# Sustainable water development and management

## A synthesis


### United Nations Environment Programme



*This report, prepared on behalf of the United Nations Environment Programme, provides a state-of-the-art synthesis of current knowledge on sustainable water development and management. It concludes that there is no single 'best' approach for sustainable water development. Enunciation of the concept of environmentally sound development is not a difficult task. While we have had reasonable success in integrating environmental considerations at the project level and some success at the sector level, we have not succeeded in designing means of integrating environmental concerns effectively at the national policy and planning levels, except in very general terms.*


### The challenge

The past 25 to 30 years have been a period of unprecedented water resources development in many countries of the developed and developing world. Water projects of all magnitudes have been built to provide societies with water and hydroelectric power needed for development and economic growth. For example, the number of storage reservoirs in the world with a capacity larger than 100 million $m^3$ has increased during the years 1951–85 from 1777 to 2357 (Voropaev and Avakian, 1986). Among the best-known examples of large-scale water projects are the Aswan High Dam which has completely modified the hydrological regime of the Nile river below Aswan, the huge Kariba and Cabora Bassa Dams built on the Zambezi river, and the over 200 m high dam at Bhakra hailed by the then Indian Prime Minister Jawaharlal Nehru as one of the 'temples of modern India'. Still larger projects are contemplated, such as the Three Gorge Project on the Chiang Jiang (Yangtze river) in China to provide flood control in the region where in 1954 floods caused the deaths of more than 30 000 people and to produce 100 trillion kWh of electricity annually.

Although water resources developments of all types are progressing at a rapid rate and many beneficial effects are being recorded, the environmental impacts of some water projects have not been what water resources planners and political leaders had expected. Serious problems emerging from time to time have drawn the attention of all concerned to the fact that water projects may yield a mixture of desirable and undesirable effects. It has become clear that several of these projects have been planned and designed without taking into account the complex interrelationships between people, water, environment and development.

This paper is concerned with the fundamental issue of how to accommodate water resources development and management within the context of environmental preservation and improvement. The purpose of the paper is to show that these goals are not exclusive of one another but rather complementary, and in the long run mutually reinforcing. As pointed out in *Our*


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*Common Future* – the recent report of the World Commission on the Environment and Development, the so-called Brundtland Commission – good development will protect and enhance the environment; attention paid to environment concerns will strengthen developmental progress and prospects. To achieve these goals, water resources undertakings must be planned, implemented and operated in an 'environmentally sound' way. What is needed is development and management of water resources such that the resource base is maintained and enhanced over the long term. This implies recognition for the need for sustainable water development – development that ensures that future generations will also have this resource to satisfy their needs.

Sustainable water development is not an easy task. This is especially true in countries plagued by critical short-term problems such as malnutrition and disease, high infant mortality, low life expectancy, high illiteracy level and chronic unemployment. Other major obstacles to sustainable water development have been identified by government and the international community (World Bank, 1988) as:

(1) fragmented sector policies;
(2) weak or non-existent institutions and inadequate coordination among sector agencies;
(3) lack of adequately trained and motivated manpower;
(4) use of technologies inappropriate for developing country conditions, and lack of knowledge of lower-cost technologies;
(5) lack of community involvement;
(6) inadequate operation and maintenance;
(7) problems with resource mobilization and utilization, including cost recovery.

In spite of these difficulties, unsustainable development and use of water resources is a short-sighted policy which can eventually result in a worse situation. This is specially true if the environmental impacts are synergistic or irreversible, or both.

This paper is addressed to engineers, as this profession has traditionally played a dominant role in water resources development and management. But it is also relevant to a variety of other disciplines such as economics, geography and law. The paper is directed to analysts and decision-makers who in the process of planning or making policy decisions are concerned with environmentally-sound development and management of inland water resources in national and international watersheds. The paper is intended to make them:

(a) better informed as to the full dimensions of water resources development, the benefits as well as the costs;
(b) more sensitive to environmental problems of water resources development;
(c) familiar with the main components of the analysis so that they could ask, for each component: Has it been considered? Have appropriate practicable methods of analysis been used?
(d) more confident of their ability to offer judgements on such matters.

This paper consists of four sections. The present section presents the basic concepts and challenges of water resources development which underlie the notion of environmentally-sound and sustainable water resources development. The second section focuses on approaches that can be used to identify environmentally-sound development and management strategies. The third section discusses problems which limit the application of environmentally sound development strategies. The final section provides an appraisal of the future directions of applying operationally the concept of sustainable water development and management.

### *Water needs and flood control*

In order to exist, people need drinking water. They also need water to prepare food and for sanitary purposes. The daily minimum consumption of water for human needs varies between 1.5 and 5 l, depending on the climate and physical activity. The daily per capita domestic use of water in urban areas is much larger. Parallel to these considerations, the supply of good quality water requires that sanitation problems be appropriately taken into account.

The Action Plan of the United Nations Mar del Plata Water Conference (1977) drew attention to the basic needs of society by launching the International Drinking Water Supply and Sanitation Decade (1980–90). In 1985, at the mid-point of the decade, 870 million people lived in urban areas of the developing world, while roughly 1.6 billion were rural inhabitants. Approximately 22% of the urban group were without a water supply service and 40% were without sanitation. The corresponding numbers for the rural population were 64% and almost 85%. These data show that for the urban water supply and sanitation category, the percentage of people unserviced is roughly the same as it was in the early 1970s, mostly due to urban population increase in the developing countries. In the same period the situation improved in rural water supply. The decade, however, is losing ground in rural sanitation. This is unfortunate since the lack of sanitation facilities and the usually associated unsafe drinking water are still some of the principal causes of disease and death in the developing world. The World Health Organization (WHO) estimates that 25 000 people a day die from waterborne diseases in developing countries.

It is clear that the problems surrounding a lack of clean water and sanitation have reached a critical stage in many parts of the world – not only from a social point of view, but also from an economic and developmental perspective. Taking into account expected population growth, there will certainly be a need for new water supply and sanitation projects in the future. But project operation and maintenance, as well as rehabilitation of existing facilities, will remain critical issues in the years to come. The developing world is plagued by broken down or badly functioning water and sanitation facilities. Involving the people who are the targets of improvements is an absolute necessity if this unsatisfactory situation is to be turned around.

As world population grows, so does the need for increased food and fibre production which consumes more water than any other human use – about 80%, mainly through irrigation. For example, it takes approximately 1000 tons of water to grow one ton of grain and 2000 tons to grow one ton of rice.

The total irrigated area in the world is on the order of 250 million ha of which about 100 million ha are in developing countries. Region-wise, of the total irrigated area in the world, about four fifths lie in the arid and semi-arid regions of Asia. In such regions waterlogging and soil salinity must always be feared if irrigation is not accompanied by adequate drainage. On a global scale, no less than 200 000 ha are lost every year to waterlogging and salinity.

From the development plans of different countries it is clear that the irrigated area will continue to grow, although small-scale projects seem to be getting more and more attention. Therefore it will be necessary to pay more attention in the future to the maintenance of irrigation projects. There is a great potential for improved water-application efficiency through better management practices.

An important aspect of water management in the agricultural sector is the prevention of soil erosion, which most often is caused by overgrazing or deforestation. Soil erosion leads to the loss of valuable topsoil and causes silting, sedimentation and turbidity problems in downstream areas. Although it is unvoidable that storage reservoirs will receive some sediment, the upper watersheds should be managed in such a way that the design lives of reservoirs are not reduced. Erosion should be prevented primarily by eliminating its causes; however, in many cases this is a task of formidable proportions. For example, in Latin America deforestation of the tropical rainforest is taking place on such a wide scale that it has become the most important environmental issue in the region.

Water is used in many industrial activities, for instance in producing foodstuffs, metals, chemicals, textiles and paper. It is needed for cooling, for boiler feeds, for processing and for assimilation into end products. Both the volume of water needed and the quality criteria differ considerably from one industry to another. Industry has several ways of ensuring the necessary supply; it can draw water from the public distribution network and it can draw water directly from surface and groundwater supplies. The choice depends on the alternatives available, on the quality of water that is needed and on economic considerations. Direct withdrawal of groundwater is often the least expensive alternative and ensures water of good quality, but water from this source may be limited. In many countries, good quality groundwater is reserved for special uses, such as potable water supplies and food processing.

Today, in the developed world, industry usually claims 40–80% of total water withdrawals, while comparable figures for the developing countries are in the order of 2–5%. But, according to the Lima Convention, by the year 2000 about 25% of global industrial output will originate in developing countries. Although this may be overly optimistic, an increase of industrialization will cause related water needs to grow substantially.

Few, if any, industrial projects are free from water pollution problems. The 'classic' form of water pollution is the discharge of substances that draw upon oxygen dissolved in water during their decomposition. The more the oxygen is consumed, the more aquatic life is impaired. But the oxygen-consuming substances usually display properties harmful to the aquatic environment only when present in relatively large amounts. Other substances are hazardous to humans even at low concentrations. They may be toxic and have long-term effects. Such substances include both organic compounds such as chlorinated hydrocarbons and inorganic substances such as heavy metals. These micropollutants have only during the last decade been given appropriate attention. This is because their identification has been made possible by new analytical techniques and because knowledge of their harmful properties has increased considerably. Although conditions in many developing countries may permit relatively liberal effluent and emission standards, it should be remembered that the cost of cleaning up water, once it has been polluted, is high; hence the need to have water quality standards capable of taking into account the cumulative consequences of industrialization of developing countries.

Large amounts of water are needed by thermal power plants. They withdraw surface water for cooling and return it at a higher temperature. Thermal pollution may have adverse consequences for the quality of the receiving water. It leads to a decrease in dissolved oxygen levels and to thermal barriers which may interfere with the migration and spawning of fish.

Hydroelectric power generation has different impacts on the environment. Being an entirely non-consumptive water use, it does not pollute the water. However, it can affect the migration of anadomous fish. Hydroelectric power generation has been the main purpose of many large water projects undertaken in the developing world, although in Africa, for example, the current annual production of hydroelectric power is still in the order of only 3% of potential output. Unfortunately, in many cases, the benefits envisaged by the planners of such projects have not materialized. Their potential for transforming the economy of the surrounding regions has often been overestimated. However, in view of the persistent demand for energy from resources other than hydrocarbons, hydroelectric generation will probably continue to receive much attention, but with a trend towards smaller, less costly and environmentally less disruptive projects.

Inland navigation is also a non-consumptive water use. It is an important means of transport for bulk goods. (Biswas, 1987a). The water needs of navigation depend on the available depth of water, on stream velocity and on whether there are natural or manmade obstacles, such as rapids or locks and weirs, respectively. Controlled waterways, with locks for changes in water level, require considerable amounts of water for their operation. Except for corrosion of ships, barges and harbour installations, the quality of water does not influence navigation. Inland navigation will continue to be one of the important components of multiple-purpose water resources development schemes.

Recreational activities such as sailing, swimming and fishing also make demands on water resources. They attach great importance to water quality which should be such that public health risks are minimized. In this respect, attention should also be given to aesthetic factors; surface waters should be in such condition that they are pleasant to the public at large. With increases in the standard of living, recreational water needs can be expected to grow substantially.

The various water needs discussed so far are sometimes difficult to satisfy, mostly during low flow periods. But water resources management is also concerned with combating the effects of excess water in streams – flooding is part of the normal life of a river. The Senegal river in Western Africa may serve as a good example in this respect. During the dry season the river flow is so small that intrusion of salt water from the ocean is felt 200 km upstream from the estuary. On the other hand, every year 15000–150000 ha are flooded during the rainy season. Although absolute control over floods is rarely feasible either physically or economically, the goal is to reduce flood damage to a level that is consistent with the social and economic costs involved. Because of the loss of human life and the disruption of regional and national economies as a result of flood, large-scale programmes of flood control will certainly be continued in the years to come.

As seen from the foregoing discussion, water resources are developed and managed in response to various needs that already exist or are anticipated in the future. Sometimes one can identify the key needs, for example protection against floods or supply or irrigation water to sustain agricultural development. However, in most cases there is a set of mutually dependent and interconnected needs – their clear articulation and separation are difficult. Moreover, quite often there is competition or conflict between different needs and it is difficult to decide which of them should be given priority. Such decisions would be considerably improved if appropriate prices for water in different uses could be devised. But so far this has proved to be difficult and only possible on a limited scale. It is therefore almost always necessary to compare one use of water with other uses.

Satisfaction of future water needs and flood control objectives are to a large extent the problems of rational resource management. There is considerable scope for rationalization of water use in virtually every sector of the economy. Existing efficiencies of irrigation systems are prodigiously low, and there is much room for water conservation in industrial and domestic sectors as well. There is a vast underutilized potential for stepping up agricultural and industrial production, primarily through more efficient utilization of water management infrastructures already created.

But more rational water use should not be interpreted, as some would like, as meaning that all water resources development must come to an end. This is impossible, if only because of anticipated population growth. What is needed is an in-depth analysis of past failures, a will to eradicate negative consequences, better analysis of new water projects to prevent undesired effects, and steps to eliminate or minimize them before they become unmanageable.

### *Water resources development measures*

Engineering structures for making better use of scarce water and for protecting against floods are among mankind's earliest technological achievements. Canals and water-lifting devices in Mesopotamia, underground conduits of Assyria and Persia, the aqueducts of Rome and many similar undertakings stand as experiences in history that can still teach lessons to contemporary water resources development.

The development of water resources requires planning, design, construction and operation of facilities to control and utilize water. It is basically a function of civil engineers, but the services of specialists from other fields are also required. This includes the assistance of hydrologists, economists, chemists, biologists, environmental scientists and other specialists in both the natural and social sciences. Moreover, water resources projects always encounter a unique set of physical, social and political conditions to which they must conform. Hence standard designs which lead to simple, handbook solutions can rarely be used. The special conditions of each project must be met through an integrated application of the fundamental knowledge of many disciplines.

The commonly accepted structural measures for improving water supply, reducing flood damage and producing water-related goods and services are the following (Linsley and Franzini, 1979):

(1) dams and storage reservoirs which can retain excess water from periods of high flow for use during the periods of low flow. By storage of floodwater they may also reduce flood damage below the reservoir;
(2) open channels which may take the form of a canal, flume, tunnel or partly filled pipe. They are characterized by a free water surface, in contrast to pressure conduits which always flow full. Especially important in this category are inter-regional or interbasin water transfer canals. In some cases, they are tens or even hundreds of kilometres long (Biswas et al, 1983; Golubev and Biswas, 1985);
(3) pressure conduits. They are often less costly than canals or flumes because they can generally follow a shorter route. If water is scarce, pressure conduits may be used to avoid loss of water by seepage and evaporation which might occur in open channels. They are also are less vulnerable to pollution than open channels;
(4) diversion structures, ditches, pipes, checks, flow dividers and other engineering facilities necessary for the effective operation of irrigation and drainage systems;
(5) municipal and industrial water intakes, including water purification plants and transmission facilities;
(6) sewerage and industrial wastewater treatment plants, including waste collection and ultimate disposal facilities;
(7) hydroelectric power plants which are usually classified as storage, run-of-river or pumped-storage plants;
(8) river channel regulation works, bank stabilization, navigation dams and barrages, navigation locks and other engineering facilities for improving a river for navigation;
(9) levees and flood walls for confinement of the flow within a predetermined channel. They are most frequently used for flood mitigation because they can be built at relatively low cost from materials available at the site.

Although this list highlights structural alternatives only, all plausible development measures should be considered – both structural and non-structural, water and 'non-water'. For example, even a study of politically infeasible alternatives may yield important and valuable information. An attractive alternative that happens to be at the time institutionally infeasible can shed light on the cost associated with existing institutional impediments and might indicate specific ways for removing or alleviating such obstacles (Haimes, Kindler and Plate, 1987). Non-water measures often form an integral part of what is commonly known as a water alternative package; for example, land transportation in combination with navigation developments or combined thermal and hydroelectric power systems. Furthermore, quite often non-structural measures are available to accomplish the same objective. The best-known example is flood protection, which can be achieved by floodplain management to protect human settlements in flood-prone areas.

### *Environmental effects of water resources development*

Broadly, four types of environmental effects of water development may be recognized.

The first is disruption of human settlements and human activities. Occasionally such disruptions are very large. The construction of the Kariba dam on the Zambezi, for example, required the resettlement of some 75 000 Tonga tribesmen, and the formation of High Dam Lake in Egypt and Lake Nubia in Sudan necessitated the displacement of more than 100 000 people. In the case of the Ban Chao Nen hydroelectric project in Thailand, 8000 inhabitants had to be resettled out of the reservoir area, presenting several psychological, social and cultural problems in addition to the economic ones. In the environmental studies conducted for this project, careful consideration was given to resettlement sites and changes in occupation, lifestyles, physical and social conditions, infrastructural services, etc. There are many other examples, including the São Simão, Itumbiara and Paulo Alfonso hydroelectric projects in Brazil, wherein resettlement problems had to be dealt with as integral parts of project construction (World Bank, 1975). Overall, resettlement plans have generally been properly implemented.

A second type of environmental effects associated with water developments in some parts of the world is the creation of favourable habitats for the parasitic and waterborne diseases, such as schistosomiasis, malaria, filiariasis and river fluke infections. This has been especially the case with certain irrigation projects, particularly in tropical and subtropical regions. Replacement of simple traditional irrigation practices with perennial schemes could lead to a considerable increase in the incidence of schistosomiasis, as discussed in more detail later. A case in point is the infiltration of blood fluke in Sudan as a result of the development of the Gezira irrigation scheme. Another example is construction of the Volta Dam which transformed 400 km of the river into Lake Volta, with an estimated shoreline of 6400 km. Such an increase of shoreline resulted in the creation of a serious potential mosquito breeding area (Lambrecht, 1981).

A third type of environmental disruption is physical or chemical. It generally results from an alteration of land use, and changes in the surface or groundwater regime, usually as a consequence of the construction of irrigation projects or flow control works such as dams or levees. Soil salinization and waterlogging due to the lack of adequate drainage facilities are classic examples of such environmental problems. In the Euphrates valley in Syria and the lower Rafadain plain of Iraq, over 50% of irrigated land suffers from these effects. In Iran such problems affect about 15% of the total area of the country. In Pakistan more than 13 million ha out of about 15 million irrigated ha are severely affected by soil salinization and waterlogging (El-Gabaly, 1977).

One of the most serious environmental disruptions of this category is siltation. Reference is frequently made to reservoirs that were built for flow control or generation of hydroelectric power where the rate of accumulation of sediment was so rapid that a major reduction of reservoir capacity occurred within a few years of the construction of the associated dam. The Sanmenxia dam on the Huanghe river in China provides an especially dramatic illustration. The river impoundment began in 1960. But within the very short period of $7\frac{1}{2}$ years of operation, the reservoir lost 35% of its total storage capacity of 9,700 million $m^3$ due to sedimentation. The Sanmen case is perhaps an extreme one, but there are other serious examples as well. The useful life of the Ambukloo reservoir in the Philippines has been reduced from 60 years to 32 years due to increasing sedimentation resulting from deforestation in the upper watershed. Similar difficulties have been experienced with water projects in various parts of Asia and Africa (Biswas, 1984).

Finally, the fourth category of environmental effects of water resources development deals with flora and fauna, including impacts on ecological systems taken in a broad sense of this term. For example, an ecological problem that has resulted from dam construction in certain regions of the world is that of the spread of aquatic weeds. Serious difficulties have been encountered as a result of weed growth in the Aswan, Kamba, Pa Mong and Brokopondo reservoirs. In the last case, the water hyacinth spread so rapidly that within two years it had covered 50% of the reservoir surface (Biswas, 1984). Elsewhere, various types of aquatic weeds covered more than 80% of the reservoirs in Egypt, and vast areas in the Congo basin. The spread of weeds has a number of secondary impacts, notably water losses through evapotranspiration. Costs of weed clearing may be in the order of millions of dollars, and sometimes the effects of the remedy may be even more destructive and hazardous than the weeds themselves. The use of herbicides is an example.

Wildlife preservation also falls into this category of environmental effects. For instance, the Kafue hydroelectric project in Zambia in its original design would have had a serious impact on 90 000 lechwe, a species of unique small antelope. Their movement patterns have been dictated largely by the grazing conditions provided by the flood cycles. By interfering with the flood regime the reservoir would haved posed a grave threat to this species, whose future is a matter of concern to wildlife conservation groups throughout the world. To compensate for the loss of natural flooding, the dam was redesigned to allow additional storage to permit the discharge of water needed by lechwe antelope during the critical months of March and April in dry years (World Bank, 1975).

It is clear from the foregoing 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. But it is also apparent that severe damage to water resources may be inflicted by activities other than those directly related to water resources development. Unfortunately many essentially 'non-water' activities are decided on without due consideration given to their potential impacts on the aquatic environment. In fact, sometimes they are decided by nobody – they just happen as a result of the specific social and economic conditions, for example the uncontrolled expansion of urban centres in many developing countries caused by migration of population from the poverty-stricken rural regions. The excessive use of fertilizers and pesticides to increase crop yields is another example of a 'non-water' activity having serious consequences for water quality. It is important, therefore, to consider linkages between environmental problems. Irrigation projects may not only result in soil salinization and waterlogging, but also may produce infestation by undesirable aquatic plants or create enlarged habitats for waterborne disease vectors. The experience underscores an important point, that remedial measures must be spread over a number of 'non-water' sectors and activities, taking into account primary and secondary environmental effects as well as their cumulative impacts.

As pointed out by White (1970), the environmental effects of water resources development are real and it seems likely that we can cope with them effectively only through a very close integration of natural and social sciences, which should be adequately reflected in educational processes and institutional arrangements. To do so we must move courageously away from undue reliance on technological measures to long-term and environmentally-sound mixed strategies of social, economic and scientific enterprise.

*Environmentally-sound water resources development and management*

In the early years of contemporary water management, respect was usually given to the preservation of nature, mostly in the form of supplementary comments in project reports. But gradually emerging problems have drawn the attention of water resources planners to broader environmental implications of water projects. For example, by the 1950s studies carried out for the Volta Dam identified questions of health, fisheries and resettlement. Because negotiations to finance the project took several years and the government became preoccupied with the urgency of building power generation and aluminium-smelting facilities (HMSO, 1956), construction started without adequate arrangements being made to deal with the health, fisheries and resettlement questions. It was rather late that actions were taken to deal with them.

In the late 1960s, keener recognition 'of the full network of ecological impacts incurred by construction of water projects' was stressed among major shifts in the perspective of river basin planning (United Nations, 1970). With the passage of time, worldwide recognition of the general decline in environmental quality has led to increasing pressure for its explicit inclusion as an objective, in addition to economic and social objectives, in water resources planning and management. Since water resources planners have always been concerned with evaluation of various intangibles and hard-to-quantify factors, the field was conceptually prepared for inclusion of the new environmental objective.

Besides the largely unsuccessful path towards aggregation of indices of performance concerning individual objectives into a single monetary measure of composite achievement, inclusion of the environmental objective has been approached basically in two different ways: (1) by application of the multiobjective framework of analysis, and (2) environmental impact assessment (EIA). Water resource planners have leaned towards a multiobjective framework of analysis. Although the multiobjective methods and techniques have not yet been applied on a wider scale, their interest in this approach continues.

The environmental impact assessment approach was pursued on a separate track. In 1970 the USA became the first country to adopt legislation requiring an EIA on major projects. Other countries followed, and parallel with the growth of legislation there has been rapid development of various concepts, methods and techniques for EIA.

The main steps in the EIA are the following:

(a) identification of the likely impacts which need to be investigated in detail, including 'scoping' activities (discussions, meetings, etc);
(b) impact prediction that involves an estimation of the likely nature of impacts in quantitative or at least qualitative terms;
(c) impact interpretation and evaluation, which involves evaluation of the relative importance of different impacts when compared with each other;
(d) identification of mitigating measures and monitoring requirements; and
(e) monitoring and communication.

The EIA approach found expression in the publication of a large number of manuals and guidelines specific to almost every single type of activity. They have been recently assessed by a UNEP-sponsored study focusing on the needs of developing countries (Biswas and Qu, 1987).

Although sometimes an 'uneasy alliance based on convenience' (Stakhiv, 1987) between EIA procedures and the multiobjective framework of water resources planning is observed, these two approaches were originally proposed for quite different decision contexts and situations. Indeed, the EIA was primarily designed to serve as a complementary aid to decision making in a site- and project-specific manner. In the industrialized countries it was to be of particular use for the type of 'health and safety oriented regulatory agencies that are guided by administrative and technical default decision criteria and a philosophy of screening alternatives through binding legal constraints' (Stakhiv, 1987).

The EIA approach seemed to be an attractive proposition for developing countries. In those countries water resources development decisions must often be made before sufficient data are available to assess all their possible impacts; hence the emphasis in many developing countries is on establishing minimum sustainable threshold levels of various environmental impacts, and treating them as constraints in project planning and management decisions. This view of environmental problems through a set of minimal standard constraints is characteristic of the methods embodied in the EIA approach (Loucks and Somlyody, 1986).

However, it has been recognized that many developing countries are confronted with broader problems related to the development and use of their water and other natural resources – problems that make it necessary to transcend the overly sectoral project-by-project assessment and to see them in a broad context of integrated river basin or regional management. For example, this is a basic challenge in the arid and semi-arid zones of sub-Saharan Africa where the problem of water management and the integrity of the environment is at stake. Environmentally-sound management of water resources must be considered there at both the zone and project levels. At both levels, account must be taken of the dynamic interrelationships between humans and their institutions, water, land, energy, climate and the entire biosphere. Land use patterns must be watched taking into account their potential impact on surface and groundwater resources. Water quality must be carefully managed and monitored. Combined forest and watershed management must contribute to water conservation in the catchment. All these factors must be simultaneously considered within the framework of a comprehensive basin-scale water resources analysis (Falkenmark, da Cunha and David, 1987).

It is no surprise, therefore, that the EIA methods that have been evolved so far 'are not proving to be particularly effective in improving allocation decisions' (Knetsch and Freeman, 1979). In fact, this would be incompatible with the purposes for which the EIA was originally developed. Instead of extending these purposes to encompass a more comprehensive evaluation perspective, an integration of EIA within the broader multiobjective decision-making framework is required.

All these considerations lead to a broader concept of environmentally-sound water resources development and management. This concept was given considerable impetus as a result of the proposal for a World Conservation Strategy by the International Union for the Conservation of Nature in 1980 which called for a reorientation of all resource management practices in favour of sustainable development. It means such development as does not assume resources are cost-free and endless – development that does not force the poor to destroy tomorrow's resources just to stay alive today.

Based on the foregoing discussion, environmentally sound and sustainable development and management implies the following (Sewell and Biswas, 1986):

(a) Development is controlled in such a way as to ensure that the resource itself is maintained and enhanced, and that adverse effects on other resources are considered, and where possible ameliorated.
(b) Options for future development are not foreclosed.
(c) Efficiency in water use and in the use of capital is a key criterion 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, namely: the recognition of a concept of sustainable development, incorporation of a more comprehensive perspective, and the pursuit of higher levels of efficiency.

None of these elements is entirely new. All have been introduced to varying degrees across the world. They cannot be pursued any further, however, without institutional arrangements compatible with the philosophy of sustainable resource use and management. This calls also for adequate handling of uncertainties and the unforeseen. Those two challenging issues which are of critical importance for environmentally-sound and sustainable management of water resources are examined briefly in the remaining part of this section.

*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. 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 possible 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 upon its problems and characteristics. Further, in any particular situation there should be a demonstrated need for a new institutional arrangement to accomplish specific objectives before the best form of such an arrangement can properly be judged. Existing agencies that are adequate for the tasks ahead should never be duplicated or superseded. Most often, however, major effort is required to devise and set up institutions which are 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 side by side. Separation of the authorities concerned with development and environment as well as lack of sufficient coordination clearly militate against the adoption of a more holistic view of water resources 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, with responsibilities for managing both water quantity and water quality, typifies such a shift. In such cases public involvement and inputs originating from local initiatives tend to be reduced. Moreover, the informational barrier of centralized institutions affects the decision-making process. Centralized water authorities are usually well informed about water supply alternatives in a given region (storage reservoirs, interbasin water transfers, etc), but they have much less understanding of the options available to individual water users for adjustment of their water demands. This deflects attention from the demand management alternatives which usually not only reduce capital requirements but are also environmentally less disruptive.

A second trend is towards decentralization, but in this case the water authority must be provided with some instruments to influence and coordinate the action of each and all independent water users. The extent to which water pricing schemes can be used for this purpose is at least debatable, especially in developing countries. What other instruments could be used efficiently is far from clear.

However, centralization and decentralization should not be seen as mutually exclusive options. Some of the most efficient management schemes feature a strong national water authority collaborating with decentralized and to a large extent autonomous regional (river basin) agencies. The 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 a catchment authority is a special-purpose regional body which administers the water and land resources of 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 boundaries. It is recognized that soil, water and vegetation resources cannot be managed for quality and sustained availability in isolation from each other. Twenty 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, and the Waikato Valley Authority, in recognition of 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 like the Catchment Authorities Association, the Municipal and Counties Associations, Federated Farmers, the Manufacturers' Federation, and the Land Drainage and River Boards Association.

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 the administrative structure seems to be ideal, laws and rules look perfect, but things do not work as expected. This is often caused by a lack of adequate motivating mechanisms. This difficulty has been most evident where authorities have relied chiefly upon regulatory processes to achieve policy objectives. The environmentally-sound management of water resources should rely more on sequential decision-making. learning feedbacks and experimentation than on detailed and usually inflexible policy schemes.

To summarize, it is important that water management institutions are not too narrowly concerned only with water. They should be sensitive to changes in human preferences, habits, desires, aspirations and management abilities. The river basins (catchments), which are coherent hydrological units relevant to all water resources planning, design and operation, should be seen in such a broad context. Moreover, water management institutions should be capable of handling various problems due to the largely unknown hydrologic and economic futures.

*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. But there are other sources of uncertainty as well. For example, the more distant future is generally unknowable as regards economic events. The sources and degrees of uncertainty differ among various aspects of water resources development 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.

In strategic water resources planning, particularly important is uncertainty concerning future societal goals and the long-term availability of technical and non-technical means by which these planning 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.

Many suggestions have been offered regarding what to do about 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 this only at the peril of their plans. Surely, to ignore uncertainty is to act arrogantly – as though forecasts were completely certain and the anticipated end results were accomplished facts. This is contrary to any rational, logical or theoretical structure.

The second option is to avoid uncertainty by incremental implementation of development plans. This strategy, unfortunately, cannot always be followed in water resources development, especially in the case of large-scale structural projects.

The third option is to reduce uncertainty, mostly at the research and data-gathering pre-planning stages. Under all circumstances, it is certainly advisible not to spare any effort to reduce uncertainty. Better understanding of cause–effect relationships is especially important in this respect.

The fourth option is to view uncertainty as a chance occurrence and build it into the planning process. Risk analysis is playing an increasingly important role in assisting water resources planners to choose between different options related to the quality, safety and sustainability of the environment. This is generally a two-part endeavour. In the first stage of risk assessment a wide range of scientific disciplines is usually used to produce some estimate of risk. Quite often, sensitivity analysis is employed at this stage, ie 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 risk are identified, evaluated and applied.

Although the foregoing may sound fairly straightforward, risk analysis, and especially the risk assessment phase, is a very complex task. The injury probability of a given event may be low, but if its perceived importance is high it may command very large prudential expenditures. This is especially true when the confidence that people feel about their knowledge of consequences of an event is low (eg groundwater contamination by nuclear waste).

## Approaches

While recognition of the challenges of sustainable water resources development and management is an important first step, it does not provide sufficient conditions to ensure environmentally-sound development. It is also essential to know how these concepts can be grasped analytically and made operational, and what types of institutional and legislative frameworks are necessary to facilitate the use of such concepts. Equally necessary are trained personnel who can effectively apply such concepts.

After some two decades of research, discussion and experience, the question is no longer whether the concept of sustainable water development and management is applicable, but rather how to incorporate the concept in different stages of the planning process. The following discussion is structured in accordance with the usual chronology of this process, stressing throughout all of its stages the crucial issue of trade-offs among economic, social and environmental goals. While sustainable development has no analytically rigorous definition, this section is an attempt to describe its characteristics and to show how to distinguish it from other concept of development.

One can legitimately ask why analysis of trade-offs is so important for sustainable water development. The answer is that most, if not all, water resources issues and problems are characterized by multiple objectives, multiple decision-makers, multiple users and multiple constituencies. Such circumstances most often lead to competitive or conflict situations when, for example, improvements in one objective (eg short-term economic gains) are associated with deterioration in other objectives (eg long-term environmental quality). In sustainable development, however, economic development and environmental quality should not be viewed as exclusive of each other, but rather as complementary and mutually reinforcing. It must be recognized that deterioration in environmental quality may eventually affect water availability, hampering achievement of anticipated economic and other social development objectives.

The ultimate goal of water resources development and management is to serve water users, and to satisfy this goal it has to be ensured that water will be available in sufficient quantity of acceptable quality, at the right location, at the right time and at the right price, now and in the future. Because of the uncertainties associated with all phases of water resources development and management, all this can be achieved only within some limits of assurance and reliability. Water resources planning and management can vary significantly in scope, space and time. The following discussion, however, focuses in particular on those features that emerge when large-scale water problems and long-term basinwide strategic management issues are being considered.

The process of water resources development and management is in principle always the same, regardless of the stage of economic and social development of a given country. However, the level of sophistication that can be brought to bear on the analysis is always adjusted to local conditions, problem formulation, the technical expertise of the manpower available, financial and time constraints. Be that as it may, several stages of water resources development and management can be identified, although there is nothing sacrosanct in this breakdown:

(a) problem identification and formulation;
(b) definition of objectives and translation into evaluation criteria;
(c) formulation and screening of policy alternatives;
(d) evaluation of alternatives, including consideration of long-term environmental and social impacts;
(e) selection of the 'best' alternative (this cannot be accomplished without the involvement of the public);
(f) implementation of the selected alternative; and
(g) monitoring and ex-post performance analysis.

In most investigations, iteration is needed among individual stages. The analyst must be free to examine initial assumptions, revise earlier work and impose additional constraints after analysing the consequences of some of the alternatives. For example, there is always a feedback loop from evaluation to formulation of alternatives. It is also important to shorten the distance between the analysts and the decision-makers. Close interaction between analysts and their clients is an important requirement for successful implementation of sustainable water resources development.

Taking all these factors into account, the following discussion of how to incorporate environmental considerations into water resources planning and management is organized in accordance with the stages identified above. Explicit consideration of 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. Raising environmental issues at the beginning of any investigation increases the chance that they will be considered appropriately during the entire planning and management process.

### *Problem identification and formulation*

There is general agreement that the problem identification and formulation step is of critical importance for the entire process of water resources development and management. There is, however, a real danger that when there is pressure to produce quick results, the analytic resources and expertise are limited, and the urgency of the resolution of the problem is critical, the importance of this initial phase of the 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 target groups, and selecting the initial approach the analysis is to take.

Planning for water resources development is initiated in response to needs that already exist as well as to needs that are anticipated for the future. Translating needs into problem formulation is itself a complex process requiring technoeconomic skills and political–institutional insights. The problem becomes further complicated because the needs may change 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 requirements of those who are responsible for 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, and various technical, political, social, economic, institutional and environmental constraints must be taken into account. Among some of the main problems and constraints that could have a direct impact on the problem-formulation process are the following:

(1) Administrative and hydrological boundaries usually do not coincide.
(2) Time and budget allocations are often limited.
(3) Various regulations and legislative requirements narrow the range of feasible alternatives.
(4) Water needs are determined exogenous to the planning process.
(5) An adequate number of trained personnel may not be available.

Furthermore, much may depend on what the problem is perceived to be 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 an environmental problem whereas a similar reservoir in an arid or semi-arid location where the reservoir would directly contribute to the production of badly needed food and fibre, and thus contribute to alleviation of hunger and employment generation, may not be considered an environmental problem at all.

The need for problem formulation is critical, especially in developing countries where data availability is a common and recurring problem and investigations must often be undertaken solely to compensate for this lacuna.

Regarding identification of environmental concerns checklists are especially 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 a checklist is valuable but it says little about the magnitude, the extent or the relative importance of the impacts. Nor does it give any idea about the time dimensions of the occurence of impacts. Various checklists currently exist (Biswas and Qu, 1987). One example is that developed by the 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, medium, and low adverse, low or insignificant, low, medium, and high benefit.

Many types of checklist are available. Among them are simple, descriptive, scaling, scale-weighted and questionnaire checklists. The potential uses of these checklists and their application to water development projects have been discussed in detail by Biswas and Qu (1987). While checklists are useful and have certain advantages, they suffer from some limitations as well. They cannot assess the dynamics of change or 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 are useful as an 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 objectives and translation of these objectives into evaluation criteria. Although the environmental objective is the main focus of this report, it is just one of several objectives that must simultaneously be taken into account. In the USA, 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 information, but not the principal factors in the final decision-making' (Eisel, Seinwill and Wheeler, 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 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 resources 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 rapidly as well.

In the case of comprehensive and basinwide water studies the objectives tend to be fairly global and they generally do not incorporate conflicting issues. They are intentionally encompassing 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 an acceptable agenda of project objectives that can be modified later on. Having reached a consensus on general project objectives, more attention can be focused on translation of these objectives into evaluation criteria that are measurable.

An evaluation criterion is a rule used to measure the extent to which an objective has been achieved. In long-term strategic analysis 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 (eg water quality, land quality, aesthetics). When the enviromental consequences of a development alternative are presented in the form of a single numeric index derived by consecutive aggregation of different environmental quality measures their validity and usability are 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 superficial sense. Furthermore, not all water quality characteristics can be aggregated to a single index because of methodological constraints.

Trying to merge too many non-commensurable entities into a single index is usually unproductive and misleading, especially as the aggregation process often call for arbitrary weightings and value judgements. The hypothesis that experts will be able to weigh the numerical consequences of, for example, water pollution *vis-à-vis* air or land degradation is difficult to prove. On the contrary, there is considerable evidence that experts do not like to answer such questions. Instead of looking at an index arrived at by questionable weighting schemes, the experts and also decision-makers usually prefer expressing their judgements on a set of explicitly stated evaluation criteria which describe in economic, physical, chemical and biological terms the environmetal consequences of a given development alternative (Miser and Quade, 1985).

*Formulation and screening of alternatives*

In the case of water resources the proper course of action may not be easy to identify without 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-sized multiobjective water development programme will invariably have a series of subproblems, 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-sized water programme. The identification of the full range of potential alternative solutions is always an important and essential step.

In short, the problem at hand can usually be solved in a variety of ways, and the full range of choices must be explored. In developing countries sociocultural factors are of special importance in the process of formulating alternatives. Considerable evidence exists of present water projects that have failed because the traditions 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, Kindler and Plate, 1987):

(a) A small number of available alternatives could lead to reduction or even elimination of the screening step.
(b) 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 development projects.
(c) 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 development and management special care needs to be taken to ensure that development alternatives do not foreclose other options. Where a choice is between preservation and development, and there are uncertainties with respect to future demands for the services of either alternative (eg recreation *v* hydroelectric power development), the associated costs and risks should be taken into account. It should be recognized that technological progress generally increases the margins of substitution in the production of commodity goods whereas it is generally incapable of augmenting the supply of environmental resources.

*Evaluation of 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 measuring the enviromental impacts of each development plan. It should be noted, as discussed in considerable detail in the following section, that water resources development includes both positive and negative impacts, and that the impact analyses should *not* concentrate exclusively on the negative impacts – as is often the case at present. Current methods of estimating environmental impacts rely on formal environmental impact methods, which could include simulation models of various degrees of complexity.

Most environmental impact 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 the matrix methods, one of the best known is 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. Flow diagrams illustrate cause/effect relationships, but the consequences of a variation in the design of a water project can be taken into account only by constructing another diagram. 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, 1987). A major criticism of these approaches is that they are too rigid, providing only a set of static pictures of reality. They take little account of relationships between the different environmental processes and the combined effects that 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 in the framework of the International Biological Programme (Patten, 1975). The biome models produced in those studies have been useful in conferring a better understanding of ecosystem structure and dynamics, but they do not readily lend themselves to answering specific questions concerning resource management. Many of these models are mathematically quite sophisticated. They contain provisions for non-linear relationships and can mimic accurately fairly complex environmental processes. But at the same time they often ignore those aspects of ecosystem behaviour which are of special interest to water resources planners. Their use in the planning and operation of water development projects has been rare.

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. The water quality model QUAL2E can stimulate up to 15 water quality constituents in any combination desired by the user (Brown and Barnwell, 1986). However, the data requirements for this model are quite demanding, and because of this it has yet to be successfully applied in any developing country. Furthermore, for many of the water quality parameters which need to be considered in the planning process, adequate theoretical knowledge is not yet available. Consequently the reliability of their analysis within a modelling context is often quite low (Biswas, 1988a).

Several groundwater models have been developed which are capable of simulating the transport and dispersion of contaminants in aquifers. Although easy to run on relatively inexpensive microcomputers, they require considerable data input and technical expertise in data acquisition. This presents a major problem for the application of these models in most developing countries. Furthermore, it has to be remembered that present knowledge of groundwater contamination processes and cause-and-effect relationships is still quite poor, and the use of groundwater models should never give the impression that all is known and that all impacts can be predicted with adequate reliability. Indeed, there is great uncertainity associated with predictions made by these models.

The experience of the United States Water Resources Council is relevant here. During the years 1973–82 a special effort was made by the Council to improve specific procedures that could be applied uniformly and consistently to evaluate appropriate beneficial and adverse effects of development alternatives. Although significant progress was achieved, the Council still considers the imperfections of such procedures to be a major obstacle to more complete realization of the multiobjective 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 the analytical complexities of multiobjective methods and techniques (Eisel, Seinwill and Wheeler, 1982).

The choice of the 'best' alternative when several evaluation criteria must be taken into account is a difficult task. During the past two decades multicriteria methods have experienced spectacular growth, capturing the attention of many and bringing about some new theoretical developments in the field of water resources management (Haimes, Hall and Freedman, 1975; Cohon, 1978; Chankong and Haimes, 1983). While the growth in theoretical and empirical studies has been phenomenal, there are few actual water studies that have utilized multicriteria methods throughout the entire course of planning, even in developed countries. However, they do appear to be a viable framework of analysis for environmentally-sound and sustainable water resources development under certain conditions.

The multicriteria framework of analysis became of interest in the area of water resources planning and management in the late 1960s and early 1970s. It represents a generalization of single-criterion analysis. The difference is that multicriteria analysis deals with several criteria simultaneously within the same analytical structure. For such problems the concept of 'optimality' must be dropped because a solution which maximizes one criterion will not, in general, maximize any of the other criteria. This leads to the notion of a non-inferior alternative (sometimes also called non-dominated, polyoptimal, efficient or Pareto-optimal) where any improvement in one criterion can be achieved only at the expense of degrading another alternative (for example improvement of short-term economic gains at the expense of long-term natural resource degradation).

Selection of the 'best' alternative from the set of non-inferior alternatives obviously involves a choice between competitive criteria and the degrees to which each of them is satisfied. This choice, leading to the selection of the most preferred or so-called 'best compromise' alternative, requires that trade-offs between the achievement of different criteria be identified and evaluated. This evaluation, to varying degrees, reflects the economic, social, aesthetic, cultural or even moral values accorded to individual criteria by those who are charged with 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 multicriteria optimization and planning. Nonetheless the complexities and constraints faced by the analysts in applying multicriteria analysis to real problems should not be underestimated.

### *Monitoring and evaluation*

If water development projects are to be sustainable, monitoring and evaluation have to be an integral part of the management process.

While a limited literature exists on monitoring and evaluation of water development projects there are many reports available on pseudo-evaluations that have been carried out in the recent past at both national and donor agency level – both bilateral and multi-lateral – which are more concerned with the protection and enhancement of the reputations of the organizations concerned, both within and outside countries, and the individuals associated with the projects than they are with project evaluation. These evaluations cannot have a beneficial impact on the management process since they either do not identify major problems and bottlenecks, or if they do their importance is significantly downplayed. Unfortunately, far too many pseudo-evaluations are being carried out at present, which in the long run is not only detrimental to society but also reduces the effectiveness of water projects as well as the perceived usefulness of the monitoring and evaluation process.

Major water projects in developing countries usually call for step-by-step implementation rather than immediate concerted action. Due to the general shortage of data, continued monitoring of impacts should already be part of project implementation. It must be recognized that uncertainities are always present, and better results can be achieved if the impacts of development are recorded from the earliest days of project implementation. Only then can an unexpected turn of events be identified early on and the project scheme be 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. Continuous monitoring of project implementation is a prerequisite for environmentally-sound management, and yet this has for the most part been neglected so far in most developing countries.

As soon as the project or development plan becomes operational, one of the issues of critical importance is an analysis of performance aimed at determining the extent to which the objectives of the project or development plan are being achieved. Such an 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 development plan, 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 this is understandable, especially in developing countries where due to the general shortage of skilled technical personnel the analyst may share some of the responsibility for 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 water development projects in contrast to pseudo-evaluations is also a problem that seems to be pervasive in many bilateral and multilateral aid agencies. This requires the immediate attention of all recipient and donor countries and organizations.

There are many reasons for carrying out systematic monitoring and evaluation of water projects, the principal ones being the following (Biswas, 1990):

- to determine the extent of achievement of the goals of a project by assessing actual impacts and then comparing them with expected impacts;
- to obtain information as to why a project may not have had anticipated impacts by identifying the magnitude, extent and location of the problems in order that corrective actions may be taken to maximize the beneficial project impacts;
- to increase the understanding of the management of the various interlinked processes and issues involved so that the resulting enhanced management understanding can be be translated into action in terms of immediate, observable, concrete decisions;
- to improve the planning, implementation and management of similar projects elsewhere through the lessons learned;
- to verify the relevant project assumptions;
- to plan later phases of the project more effectively based on the evaluation of the performance of the previous phases;
- to provide facts and success stories at the ministry or department level which can not only defend existing policies and programmes but may also assist in getting additional financial support;
- to provide national policy makers with objective information in order that they can decide to what extent such activities should be continued in other parts of the country.

It should be noted that the reasons outlined above for carrying out monitoring and evaluation are not mutually exclusive since they are often interrelated. Equally, it is not enough to identify and to analyse the technical, social and economic aspects of the various issues and problems; as indicated earlier, it is also essential to examine institutional arrangements. Such arrangements should be reviewed as well, since it is the institutions concerned which, in the final analysis, have to develop ameliorative policies and implement them.

There are some fundamental requirements for designing any monitoring and evaluation system for a water development project. Among the primary requirements are the following:

- timeliness;
- cost-effectiveness;
- maximum coverage;
- minimum measurement error;
- minimum sampling error;
- absence of bias; and
- identification of users of information.

These are briefly discussed.

*Timeliness.* Most management decisions have a time dimension, even though the timeliness of making some decisions may be more important than others. For example, if the farmers at the tail end of watercourses are not receiving their share of irrigation water regularly, or if fertilizers and pesticides are not available at the right time of the cropping seasons, it is necessary that immediate remedial measures be taken. If not, the result could be a poor harvest, and the income forgone by the farmers may never be recovered. Thus it is essential that the information collected reach the appropriate decision-makers on time so that rational decisions can be made in time based on the monitored data. Accordingly, for a rational management system, monitored information should be channelled in a timely fashion so that it can be converted into decision and action.

The danger is that if monitoring and evaluation information from the project does not reach the managers on time, it is likely that one or more of the following consequences, which are not mutually exclusive, may occur:

- the wrong action may be taken;
- the decision taken may not be optimal on a long-term basis;
- no action may be taken when one is desirable;
- the decision taken may result in irreversible damage; or
- the decision taken may unnecessarily increase the cost and timeframe required for the resolution of a specific problem.

It is therefore essential that a monitoring and evaluation system for a water project be set up in such a fashion that relevant information in usable form reaches the people who need it on a continuing and timely basis.

*Cost-effectiveness.* Information collection, processing, analysis and scaling require financial resources, expertise, manpower and equipment. Since the ready availability of all these resources in developing countries is limited, any monitoring and evaluation system designed for water projects should be cost-effective. This essentially means a sensible trade-off between the depth and context of information to be collected as well as between amount, relevance and accuracy. As a general rule, the value of the information collected should exceed the cost of obtaining that information.

For most projects, the value of information generally increases with the extent and accuracy of information available. The value of information for most decisions, however, generally approaches a plateau at a certain stage, beyond which it increases only marginally. In contrast, the cost of obtaining information continues to increase with more coverage and more accuracy. There is a cost-effective zone, beyond which the cost of obtaining information rapidly exceeds its intrinsic value. Exactly where within the cost-effective zone a decision should be made depends on a variety of factors such as the type of project, management experience and potential impacts, but such trade-off considerations are often made on the basis of value judgements.

There is often a tendency to collect more data than are necessary. For any monitoring and evaluation process to be efficient and cost-effective, it is essential to have a clear idea about who is going to use the data, what types of data are needed, how the information will be used, and when and in what form they will be made available. Without such a clear focus, unnecessary and non-essential data may be collected, which is an expensive luxury most countries cannot afford.

*Maximum coverage.* For monitoring and evaluation of water development projects, especially large ones, a major difficulty arises from the fact that a wide area may need to be covered wherein it may be necessary to get an objective view of the operation of the system, its impacts on agricultural production and the overall quality of life of the people in the area. Thus, maximum coverage taken literally may prove to be an expensive, complex and time-consuming process.

As a general rule, sociologists and anthropologists prefer to have as much breadth of coverage as possible. However, given the high resource costs of manpower, time, transportation and other related factors, as well as the high opportunity costs of these resources, a decision may often be necessary to limit coverage to a few selected variables, and to use the balance of the available resources to obtain more detailed information on specific aspects and/or areas that are critical from a management viewpoint. Accordingly, maximum coverage in the present context should be interpreted to mean collection of maximum data that are necessary and will be used for management purposes, subject to the resources (funds, manpower, expertise, equipment and time) available.

*Minimum sampling error.* Since it is neither necessary nor desirable to monitor all possible developments in the project area, sample surveys are essential. Water projects cover numerous issues and diverse disciplines, and accordingly there is no straightforward or uniform solution as to what may constitute a suitable sample size. For example, for the analysis of rainfall one rain gauge per square kilometre is considered to be an extremely dense network, and thus totally unnecessary unless very exceptional circumstances warrant it. In contrast, the identical sample size would be totally unacceptable to sociologists. In the final analysis, determination of sample size will depend upon the type of information to be collected and the use that will be made of that information.

*Minimum measurement error.* The level of accuracy and reliability of the data to be collected are important considerations for the monitoring and evaluation process. Generally, engineers and physical scientists are more concerned with the accuracy of measurements and data collected than are sociologists and anthropologists. For water projects, measurement error could be a real problem when small farmers and landless labourers are being considered. They are often illiterate and may even have some difficulty with precise numerical quantification. Accordingly, they may not be reliable or they may even be somewhat vague about the rates of change, especially when changes are within the order or 15–20% and some time has elapsed between the two periods in time which are being monitored. The enumerators and data collectors should be aware of this potential problem and attempt to ensure that the changes are properly reflected.

*Absence of bias.* Monitoring and evaluation of water projects often suffer from the biases of the people performing the task. This happens because evaluators, often due to their disciplinary orientation, expertise and past experiences, may have the tendency to concentrate on specific issues at the cost of other issues which may be of similar, or even more, importance. Among the common biases observed are consideration of the water entering watercourses but not the losses in the system, irrigation but not drainage, fields near roads along canals and watercourses but not those to which access is difficult or uncomfortable, review during healthier, better-fed dry seasons when climate is pleasant but not during food-scarce, unhealthy, unpleasant and wet seasons, and interviewing large farmers or men but not small farmers or women. Equally, there is a danger that biases may be introduced in terms of one's discipline, since unidisciplinary professionals often tend to concentrate on areas that they are familiar with.

It should be noted that in the real world an issue is an issue. It is often labelled engineering, economic, social, legal or whatever depending upon the individual's discipline, experience and ways and means of approaching it. Thus, ideally, evaluations should be carried out by professionals who may specialize in one discipline but are knowledgeable in other disciplines.

Such evaluators should be flexible, observant, sensitive, eclectic and constructive. They should be capable of intermixing freely and questioning sympathetically and inventively. Since, in reality, such qualified and experienced individuals are very difficult to find, one may have to depend on who is available. To a certain extent the problem can be resolved by carefully choosing a multidisciplinary team, which may offset the biases of individual members by the juxtaposition of the insights of various disciplines. Past experience indicates that the use of multidisciplinary teams for monitoring and evaluation of water development projects, where team members are not familiar or do not have established working relationships with each other, generally does not produce an integrated multidisciplinary approach or report.

*Identification of users of information.* If the results of any monitoring and evaluation are to be used, it is necessary to identify who is going to use the information and their informational requirements before designing a monitoring and evaluation system. At different levels of management the hierarchy of information needs is different. For example, at a certain level of management detailed information on a specific aspect of an irrigation project may be necessary, whereas at other levels (generally higher) aggregated information may be required. It is necessary that the right type of information be provided to the appropriate levels.

For any utilization-focused evaluation, after identification of relevant information users, it is desirable to (i) actively involve the users in ways that would increase their commitment to the utilization of evaluation findings; (ii) train users to increase their understanding of evaluation and make it possible for them to play a useful role in the evaluation process; and (iii) provide genuinely useful information to the users so as to reinforce their future commitment to evaluation.

*Trade-off between the requirements.* The principal requirements discussed above should not be considered in isolation since some may reinforce each other and thus are mutually supportive whereas others may be in conflict. The quality of any monitoring and evaluation system is determined not by any one requirement but rather by how effectively they are integrated in one system. For example, there is always a trade-off between maximum coverage, minimum sampling error, minimum measurement error and cost, and these trade-offs are generally case specific. There is no universal solution.

There is sometimes a tendency to emphasize one or more of the requirements at the cost of others because of bias. A good example of this is the monitoring and evaluation of irrigation projects and programmes in Nigeria during the past 10 years that were funded by the World Bank. Massive resources were devoted to monitoring and evaluation activities, and equally massive amounts of data were collected by the Agricultural Projects Monitoring Evaluation and Planning Unit (APMEPU), which was established in Kaduna in 1975 to coordinate the monitoring and evaluation activities of the various agricultural development projects/programmes (ADPs). In spite of such intensive efforts by APMEPU, the impact of the ADPs on food production or consumption is far from clear. A major problem arose because of APMEPU's overriding emphasis on minimizing sampling errors. This contributed to a lopsided approach which gave high priority to statistical considerations but low priority to other requirements including the resources necessary to perform all the monitoring and evaluation tasks. While the sampling error was minimized, all types of other errors were introduced at a level that was unacceptable. This meant data massaging, further analysis, and re-analysis which not only took time but also contributed to the development of a credibility gap between the unit and project management and other users of the information. It is thus essential that a cost-effective monitoring and evaluation system be developed that provides information required by managers in a timely fashion, subject to resources and manpower constraints. Development of an effective system is an evolving process that requires regular, good feedback between the monitoring and evaluation unit and users of the information (Biswas, 1990).

Monitoring and evaluation are integral components of all water development projects. However, this does not mean that if monitoring and evaluation are carried out, this will automatically improve the efficiency of the management of projects. On the basis of a review of monitoring and evaluation activities of irrigation projects in Asia and North Africa, the general situation appears to be that monitoring and evaluation are having far less impact on the management process than expected or even possible.

One of the main reasons for this is that monitoring and evaluation are being imposed from above by the donor agencies, both multilateral and bilateral, on developing countries. A condition of any loan or grant by the World Bank, IFAD or similar funding agencies has been to establish monitoring and evaluation activities within a project. The monitoring and evaluation requirements of these external agencies are not uniform. Furthermore, the managers at project level do not have a good understanding of the process. Under such unsatisfactory conditions, monitoring and evaluation get done not because the managers feel that it is necessary, but because it is a condition of the loan or grant. Accordingly, it is not surprising that monitoring and evaluation activities generally lack a sharp focus and the processes are seldom constructively reviewed by either national or international agencies. Monitoring and evaluation in many projects have become routine and perfunctory affairs that are done mainly because of administrative requirements, wherein activities and impacts are routinely monitored and documented, reports are neatly filed, but the project activities continue merrily on their way, unaffected in any sense, with a business-as-usual attitude (Biswas, 1990).

For monitoring and evaluation to succeed, we need a new ethos. As Brown (1976) has aptly noted, the heart of evaluation is an attitude, a frame of mind which enables one to review the project activities and performance in a constructively critical light. This should be done with emotional detachment. Managers need to develop a new evaluative mindset that allows them to appraise performance, reflect on what has been learned for future activities, and then adjust policies, if necessary, in response to what has been learned. Without such an ethos it is unlikely that the benefits of monitoring and evaluation will be fully harnessed.

*Institutional framework*

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

Several responses have been made. One response has been to highlight social effects in environmental impact assessments of water development projects. Another has been to foster the preparation of broadly based strategic plans for regions which are currently sparsely inhabited but which could come under considerable pressure for development in the future. In Canada the lead for such planning to date has come mainly from proposals for offshore oil development, as in the Beaufort Sea and Lancaster Sound. But some of it will have relevance to water resources as well. Possible developments in the Mackenzie river basin are a case in point.

Each of these has resulted in a different institutional response. 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 change with respect to a particular water use or to a particular water management purpose, such as reduction of damages from floods or droughts, as was the case in the USA and Canada. A brief summary of some of the responses is provided in Table 1.

Experience in the adoption of the various concepts has varied considerably from one country to another. This reflects the fact that problems vary in both nature and severity from place to place. It has also reflected differences in political cultures. 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 other countries where management today is just about the same as it was 30 years ago – 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 some instances this is likely to result in an increasing degree of government involvement. Such a situation might contrast markedly with developing countries where legal codes are simple, policies cover fewer issues and administrative arrangements tend to deal with single issues rather than with a broad spectrum of problems.

## Constraints

A voluminous literature exists at present which considers at least some aspects of sustainable 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 dis-

**Table 1. Contemporary concepts in water management and associated institutional responses.**

| Concepts | Institutional response | Institutional locations |
|---|---|---|
| 1. Broadening perspective | | |
| (a) Coordinated water management | Omnious national water agencies | India, Jordan, Israel, Hungary, Egypt, Sudan, Zambia, Zimbabwe |
| (b) Links with environmental management | Ministries of environment with water resources branches | Canada, UK, France |
| (c) Links with economic and social policy | Planning commissions or coordinating bodies | Hungary, France, India, Israel |
| (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 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, floodplain 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 |
| | Allocation to reflect value in use, metering | Fyide (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), RWAs (UK), ABFs (France), DVC (India), Genossenschaften (FR Germany) |
| 5. Public involvement | *Ad hoc*, usually at end of process, narrow range of methods | Most countries |
| | Continuous, often required by law, using wide range of methods | USA, Canada, UK, France |
| 6. Environmental protection as a 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 rights | Canada, USA, New Zealand |
| | Institution of compensation measures | Canada, USA, New Zealand |

ruptions 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;
(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 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 technoeconomic ones in which society is interested. Accordingly, increasingly more enironmental 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 waterborne 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, irrigation 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, mid-term evaluation of Bhima Command Area Development Project in Maharastra, 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 Figure 1. At present, instead of considering the overall health situation in project areas only the negative impacts are being accentuated.

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 Mediterrainean due to the dam. On the basis of data available in FAO databanks, fish production in Egypt in the High Dam Lake, the Meditarranean and other areas was analysed for the period 1963–82. This

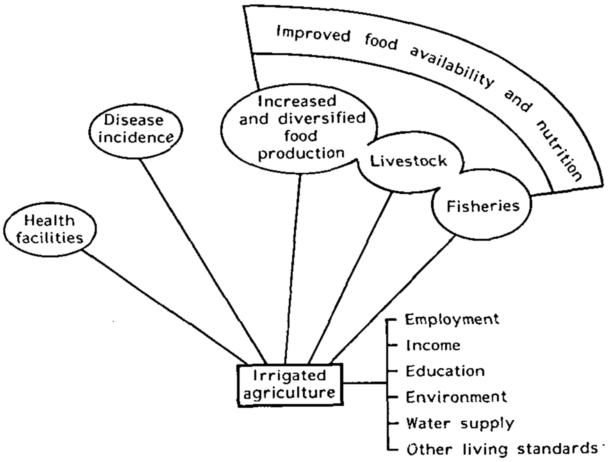


**Figure 1.** Pathways of interrelationships between irrigated agriculture and health.

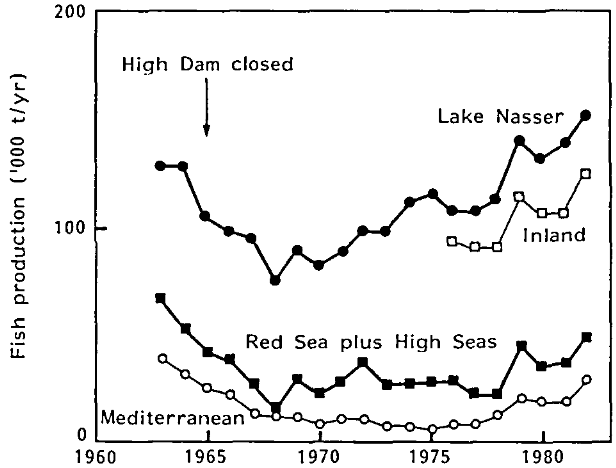


**Figure 2.** Contribution of Lake Nasser to fish production in Egypt, 1963–82.

is shown in Figure 2. This figure demonstrates that fish production from the Mediterranean started to decline about 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 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 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. If the combined fish production in the Mediterranean and High Dam Lake is considered, there is no question that it has always 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 is overwhelmingly positive, and not negative as most environmental literature indicates.

The beneficiaries, however, are not the same. There is no question that 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 socioeconomic 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 rather than enlighten the overall process of water development. As already pointed out, what is urgently necessary is the integration of EIAs into a broader multiobjective 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, timeframe 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 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 is our knowledge 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.

If malaria is considered, 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 question that irrigation, agricultural practices, rice cultivation and migration of agricultural labour have all had an important bearing on mosquito vector fauna and malaria transmision (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 ha 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% of mosquito bites were from the *Anopheles gambiae* complex (principal vectors of malaria in tropical Africa), 28% were of *Mansonia* species (vectors of lymphatic filariasis and Rift Valley fever), and 5% were of *Culex quinquefasciatus* variety (another vector of lymphatic filariasis). In contrast, 99% of the mosquitoes in the older village belonged to *Mansonia* species and less than 1% were *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 as well. 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 due to 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 further 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 further 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 inter-related 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 analyses, it is a difficult task under the best of circumstances.

Second, 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.

Third, 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 longstanding 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.

## Future directions

Water is essential for sustaining life, not only for drinking, but also for other domestic and industrial needs, and in vastly greater quantities for agriculture. Equally, however, water can contribute to significant losses to human and animal lives and can damage crops, homes and industry through storms and floods. There is thus a real need to plan the development of water resources so as to make the most efficient use of them when they are scarce and to control them when they are excessive. But development and management of water resources must always be considered along with other socially desirable objectives.

This report has emphasized the need to appreciate fully the interrelationships between water resources development and the environment. It has argued that the quality of the natural environment should be protected and, where possible, enhanced by water developments.

Although currently no precise definition of sustainability is available, the concept clearly extends beyond purely conventional economic and engineering approaches. The fundamental questions must be asked as to what are the overall long-term impacts of these projects on the biosphere. These impacts must be examined with the related uncertainties and risks taken into account. Values should be placed upon risks taken or not taken and explicit statements as to the benefits from risk reduction should be made. Decision criteria must extend beyond engineering and economics.

Sustainable water resources development and management present many important challenges and there are several approaches by which this concept may be promoted and translated into action. It is, however, inseparable from the overall social and economic development of society, as sustainability invariably depends on the interaction between water development and the economic, social, cultural and environmental implications of that development. This is why making explicit trade-offs between different short-term and long-term objectives is an important aspect of the process. It is important and at the same time very difficult because the degree of sustainability is not easily measured since the quantitative and qualitative dimensions of the plan are mutually reinforcing and not separable. Furthermore, operationalizing the concept of sustainable development is a complex task under the best of circumstances.

Development and management of water resources can only be sustainable when planners and politicians have adequate knowledge of resources and the constraints within which the resources must be managed. Developing countries seldom have adequate information about their water and related land resources. Without an adequate and reliable database, management is a difficult task.

Sustainable water development in any region is directly affected by land use patterns and practices. Uncontrolled deforestation, unplanned urban growth and unmanaged industrial development directly affect the availability of water resources and the quality of both surface and groundwater. These and other impacts directly affect sustainable water development, and water management in turn affects the aforementioned factors. It is not through the development of any one resource but in the interrelated development of all resources that the sustainability of development of individual countries can be assured.

It should be emphasized that in the area of water development there is no single approach that is 'best' suited to all countries. Different countries are at different stages of development, and thus may not have the same access to investment funds or to professional expertise. Nor do they have similar cumulative experience in planning, developing and managing medium- to large-scale water development projects. Moreover, the planning process and the institutions responsible for implementing water development plans vary from one country to another, and often within the same country. Water availability in terms of quantity, quality and annual fluctuations is different; also, social and cultural practices and legislative frameworks are different. Under these circumstances each country must look for approaches that are most suitable to the management of its own resources. The experiences of other countries are worth reviewing, especially those approaches which have been applied successfully and those which have failed, and the reasons for their success or failure. In the final analysis, however, each country has to develop its own plans for sustainable water development and management tailored to its particular needs.

It should be recognized that such plans cannot be developed and implemented without having appropriate institutions, responsive to environmental quality issues as well as to accelerating managerial, technological and social change. The institutions must be guided by a set of environmentally sound strategic guidelines and an analytic framework within which individual water projects can be undertaken.

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