertain factors external to water management for which the past offers little guidance. A retrospective examination shows that several large water projects have been built with little heed paid to the possibility that actual conditions might turn out to be substantially different from those assumed in the plans. There are no methods that could foretell the future, but by allowing for a more complete expression of uncertainty surrounding future goals and objectives, one can frequently point out more flexible, less risky and thus more sustainable alternatives. It should, however, be noted that water sector alone does not suffer from such uncertainties: all development programmes face similar uncertainties.

Many suggestions have been offered for tackling uncertainty, but in principle it may be dealt with in four different ways (Kaynor 1978). First, it may be ignored, but experience shows that planners can do it only at the peril of their plans. It may be possible to ignore uncertainties for small projects having limited life spans. However, to ignore uncertainty is to act arrogantly—as though the forecasts to take action were completely certain and anticipated and results were *faits accomplis*. This is contrary to any rational logic or theoretical structure.

The second option is to avoid uncertainty by incremental implementation of development plans. This may reduce the potential impacts of uncertain events, but it cannot eliminate all problems. Furthermore, this strategy, unfortunately, cannot be always followed in water resources development, especially in case of large-scale structural projects.

The third option is to reduce uncertainty, mostly at the research, data collection pre-planning stages. Better understanding of the cause–effect relationships is especially important in this respect. It should be noted that uncertainties may be reduced but cannot be completely eliminated. Furthermore, reduction of uncertainties generally has financial implications. Since the amount of funds available is limited, cost-effective solution that may carry acceptable levels of risks should be considered.

Finally, the fourth option is to view uncertainty as a chance occurrence and then incorporate the risk in the planning process. Risk analysis is playing an increasingly important role in assisting water resources planners to choose from different options related to the quality, safety and sustainability of the environment. It is generally a two-part endeavour. In the first stage of risk assessment usually a wide range of scientific disciplines is used to produce some estimate of risk.

Quite often, sensitivity analysis is employed in this stage, i.e. the technique of varying assumptions as to the behaviour of various factors. Next, those assumptions are examined in terms of the related economic and social benefits and costs. In the second stage of risk management, procedures and approaches to minimize risks are identified, evaluated and applied.

Although this may sound fairly straightforward, risk analysis, and especially the risk assessment phase, is a complex endeavour, often requiring a multi-disciplinary approach. The damage probability of a given event may be low, but if its perceived importance is considered to be high, it may require a high level of expenditures to reduce that perceived risk so that the project may be acceptable to the society as a whole. This is especially true when confidence people have on their knowledge of the consequences of that event is low (e.g. groundwater contamination by nuclear waste).

THE FRAMEWORK OF SYSTEMS ANALYSIS

Systems analysis, or the systems approach as it is commonly called, is aimed at considering a given entity in terms of the interrelationships between its components, rather than in terms of their individual properties. According to Miser and Quade (1985):

> A system analysis is an explicit analytic inquiry carried out to assist decision or policy-makers in a problem situation where uncertainty is present. The purpose is to help determine a preferred action or policy by identifying and examining alternatives and comparing them in terms of their consequences.

To avoid common confusion, modelling is not synonymous with systems analysis. To quote again the same authors:

> A system analysis is an attempt to discern and answer questions of importance in the choice of a decision or policy; a model is merely a useful device in obtaining answers to such questions.

The use of mathematical models is not, then, all that systems analysis is about.

It should be recognized also that most, if not all, water resources issues and problems are characterized by multiple objectives, multiple criteria, multiple decision-makers, multiple users, and multiple constituencies. This often leads to the competitive or conflicting situations.

The methods of multi-objective analysis have been developed especially to deal with such competitive situations, when, for example, the improvement in one objective is associated with the deterioration in another. On a long-term perspective, however, economic, social and environmental objectives should not be viewed as competitive but rather complementary and mutually reinforcing. Accordingly, deterioration of the environmental quality may eventually hamper achievement of anticipated economic and social benefits that could arrive from any water development project.

The ultimate goal of water resources planning is to ensure that water of acceptable quality will be available in sufficient quantity at the right location, at the right time, at the right price, continuously on a reliable basis. Another developmental goal could be the protection against water excess—flood management and control. Because of the uncertainties inherently associated with all phases of water resources planning, all this can be achieved only within some limits of assurance, reliability and cost. Water resources development planning can vary significantly in scope, space and time. The following discussion, however, focuses on those features of environmentally-sound water resources development planning and management that emerge when large-scale water projects and long-term basin-wide strategic issues are being considered.

The overall approach of systems analysis is in principle always the same, irrespective of how advanced the stage of economic and social development of a given country may be. However, the level of sophistication that can be brought to bear on the analysis should be adjusted on the basis of expertise available, financial and time constraints, and the institution within which various alternatives will be considered. In general seven stages of systems analysis can be identified:

1. problem identification and formulation;
2. definition of objectives and their translation into evaluation criteria;
3. formulation and screening of policy or decision alternatives;
4. evaluation of alternatives including consideration of long-term environmental impacts and social effects;
5. selection of the 'best' alternative;
6. implementation of the selected alternative; and
7. ex-post performance analysis.

In most investigations iteration is needed among individual stages. The planner must be free to examine initial assumptions, to revise earlier work, and to impose additional constraints after analysing what some of the consequences of potential decisions could be. For example, there is always a feedback loop from evaluation to formulation of alternatives. As pointed out by the decision support approaches, it is also important to shorten the feedback loop between the planners and the decision-makers, with a frequent repetition of the study cycle. Thus, close interaction between the analysis and their clients is an important requirement for successful realization of the sustainable water resources development planning.

Taking these factors into account, the following discussion on how to incorporate environmental considerations into water resources planning is organized in accordance with the stages identified above. Explicit consideration of environmental concerns is necessary at each of these stages and various approaches may be used to accomplish this task. It should be recognized, however, that the planning process increases in rigidity from the problem identification to the implementation phase; thus insertion of environmental issues at the later stages becomes an increasingly more difficult and complex task. It also becomes an expensive process, and the results could often be sub-optimal (Biswas and Qu 1986). Raising environmental issues at the beginning of any planning process increases the chance that they will be considered appropriately during the entire planning and management phase and also is likely to generate more cost-effective solution than may be otherwise possible.

PROBLEM IDENTIFICATION AND FORMULATION

There is a general agreement that the appropriate problem identification and formulation is of a critical importance for the entire planning process. There is, however, a real danger that when there is a pressure to produce quick results, when the analytical resources and expertise are limited and the urgency of the resolution of the problems is critical, the importance of this initial stage of analysis may easily be overlooked. As stated by Quade (1980):

> Problem formulation is concerned with such things as determining the goals to be achieved by a solution, setting boundaries on what is to be investigated, making assumptions about the context, identifying the largest groups, and selecting the initial approach the analysis is to take.

Planning for water resources development projects is initiated in response to needs that already exist as well as to needs that are anticipated for the future. Translating needs into a properly definable problem is itself a complex process requiring techno-economical skills and political-institutional insights. The problem becomes further complicated because the needs may vary with time due to changing conditions as well as changing attitudes and perceptions of the different groups of people involved. Initially, how the problem is formulated must be compatible with the language and precision requirements of those who are responsible for the initiation of the plan. A wide range of different situations may be encountered at this stage. Hence, problem formulation depends on the nature and scope of the problem, as well as the various technical, social, economic, institutional and environmental conditions within which the problem is to be resolved.

Among some of the main issues and constraints that could have a direct impact on the problem formulation are the following: (i) administrative and hydrological boundaries are seldom identical; (ii) time and budget allocations are always limited; (iii) various regulatory, legislative and political requirements are likely to narrow the range of feasible alternatives; (iv) water needs are predetermined exogenously to the planning process; and (v) adequate number of trained personnel may not be available. Furthermore, much may depend upon what may be perceived to be the main problem by the local population. For example, building a storage reservoir in a temperate area for a more affluent, nature- and conservation-oriented society, may be considered to be a serious environmental problem. However, construction for similar reservoir in a very arid or semi-arid developing country, where the reservoir is likely to contribute directly to much higher agricultural production and for hydropower generation, and thus contribute to poverty alleviation and employment generation, may not be considered to be a serious environmental problem.

The need for a clear and unambiguous problem formulation is critical, especially in developing countries, where data availability and reliability is a common and recurring problem and serious investigations must often be undertaken, solely to improve the information base.

Regarding identification of potential environmental concerns, checklists are particularly helpful at this stage of analysis. These checklists make use of impacts that might be expected from different activities and are based on past experiences. By itself this is valuable, but it says little about the magnitude, type, extent or the relative importance of the impacts. Nor does it give any idea about the time dimension of the occurrence of impacts. Various checklists currently exist (Biswas and Qu 1986). One example is that developed by US Agency for International Development (USAID) for assessing rural development projects in developing countries (USAID 1980).

This checklist contains several questions such as:

Will the project

- increase vector habitat?
- decrease vector habitat?
- provide opportunity for vector control?

There can be three answers depending on how much is known about the particular impact under consideration: Yes, No or Unknown. If an answer can be reached, then the checklist provides a qualitative classification for describing the intensity of the impact. There are eight intensity levels that can be considered: not determinable, high adverse, medium adverse, low adverse, low or insignificant, low benefit, medium benefit, and high benefit.

Many types of checklists are available. Among them are simple, descriptive, scaling, scaling-weighted, and questionnaire checklists. The potential uses of these checklists and their applications to water development projects have been discussed in detail by Biswas and Qu (1986). While checklists are useful and have certain advantages, they suffer from some limitations as well. They cannot assess the dynamics of change and the related uncertainties. Moreover, they deal only with the environment. Attention is focused only on the environmental impacts and project performance in terms of other objectives is not considered. Nonetheless, checklists, if used properly, are useful as initial guide, helping to ensure that important environmental factors are not left out of the analysis.

OBJECTIVES AND EVALUATION CRITERIA

An important step in the analysis is definition of the study objectives and translation of these objectives into quantifiable criteria. An objective is a goal that decision-makers seek to reach by means of the decision taken. Although the environmental objective is main focus of this book, it is just one of the several objectives of water development that must simultaneously be considered by the analysts. In the United States of America, for example, 'Principles and Standards for Planning Water and Related Land Resources' identify four objectives to be promoted through planning: (1) national economic development, (2) environmental quality, (3) regional development, and (4) social well-being. However, only the first two objectives are required to be optimized during the project planning process. The last two objectives are only 'accounts for displaying additional informaion, but not the principal factors in the final decision-making' (Eisel *et al.* 1982).

The choice of socially relevant objectives requires judgement both on the part of the water resources planner, and on the part of other participants in the planning process, especially the politicians.

Planners need to get clear guidance on this from the politicians which unfortunately does not happen very often. This was stressed by Major (1977), who states that 'much of the confusion and debate about water resources projects that have been proposed in recent years has arisen because the planners were not developing design options responsive to the objectives of the political process'. This often occurred in the past because the water engineers who were responsible for the planning process considered it to be a technical issue, primarily in their domain, and as such to be decided by them. With changing social and environmental attitudes, this perception is changing as well.

Another reason has been due to the lack of understanding of the decision-making process by the planners and system analysts. Even though the existing literature on systems analysis for water management is replete with terms like 'decision-maker' or 'policy-maker', regrettably very few analysts have made any serious attempt to understand the decision-making process in the real world. As Biswas (1988) notes:

> The 'decision-maker' referred to in nearly all papers published in the area of systems analysis is really a mythical person who has to decide between some alternatives conjured by the analysts, on the basis of some narrow criteria identified by the analysts that have very little bearing to the situation in the real world.

Fortunately some analysts have now realized this problem. They are making a determined attempt to understand the mindset of decision-makers and see first-hand how decisions are actually made. Such attempts should be welcomed and encouraged since they have the potential to significantly improve the present planning and decision-making process.

For comprehensive basin-wide planning studies, the objectives tend to be fairly global and they generally do not incorporate conflicting issues. They are intentionally made all-encompassing in order to ensure the broad support of the various constituencies and stakeholders. Negotiation and compromise are integral elements of the planning process, and for negotiations to succeed, the parties must start with acceptable agenda of project objectives that can be modified later. Having reached a consensus on general project objectives, more attention can be focused on translating these objectives into evaluation criteria.

An evaluation criterion is a rule used to measure the extent to which an objective has been achieved. Thus, the criteria used should be quantifiable. In long-term strategic analyses, there is a natural tendency towards limiting the number of evaluation criteria. Concerning the environmental objective, the use of an aggregated impact index has often been advocated. However, the aggregation process should not be carried too far. Each criterion should reflect, at least to some extent, specific aspects of environmental quality to be maintained and/or enhanced (e.g. water quality, land degradation, aesthetics, etc.). When the environmental consequences of a development alternative are presented in the form of a single numerical index derived by consecutive aggregation of different environmental quality measures, its validity and usability are mostly limited. For example, if various water quality characteristics are aggregated into a single water quality index, it may not give a clear picture of the situation except in a somewhat superficial sense. Use of such indices, under many conditions, could even be misleading.

Trying to merge too many non-commensurable entities into a single index value is usually an unproductive process, especially as the aggregation process often calls for arbitrary weightings and value judgements. The hypothesis that experts will be able to weigh numerically the consequences of, for example, one aspect of water pollution with another, or water pollution to impacts caused by upper catchment deforestation, is difficult to accept. On the contrary, there is a considerable body of evidence that experts do not like to answer such questions. Instead of considering an index arrived at by weighting schemes which can always be questioned and/or manipulated, the experts and decision-makers generally prefer to express their judgement on a set of explicitly stated evaluation criteria which describe in physical, economic and social terms the environmental consequences of a given development alternative (Miser and Quade 1985).

Although specification of evaluation criteria is always problem- and context-specific, it must be recognized that most of them cannot be defined by using the same units of measure and thus they are not intercomparable. Under these circumstances, it is inevitable that those responsible for the solution of the problem must become involved in the process of evaluating trade-offs among the degrees of achievement in terms of the various criteria.

FORMULATION AND SCREENING OF ALTERNATIVES

Identification of the proper course of action for water resources management requires careful consideration of all the feasible alternatives. As pointed out by Davis (1968):

> ... if the most desirable answers were generally evident, the solution would consist mainly of working out the technical details of a simple, straightforward engineering problem.

Except for very simple and perhaps small projects, this, however, is an exception rather than a rule. Any reasonable size multi-objective water development programme invariably will have a series of sub-problems, each of which is likely to have a series of alternative solutions. Thus, a significant number of alternative solutions is always present in any reasonable size water project. The identification of the full range of potential alternative solutions is always an important and essential step.

The problem can usually be solved in a variety of ways, and the full range of choices should be explored. In developing countries, socio-cultural factors are of special importance in the process of formulating alternatives. Considerable evidence exists at present of water projects that have failed because the tradition and habits of the user community were ignored. Several examples are given by White and White (1978) and Biswas (1981, 1988), which clearly indicate the dangers of ignoring community choices and preferences by the planners.

In principle, three possibilities exist for formulating and screening alternatives (Haimes *et al.* 1987):

1. A small number of available alternatives could lead to the reduction or even eliminaton of the screening step;
2. A large number of available alternatives requires a preliminary analysis to explore the trade-offs between project objectives. This requires people with technical knowledge and experience in practical aspects of water resources development projects;
3. A large number of available alternatives requires the use of

hierarchical screening in stages, with an increasing rigidity of selection and/or exclusion criteria being adopted as the screening process proceeds.

For environmentally-sound water resources planning, special care needs to be taken to ensure that to the extent possible selected development alternatives do not foreclose other viable options. Where a choice is between preservation and development, and there are uncertainties with respect to future demands for the services of either alternative (e.g. recreation v. hydroelectric power development), the associated costs and risks should be taken into account. It should be recognized that technological progress generally increase the margins of substitution for water in the production of commodity goods whereas it is generally incapable of augmenting the supply of environmental resources.

EVALUATION AND ALTERNATIVES

After the development alternatives have been reduced in number through the screening process to a few select ones, it is necessary to have some means of predicting, and whenever possible measuring, the environmental impacts of each development plan. It should be noted that all large-scale water resources development projects will contribute to both positive and negative impacts, and that the analysis should not concentrate exclusively on the negative impacts—as is often the case at present (Biswas 1988b). Current methods of estimating environmental impacts include Environmental Impact Assessments (EIA) and simulation models of various complexities.

Most EIA methods are based on matrices or flow diagrams which are designed to ensure that all potential interactions and impacts are at least included, with some indication of their relative importance. Among matrix methods, the earliest one used is known as the Leopold Matrix (Leopold *et al.* 1971), which consists of a horizontal list of development activities ranged against a vertical list of environmental criteria and conditions. Within each cell, the magnitude and importance of each possible impact are ranked on the scale 1 to 10. Several other types of matrices have now been developed, some of which have been used successfully in analysing the environmental impacts of water development projects (Biswas and Qu 1986). Flow diagrams which illustrate cause/effect relationships are also available, but the consequences of a variation in the design of a water project can be taken into account only by constructing another diagram.

A major criticism of all these approaches is that they are somewhat mechanistic, and provide only a set of static pictures of reality. They take little account of the interrelationships between the different environmental processes and the combined effects they can produce.

Simulation models are designed to track explicitly the dynamics of systems. A number of large-scale ecosystem models have been developed during the last two decades. Their development was largely stimulated by the series of biome studies (grassland, desert, tundra, deciduous and coniferous forests) carried out within the framework of the International Biological Programme (Patten 1975). These biome models have been useful in conferring better understanding of ecosystem structure and dynamics, but they do not readily lend themselves to answering specific questions concerning resource management. Many of those models are mathematically quite sophisticated. They contain provisions for non-linear relationships and can represent fairly complex environmental processes. But at the same time they often ignore those aspects of the ecosystem behaviour which are of major interest to water resources planners. Their actual use in planning and management of water development projects is, for all practical purposes, negligible.

There are also several simulation models which concentrate on hydrological or water quality impacts. For example, the well-known Stanford Watershed Model which, among other purposes, can be used to simulate sediment transport processes and to evaluate land use changes in river catchments. Another model, QUAL2E can simulate the behaviour of up to 15 water quality constituents in the river system in any combination desired by the user (Brown and Barnwell 1986). However, data requirements for these models are demanding and that is why they have not been often applied in developing countries. Their use in developed countries has been limited.

Several groundwater models have also been developed, which allow for the simulation of flow dynamics and dispersion of contaminants in aquifers. Although many of these models are now readily available and easy to run on relatively inexpensive microcomputers, they again require considerable input data and technical expertise in data acquisition. This presents a major problem for the application of these models in many developing countries. Furthermore, it has to be remembered that present knowledge of many environmental processes and cause-and-effect relationships is still very poor and the use of models should never give the impression that all is known and that all impacts as well as their magnitudes can be predicted with adequate reliability. Indeed, there is a considerable uncertainty associated with predictions made by these models.

The experience of the United States Water Resources Council is relevant here. During the years 1973–82, special effort was made by the Council to improve specific procedure that could be applied uniformly and consistently to evaluate appropriate beneficial and adverse effects of planning alternatives. Although significant progress was achieved, the Council still considers imperfections of such procedures to be a major obstacle to more complete realization of the multi-objective intent of the official 'Principles and Standards for Planning Water and Related Land Resources'. This problem is considered to be more fundamental than the difficulties related to analytical complexities of the multi-objective methods and techniques (Eisel *et al.* 1982).

CHOICE OF THE 'BEST' ALTERNATIVES

A whole range of quantitative and qualitative methods is being offered by systems engineering, operations research and management science for ultimate selection of the most promising planning alternatives. The focus of this selection is on the multi-criteria methods of analysis. Although the use of 'objective' to mean 'criterion' is incorrect, the terms 'multi-objective methods' and 'multi-criteria methods' have practically the same meaning. During the past two decades, these methods have experienced spectacular growth, capturing the attention of many and bringing about some new theoretical developments in the field of water resources management (e.g. Haimes *et al.* 1975; Cohon 1978; Chankong and Haimes 1983). Although one would be hard pressed to identify even one successful case where multi-criteria method has been actually used throughout the entire course of planning, even in a single developed country, they do appear to provide a viable framework of analysis for environmentally-sound and sustainable water resources development and management.

There are several reasons for relatively slow adoption of the multi-criteria methods (Biswas 1988b). Some of them require information which is difficult to obtain in a real-world setting. Sometimes the complexity of mathematical formulations puts off the potential users.

Generally, prevailing institutional arrangements are not favourable for their application. But as Cohon (1978) has stated: 'real world problems are multi-objective (multi-criteria) and imposition of a single-objective approach on such problems is overly restrictive and unrealistic'. There may be problems with practical introduction of certain methods or techniques, and/or with the abilities of existing institutions to carry out particular studies, but not, at least conceptually, with the multi-criteria framework of analysis as such.

The multi-objective methods of analysis represent a generalization of the single-objective approach—instead of a single objective to be optimized, multi-objective analysis deals with several objectives simultaneously. For such problems the concept of optimality must be dropped because a solution which maximizes one objective will not, in general, maximize any of the other objectives. This leads to the notion of a non-inferior solution (sometimes also called non-dominated, poly-optimal, efficient or Pareto-optimal), where any improvement in one objective can be achieved only at the expense of degrading another (for example, improvement of short-term economic gains at the expense of natural resource degradation). A set of non-inferior solutions sometimes appears in the literature under the name of a transformation function.

The problems that yield to multi-objective analysis may be classified in many different ways, although distinction is usually made between continuous and discrete problems. Continuous problems encompass an infinite number of choice possibilities that meet the constraints of a system under study, while discrete problems display a finite number of feasible choices (courses of action, strategies, solutions, project alternatives, etc.).

For a better understanding of the basic concept, let it be assumed that there are five feasible project alternatives in a three-criteria problem of economic efficiency, water quality and land degradation are given as in the following table (adapted from Cohon 1978):

	Alternatives				
Criteria	A	B	C	D	E
Economic efficiency	5	4	4	3	2
Water quality	8	9	4	10	9
Land degradation	7	2	4	6	8

Let it be further assumed that the numbers given in the table represent rating of each criterion on the specific project alternative. The more efficient or better in terms of a given criterion is the alternative, the higher is the rating. If we consider a single criterion of economic efficiency, alternative A is certainly the best (optimal) one. Alternatives D and E are optimal for water quality and land degradation respectively. Under these conditions, what can be done when all three criteria have to be simultaneously taken into account? First, the notion of non-inferiority must be defined. To determine the non-inferiority of an alternative, its ratings for all three criteria are compared with the ratings for all other alternatives.

Consider first alternative A. Projects B, D and E give better water quality, but are less attractive from the point of view of economic efficiency and land degradation—project C gives less in terms of all three criteria—project E yields better water and less land degradation, but is worse in terms of economic efficiency. Therefore, alternative A is non-inferior. Comparing alternatives with one another leads to the conclusion that only project C is inferior (is dominated by project A) and projects A, B, D, and E are non-inferior.

But even in a multi-criteria analysis, it may happen that there are some other criteria important to the decision-makers that have never been explicitly articulated. In such cases, the 'best' alternative may be located among the inferior alternatives and not necessarily among the non-inferior ones. These are only the words of caution that rejecting automatically all inferior alternatives is not advisable.

An additional limitation of the analysis to the non-inferior set of alternatives is that they are not comparable. For example, alternative D is better than E in terms of economic efficiency and water quality but it is worse for land degradation. Which one is better? Is it worth giving up one unit of water quality and one unit of economic efficiency to gain two units of land quality in moving from project D to E? This obviously involves the choice between competitive criteria and the degrees to which each of them is satisfied.

Selection of the most preferred or so-called 'best compromise' alternative requires additional information on the trade-offs between achievement of different criteria to be identified and evaluated. This evaluation is never a purely mathematical or quantifiable exercise. To varying degrees, it reflects the economic, social, aesthetic, cultural or even moral values accorded to individual criteria by those who are charged with the decision-making responsibilities.

This is undoubtedly the most difficult stage of the analysis and several methods have been proposed as aids in the search for the best compromise alternative. These aids can be found in any of the numerous textbooks on multi-objective (multi-criteria) analysis and planning. Since these methods allow for non-commensurate criteria to be traded without artificially combining them, it is a significant step forward in analytical capability.

IMPLEMENTATION OF THE SELECTED ALTERNATIVE

Major projects in developing countries usually call for step-by-step implementation, rather than immediate concerted action. Due to the general shortage of data and the limited understanding of all possible environmental impacts, continued monitoring of impacts should be an important part of the implementation process.

It must be recognized that uncertainties are always present and better results can be achieved if the impacts of development are monitored from the beginning of project implementation. Only then can an unexpected impact be identified early on and the plan or policy appropriately modified. This is an especially important consideration since at the current state of knowledge it is not possible to predict all environmental impacts, the time when they may occur, or their magnitudes. Only monitoring can identify problems as they arise, and steps can then be taken to ameliorate such problems. Continuing monitoring of water development projects is a prerequisite for environmentally-sound management, and yet this has for the most part been neglected so far in most countries.

PERFORMANCE ANALYSIS

As soon as the project or policy becomes operational, one of the issues of critical importance is analysis of performance, aimed at determining the extent to which the objectives of the project or a policy are being achieved. Such analysis may, for example, ascertain how much water from an irrigation project is actually used, what the originally unanticipated responses of project users are, or what the impact of the project on the downstream groundwater regime is. Such a performance analysis is indispensable for assessing the effectiveness of the project or policy initiatives and it may help prevent mistakes in the future.

Unfortunately, there tends to be a reluctance to examine past experience, simply because of a fear that objectives have not been attained or that unanticipated effects have appeared. While such reluctance is understandable, especially when analysts may share some of the responsibility for the past decisions, the future is better served by a system that creates positive incentives for the pursuit of this kind of feedback in operation. Competent evaluation of the performance of the water development projects in contrast to pseudo-evaluation also is a problem that seems to be pervasive in many bilateral and multilateral aid agencies (Biswas 1988).

SYSTEMS ANALYSIS IN DEVELOPING COUNTRIES

As already mentioned in the preceding sections, systems analysis can and should be applied in the developing countries, although the extent and means of its application may vary from one country to another. Making general statements about these differences is difficult, for what is valid for one developing country may not be applicable at all to another, as these countries are not homogeneous and could be at different stages of development. But at a risk of some oversimplification one could say that in preparing water resources development plans in developing countries emphasis should always be on the development of people and not on material things. If development is to benefit the people, as discussed in detail elsewhere in this book, local communities should be encouraged to participate throughout the project cycle, i.e. from planning to the operation and maintenance stage. This is the best way to create the sense of ownership and to provide for the early transition of responsibility from the government to local communities for the operation and maintenance of their water projects.

The socio-cultural factors are of particular importance in all stages of analysis, especially in formulating planning and policy alternatives. Many problems have emerged in developing countries due to the lack of understanding of the local conditions and value systems. Uncritical importation of foreign technology is a classical example in this respect. In many instances it has contributed not only to technical problems but also to the increase of social disparities as well. Alternatives and solutions should come first from observing the local environment and carefully examining the traditional strategies, and next from outside inspiration.

While the use of systems analysis is increasing, its potential for improving water resources planning and decision making has not been fully explored in the developing countries. Among major factors considered responsible for this state of affairs are: shortage of expertise and trained personnel, shortage of reliable data, and lack of confidence in modelling, which although not synonymous with systems analysis is one of its main tools.

As pointed out by Biswas (1981), the first factor is easily overcome since people can be trained quickly—'provided those who are in power are willing to see this done'. Data availability in developing countries is certainly a more acute problem than in developed countries because of the generally much shorter period for which measurements, observations, and scientific studies have been in progress. But it should be recognized that systems analysis can assist in data collection and processing. Moreover, the analysis can and should always be adapted to the limitations of data availability.

The lack of confidence in modelling cannot be considered to be a special attribute of developing countries since, to some extent, it may be observed all over the world. Admittedly, models are often built seeking academic rather than policy goals, but fitting the problem to familiar mathematical tools rather than tools to the problem (this has been called by Biswas [1981] solution-in-search-of-a-problem approach), or by describing what one can describe, not what is relevant (Miser and Quade 1988). But this is not to diminish the value of modelling, which if properly carried out can be of great assistance, even when insufficient quantitative data or only qualitative information is available as input to the model. A possible way out of such difficulty suggested by Frenkiel and Goodall (1982) is to build

> . . . a simplified model based on previous knowledge regarding the identification of the relevant variables, and of the existing relationships between the variables; this simple model could then be used to determine at least the qualitative effects which relevant variables will have on the environment. The results of such studies may become useful to decision-makers in understanding the potentiality of simulation modelling, and a more advanced simulation modelling study with the necessary quantitative data base could then be initiated.

It should be recognized that problem-solving is not the only payoff from systems analysis. In many instances, its most important contribution is simply to increase understanding of some relevant concerns or to force rethinking on a complex problem. In this regard systems analysis may also be able to derive substantial benefits in the developing countries.

In the past decade, water resources planning has relied increasingly on concepts and procedures of systems analysis. It should be recognized, however, that water resources planning possesses a number of difficult-to-deal characteristics, the most important of which are uncertainty and underlying diversity of problem perceptions, objectives, criteria, and constraints.

As pointed out by Liebman (1976) more than a decade ago, single-objective optimization cannot and should not be used to resolve conflicts due to this diversity. It can be very useful, however, in illuminating these conflicts and generating non-inferior alternatives for further exploration. Using optimization in this fashion would save a lot of disappointment in some of the past applications of systems analysis to water resources planning.

Few observations that seems to be particularly important for environmentally-sound water resources planning and decision-making are the following:

1. Water resources planning should be linked on a continuing basis with the social and economic institutions of each country, as they also change and develop.
2. Appropriate treatment of uncertain, unknown and risky factors is imperative.
3. More emphasis should be laid on understanding decision-making environments, and clarifying advisory and advocacy roles.
4. There is a need of techniques for rapid responses to changing contexts of decision-making in water resources management.
5. There should be more reliance on sequential decision making, learning feedbacks and experimentation, instead of detailed policy schemes.
6. Efforts should be directed more at improving data base for decision making in water resources management and less towards preparing detailed long-term projections. The degree of detail of the latter should be compatible with the time horizon of a given plan.

It should be recognized that all these goals cannot be achieved without having appropriate institutions, responsive to environmental quality issues as well as to accelerating technological and social change.

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