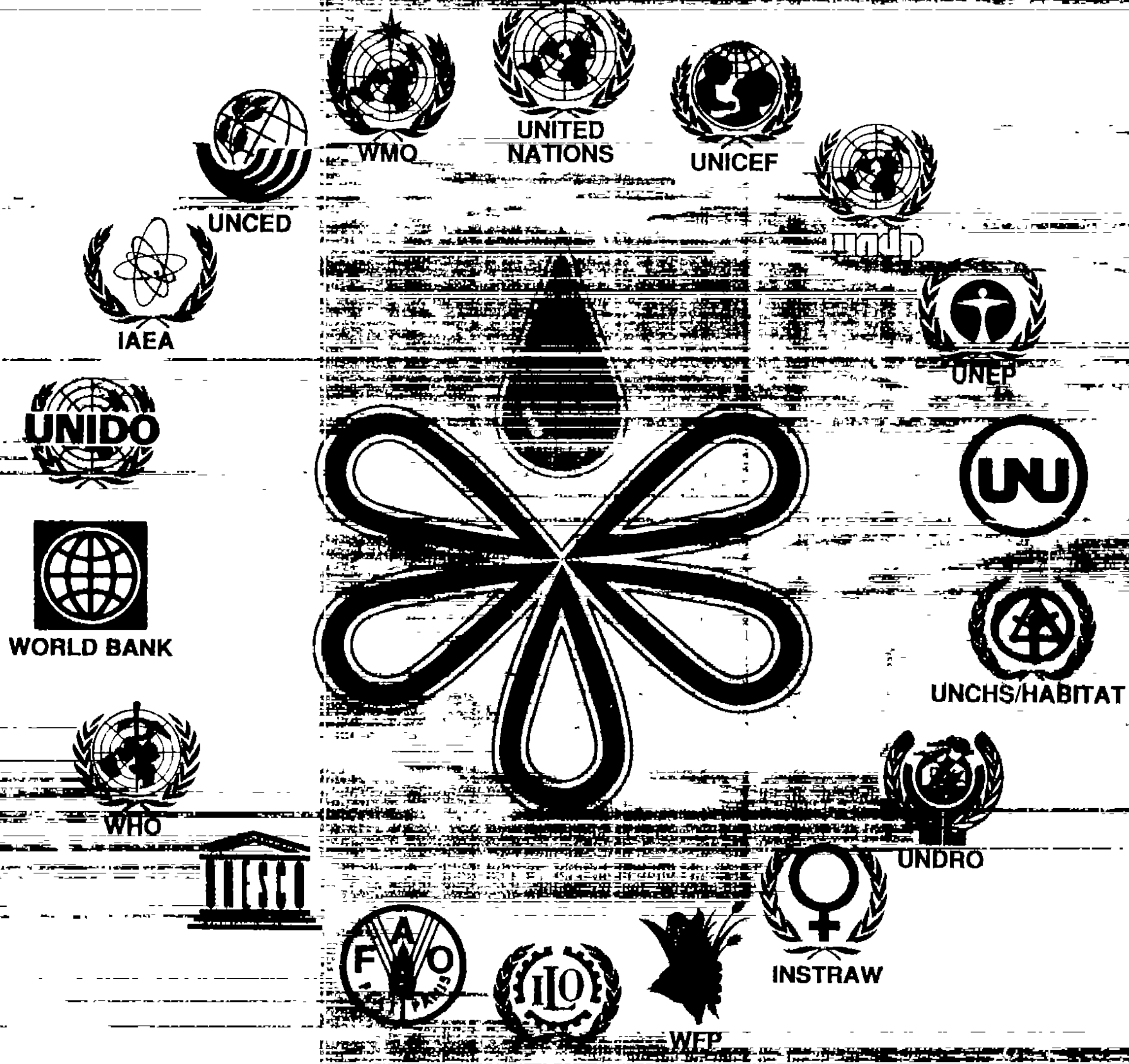
International Conference on Water and the Environment:

Development issues for the 21st century

26-31 January 1992, Dublin, Ireland



KEYNOTE PAPERS

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World Bank (IBRD)
World Meteorological Organization (WMO)
United Nations Industrial Development Organization (UNIDO)
International Atomic Energy Agency (IAEA)
United Nations Conference on Environment and Development (UNCED)

The ICWE logo

Constructed in a similar way as traditional celtic knotwork, the ICWE LOGO represents 3 elements:

- unification of people - symbolized by interconnecting knots and the joining of 5 continents;
- enlightenment - the burning flame depicting time and the urgency of the environment dilemma;
- nature - the droplet of water falling on a flower shaped like the Gentian which grows in the Burren - a world famous habitat in the West of Ireland.

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Preface

The first "Earth Summit", the UN Conference on Environment and Development (UNCED), will be held in Rio de Janeiro in June 1992. It will cover a wide range of environment and development issues fundamental to the establishment of a sustainable basis for life on this planet.

Water is a basic and essential component of life. Life could not have been created without water and will not continue without it. Water is essential to our health and economic prosperity. Freshwater is indispensable for drinking and for the transport and treatment of wastes, that are both so important to our health. Our agriculture is often dependant on the irrigation of crops, and our industries, food production, forest products, metal refining, all depend on good supplies of clean water. It is also important to remember that water resources are a key component of the aquatic ecosystem. Managing water resources and safeguarding them from pollution will ensure a healthy and sustainable ecosystem. We should also not forget the role that water plays in leisure activities and as an essential visual amenity. Thus water will feature prominently in the discussions and decisions at the "Earth Summit".

The goals for the "Earth Summit" have been stated in General Assembly resolution 44/228, they cover a broad range of issues including climate change, freshwater resources, desertification and drought, waste management, rural and urban development, and the protection of human health. Water touches so many aspects of our lives and it is not surprising that many of the issues for the "Earth Summit" are water-related issues.

The "International Conference on Water and the Environment: Development Issues for the 21st Century" is an official UN freshwater lead into PrepCom IV and the Brazil "Earth Summit". The Conference will be hosted by the Government of Ireland and is being convened by the World Meteorological Organization on behalf of the more than 20 bodies and agencies of the UN system which are represented on the UN Administrative Committee on Co-ordination Inter-Secretariat Group for Water Resources (ISGWR).

The preparation of the keynote papers appearing in this volume resulted from the guidance and assistance of the ISGWR. The UNCED Preparatory Committee has recognised the role of the Dublin Conference and has challenged its participants:

- to consider an action framework on sustainable development and management of freshwater resources, including where feasible and appropriate, targets, timetables, and possibly cost estimates, with due account being given to strategies for rational and efficient use of scarce water resources, and to identify key elements of a strategy for its implementation;
- to prepare guidelines for the elaboration of national and where appropriate regional action plans for the integrated development and environmentally sound management of water resources;
- to identify appropriate mechanisms, including economic instruments, for implementing and coordinating programmes;
- to identify options for improved coordination and cooperation on water management at the local, national, regional and global levels.

This collection of keynote papers prepared for the "International Conference on Water and the Environment" comprehensively covers the whole range of issues related to water and development. The authors are to be congratulated on their contributions. They provide essential background material on fresh water issues and ideas and proposals that will stimulate discussions in Dublin.

G.O.P. Obasi
Secretary-General
World Meteorological Organization

Foreword

The phrase, "water is life" has been repeated so often that it has become a catch phrase rather than a call for action. Yet water was essential to the creation of life on earth and without it life would quickly disappear. Freshwater is the essential resource for the creation and existence of virtually all life forms on earth. Without water none of the biological, chemical and physical processes that make up what we know as life would be able to take place.

As well as being essential to the creation and existence of life, water is also a key component of the social and economic system that we have created for ourselves. Without water the agricultural sector that provides us with our daily food would not function. The whole system from irrigation of crops and cattle watering through food processing to food preparation is highly water dependant. The water that we use for washing and disposal of our wastes has important health implications for us. Industrial activity provides us with our goods and services and uses huge quantities of water for everything from steel production, to textiles and electricity generation. Often underestimated or forgotten are the aesthetic qualities of water which are essential to our enjoyment of nature and recreational activities. We should not forget that too much water or water in the wrong place at the wrong time can cause tremendous problems. It results in floods and water-related natural disasters such as landslides and avalanches while absence of water brings about drought. Despite the efforts under the United Nations International Decade for Natural Disaster Reduction these disasters can set the development of a country back by many years.

Less than 1 part in 100,000 of the Earth's water is available for human use

Looking around at what we do to water it is difficult to believe that water is so precious to us and that our very existence depends on it. Almost all human activities impact on water and usually lead to its degradation. Overuse of water is obvious in our irrigation methods, in our disposal of domestic wastes, and in our industrial practices. Our abuse of the purity of water is even more pervasive and more likely to damage irreversibly water's life giving properties. We pollute it with our own wastes and cause extensive and serious human health problems. Our agricultural practices pollute our rivers and lakes with pesticides that damage the environment, harm drinking water sources and contaminate the fish that we use for food and wildlife. Industries contribute a wide range of persistent and toxic chemicals to surface water and groundwater from heavy metals, like mercury and lead, to organic chemicals like dioxin and PCBs. These chemicals bioaccumulate up the food chain and end up in our bodies. They can cause serious health effects such as cancer and birth defects.

Cleaning up contaminated water resources is a costly and sometimes impossible task. A preventative strategy is always preferable to a remedial action.

During the last decade it has become apparent that environmental issues in general and water issues in particular can no longer be addressed in a piecemeal manner nor in isolation from other issues. Water resources have to be managed in an integrated manner, considering all the components of the water cycle, and all the uses, agriculture, urban, rural and industrial including the maintenance of the aquatic environment. Fully integrated water resource management can only be accomplished by bringing the land component into the picture. Sustainable development of our water resource means developing the resource to meet the needs of the present without compromising the ability of future generations to meet their own needs. Integrated water resource management can help meet this difficult goal. However, and this is a much more difficult challenge, sustainable development can only be achieved if environmental, social, and economic concerns are also factored into water resource decisions.

The availability and quality of freshwater is intimately linked to broader environmental concerns.

The main purpose of the "International Conference on Water and the Environment" is to formulate actions for addressing worldwide freshwater issues and to bring these forward to the United Nations Conference on Environment and Development (UNCED) 1992. With this purpose in mind, most of the time at the conference will be spent in working group sessions developing action plans and a "Dublin Statement". To set the stage for these sessions a series of keynote papers will be presented during a plenary session on the first working day. During the plenary session water resource experts will present the current information and projections for the future of water and the environment. The speakers will also present different perspectives, promote in-depth thinking and stimulate discussion. Key international experts, representing a broad cross-section of water resource issues and from wide geographic backgrounds have been invited to contribute significant papers on major freshwater topics. This volume collects together these papers.

International Conference on Water and the Environment
The main objectives of the Conference are:

a. To assess the current status of the world's freshwater resources in relation to present and future water demands and to identify priority issues for the 1990s:
b. To develop coordinated inter-sectoral approaches towards managing these resources by strengthening the linkages between the various water programmes;
c. To formulate environmentally-sustainable strategies and action programmes for the 1990s and beyond to be presented to the United Nations Conference on Environment and Development;
d. To bring the above issues, strategies and action programmes to the attention of governments as a basis for national programmes and to increase awareness of the environmental consequences and developmental opportunities in improving the management of water resources.

The authors of the keynote papers were challenged as a group to cover all aspects of freshwater, including social, economic, environmental, and scientific concerns. The authors have met this challenge. We know now that population pressure is increasing the demand for water, accelerating the progressive deterioration of water quality, and increasing environmental degradation. But how much do we know about water itself in the rivers and lakes, stored in the aquifers and glaciers and in the semi-permanent snow cover? What of its distribution in space and time and its physical, chemical, biological and aesthetic properties? In some parts of the world we know nothing or very little. Observations are not made, instruments are lacking and even images from space give only a subjective appreciation, because ground truth measurements are lacking from these areas. In more favoured regions we have many of the required measurements to answer these questions, and even newer methods like radar that provide us with even more information. With this data we can make sound management decisions concerning the water resource rather than uninformed guesses based on the assumption of continuing availability. We know a lot about the world's water but we certainly need to know a lot more in terms of availability, variability, reliability and quality if we are to manage the resource properly.

It is now necessary to manage the water resource such that we strike a balance between the desire for economic growth and the need to preserve the environment. However, striking a balance between the development of the water resource and its environmental protection is viewed very differently in less developed countries than in the developed countries. Everyone has come to realize the importance of preserving the water resource if development is to be sustainable. Less developed countries demand their share of growth and prosperity, which is to be gained by rapid economic development. Many countries see the immediate concerns for protecting the water resource as secondary to economic growth.

Polluted water affects the health of some 1.2 billion people and contributes to the death of some 15 million children under 5 years old every year.

Providing safe water for people is important for their health and well-being. This goal was promoted at the 1977 UN Water Conference held at Mar del Plata, Argentina and resulted in the International Drinking Water Supply and Sanitation Decade. Due to economic constraints in the 1980s the International Drinking Water Supply and Sanitation Decade has not met its goals. There are proposals to meet these goals encompassing such aspects as community-based control efforts that are geared to local conditions. As sources of good drinking water diminish there is also a need to protect usable sources. The increasing demand for drinking water can only be met by the formulation and application of cost recovery and cost containment practices. As urban centres expand so does their need for drinking water. This demand impacts on other sectors, such as agriculture, and mechanisms need to be developed to ensure optimal use of limited resources.

Water is the limiting component of agriculture, with 83% of the world's cropland being rainfed.

The population of the world is expected to pass the 6 billion mark by the end of the century, with the rate of increase in developing countries being 3.5 times that of developed ones. Agricultural food production in developing countries will not match this population growth, and the limiting factor is water. Sustainable development for the rural sector is interpreted as having the aim of sustainable livelihood security. A review of the environmental effects of water resource and irrigation development shows effects from health hazards, reduction of downstream flows and pollution by agrochemicals. Rural water management needs to consider not only the single environmental impacts such as terrestrial and direct utilization, but also the cumulative effects from many activities in one basin. A variety of strategies are necessary for the environmentally sound management of rural freshwater resources including, strengthening institutional capabilities and legislation, and the development of basin utilization information.

Pollution abatement and water conservation are essential components of urban water management.

The predicted explosive rise in urban populations and industrial development will put a tremendous strain on the water supply and wastewater systems of those cities in developing countries that have these systems. Urban areas will also enjoy higher economic development than other areas and it is well known that with prosperity comes higher water consumption. Therefore urban water demand will be increased by three factors, population growth, industrial development and increasing prosperity. If the crisis in urban water is to be avoided action must be taken that stresses pollution abatement and water conservation. It is also of crucial importance to price water so that existing water services and water supply capacity are maintained. Paralleling the increased demand for urban water will be an increasing volume of wastewater for collection, treatment and disposal. It is important to bring together organizational and institutional issues when dealing with urban water resource management such as, conservation and recycling, privatisation, and public awareness, all of which are needed for urban water management.

Global warming could affect the world's freshwater, changing soil moisture and river runoff in many parts of the world.

Our attempts to develop and manipulate the earth for our social and economic well-being have resulted in wide ranging environmental damage that we are only now beginning to appreciate. Damage to the water component of the environment has resulted from deforestation, causing flooding; from agriculture, causing salinization and contamination of groundwater with pesticides; and from industrial activities, causing toxic chemical contamination of our water supplies. Global warming from increased carbon dioxide, and its potentially devastating effects on water supply, and the long range transport of pollutants, such as sulphur dioxide, and the acidification of lakes both show that humans are now having a global effect on the water resource. Traditionally these environmental impacts resulting from development were regarded as a necessary evil and that development should take precedence over environmental protection. We now realize that not only are our development activities affecting the water environment, but they are also jeopardizing our future use of water. If water is to be available for future development then we have to conserve and protect it now. This of course is the concept of sustainable development. If sustainable development is to work, and it has to if we plan to use water in our future development, then water resources must be managed as an integral part of a nation's social and economic development. If this is to happen, water resource management agencies must take the initiative and play a more active role in guiding and stimulating socio-economic development both at the international and national level.

Our scientific and technological knowledge is sufficient for us to make the 1990s the "Turn Around Decade".

The development of water resources in a sustainable manner will present considerable technical challenges to the industries, to agriculture and to all other water users. There already exists a considerable body of knowledge of solutions to the design and construction of structures for water resource systems, as well as methods for cleaning up pollution. However, the challenge is to apply and when necessary adapt these technologies to countries with different climate conditions or societal traditions. There is no shortage of challenges for engineers and scientists to innovate and transfer water management technology.

We would like to express our thanks to the authors of the keynote papers for providing the stimulus for our discussions in Dublin. We would also like to thank the members of the Steering Committee for the International Conference on Water and the Environment for their guidance and help. Finally, we would like to express our considerable thanks to A.R. Davis (Canada), M. Puupponen (Finland) and H.O. Ibrekk (Norway) for the initial editing of this collection of papers and to C. Kirby, J.H. Griffin and H.K. Stevens, Institute of Hydrology (United Kingdom), for the additional work on them. The governments of Canada, Finland, Norway and United Kingdom have generously supported these efforts.

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The world's water: assessing the resource

N. B. Ayibotele (Ghana)

EXECUTIVE SUMMARY

Water is a vital element in the Earth's environment, without which it will not function to regulate climate and provide support for living things in the world's varied ecosystems The amount available for human development is only a small part — less than 0.01 per cent — of the total water in the earth system, which is renewed annually.

Mankind has so far derived tremendous benefits for his well-being by exploiting the water and land resources to meet his needs. Now, however, population pressure is:

(i) increasing the demand on water resources, so that every year there will be less water available for use: indeed, in some places there is already less water to meet demand than in former years.
(ii) accelerating the progressive deterioration of water quality because of increased domestic, municipal, agricultural and industrial effluents being discharged into water bodies, and atmospheric pollution.
(iii) increasing environmental degradation resulting from urbanisation and deforestation.

There is some knowledge about the world's water. However, the knowledge about availability, variability, reliability and quality has to become more precise. More effort is required to assess water resources for rational planning and management The need to do this is heightened by the threat that we face from increasing human development of the land and from impending global climate change.

Efforts in water resources assessment have been constrained by institutional weaknesses, inadequate networks for collecting water cycle and physiographic data, poor data transmission processes and archiving problems, inappropriate technologies for field, laboratory and office work, and the wrong analytical tools. Deficiency of staff and their capability, and the lack of relevant research have constrained efforts further. The strategy for improvement in the 1990s calls for institutional reforms, improvements in the knowledge of hydrological processes, and increases in funding, capacity building and international cooperation on national, sub-regional, regional and global projects.

CONTENTS

1 Introduction

1.1 Water as part of the environment

Water covers about 70 per cent of the surface of the earth. In its various vapour, liquid and solid states it interacts within the geosphere, atmosphere and biosphere in a complex way to keep the earth system functioning. It interacts with solar energy to determine climate through heating and cooling of the atmosphere through the evaporation and condensation processes (Grassl, 1989; MacBean, 1990). It is responsible for the transformation and transportation of physical and chemical substances to provide nutrients to biota to ensure their survival and diversity. Hence the availability of water in the earth system is a precondition of human existence.

1.2 Nature of water as a resource

Water occurs in the earth system at all space and time scales. The time scales vary from microseconds, as in the formation of clouds; days to a few weeks, as in water vapour circulation around the earth; a few weeks, as in river runoff; centuries to a millennium, as in deep ocean circulation; to more than 100,000 years as in the residence of snow in ice caps (WRI, 1986).

The mobility of water on land, in the oceans and in the atmosphere makes it unique among the natural resources upon which human development depends. This mobility creates transboundary problems among nations, however. In the terrestrial environment water allocation and pollution issues arise among states sharing the same river, lake or groundwater aquifers. Typical examples are the transboundary basins of the Great Lakes in North America, the Rivers Rhine and Danube in Europe, the Amazon in South America, the Nile in Africa, the Tigris and Euphrates in the Middle East and the Mekong in Asia. In the coastal and marine environment pollution and erosion problems may be transferred from one country to another as in the Mediterranean Sea or along the coasts of western and central Africa. In the atmosphere, gaseous effluents and particulate matter generated in one country can be transported over long distances to cause pollution in another. Examples are the acid rain problems in Europe and North America. International conventions and treatises have been developed to deal with the terrestrial, coastal and marine transboundary problems, leaving those of the atmosphere to be addressed by the Montreal Protocol and the proposed Climate Convention.

1.3 Water as a finite resource

Locally occurring freshwater resources (rivers, lakes, groundwater) on which human development depends in the various regions are in the long term finite. However, local sources can be augmented by long distance water transfer from water surplus to water deficient areas or by desalination of sea-water, provided the price at which the water is provided is affordable.

1.4 Impact of global climate change on water resources

It is now feared that the limited water resources could be redistributed if the climate were to change. There is considerable discussion at present on global climate change due to the release of carbon dioxide and other 'greenhouse' gases into the atmosphere as a result of human activities. As assessed by the Intergovernmental Panel on Climate Change (IPCC, 1990) this change could impact in various ways on natural resources, including water, and on socio-economic activities and the environment. Although there appears to be a consensus among the scientific community that temperatures will rise globally, there are considerable uncertainties about how this will occur and what its impact on a continental or regional basis will be.

1.5 Population growth and water demand

As has been stated earlier, water is a prerequisite for the survival of man and for his development. Current and projected problems with freshwater resources arise from the pressure to meet the food, agricultural, human settlement and industrial needs of a fast-growing global population There is also the need to meet the rising standards of living in the affluent sections of the population in both developed and developing countries.

According to the UNFPA (1991), the global population, which was 2.5 billion in 1950, is expected to increase by 150 per cent to 6.3 billion by the year 2000, with 95 per cent of the population growth taking place in developing countries. Figure 1 presents the population size ranges into which various countries fell in mid-1989. The growth in population will be accompanied by increasing urbanisation as the percentage of the urban population in 1950 (29 per cent) will virtually double (to 47 per cent) by the year 2000. The number of cities with one million people or more — 78 per cent in 1950 — is expected to increase to 408 by the year 2000. Again, the cities with 10 million people or more, only 3 (2 and 1 in developed and developing countries respectively) in 1950, will increase to 22 (4 in developed and 18 in developing countries respectively) by the year 2000. This population increase will impose serious stress on the freshwater water resources, particularly with consumptive uses. This depressing statement is supported by the assessment of global water demand for agricultural, municipal, domestic and industrial uses for the period 1900 to 200 published by Shiklomanov (1991) and for the period 1680 to 1985 by Turner *et al* (1991). Table 1 presents data compiled by Shiklomanov. Although they show an increasing growth of demand in the face of finite resources, it is important to stress that the forecasts should be viewed with caution. This is because even in the developed countries few users meter water use. The situation is worse in the developing countries, and is compounded by the fact that even where data on water use are available it is difficult to obtain them from central depositories.

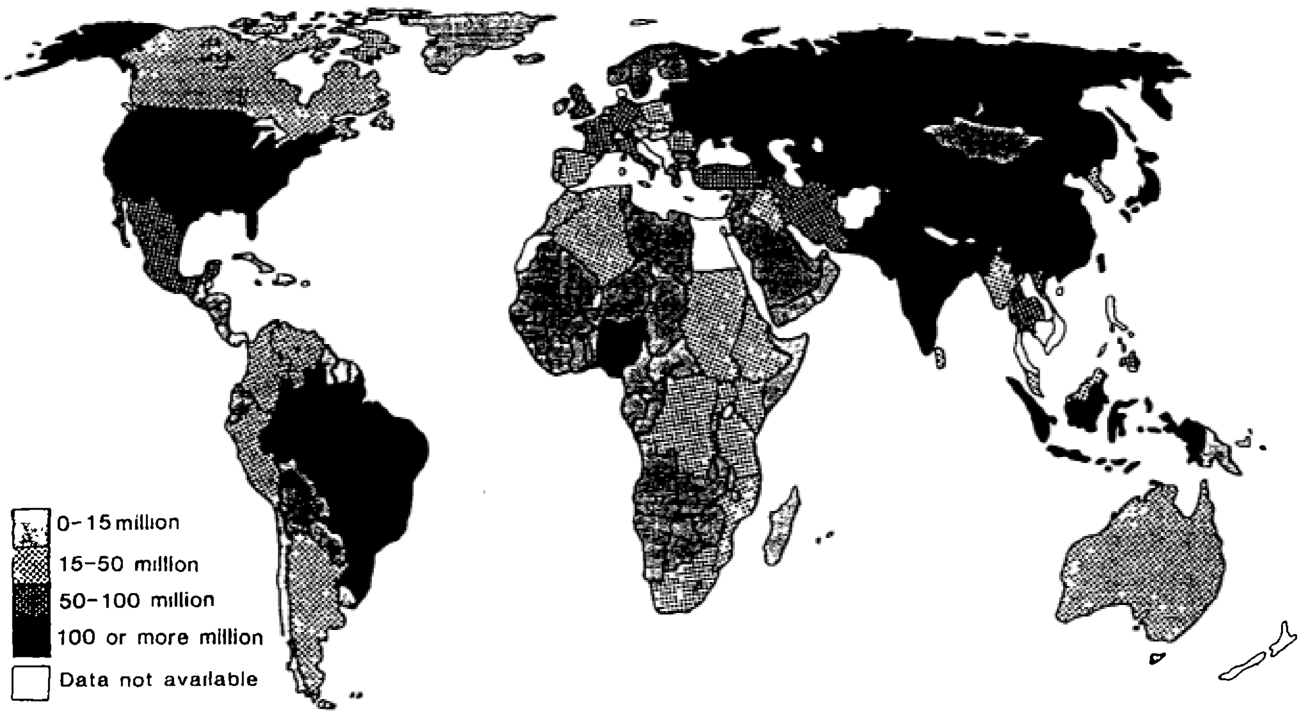

Figure 1 *Global population distribution in mid-1989 (source. World Bank, 1991)*

1.6 Consumptive water uses

It is seen from Table 1 that by 1990 irrigation water demand represented 68.9 per cent of the global total water demand, while industry and municipal water demand accounted for 27.5 per cent. It is projected that by the year 2000 the share of industry and municipal water demand will increase to 33.2 per cent and that for irrigation will decrease to 62.6 per cent. However, the area of land under irrigation is expected to increase from 272 million hectares in 1990 to 347 million hectares by the year 2000. The use of irrigation has helped to increase and stabilize food production in many parts of the world. According to FAO (1990) even though irrigated land formed only 15 per cent of the global cultivable land, it contributed 36 per cent of the total crop production in the mid

Table 1 *World water demand (km^3 y^{-1}) according to use (source: Shiklomanov, 1991)*

Water users	1900	1940	1950	1960	1970	1980	1990	2000
Irrigated area (Mha)	47.3	75.8	101	142	173	217	272	347
Agriculture								
A	525	893	1130	1550	1850	2290	2680 (68.9)	3250 (62.6)
B	409	679	859	1180	1400	1730	2050 (88.7)	2500 (86.2)
Industry								
A	37.2	124	178	330	540	710	973 (21.4)	1260 (24.7)
B	3.5	9.7	14.5	24.9	38.0	61.9	88.5 (3.1)	117 (4.0)
Municipal supply								
A	16.1	36.3	52.0	82.0	130	200	300 (6.1)	441 (8.5)
B	4.0	9.0	14	20.3	29.2	41.1	52.4 (2.1)	64.5 (2.2)
Reservoirs								
A	0.3	3.7	6.5	23.0	66.0	120	170 (3.6)	220 (4.2)
B	0.3	3.7	6.5	23.0	66.0	120	170 (6.1)	220 (7.6)
Total								
A	579	1060	1360	1990	2590	3320	4130 (100)	5190 (100)
B	417	701	894	1250	1540	1950	2360 (100)	2900 (100)

A. Total water consumption, B Irretrievable water losses Percentage figures in parentheses.

1980s. In Africa where only 6.5 per cent of the cultivable land is under irrigation it accounted for 20 per cent of the value of crops produced in 1980 (FAO 1986).

The increased use of water for domestic/municipal purposes has contributed significantly to the improvement in the health of people around the world so releasing their energies for economic activities. Water use per capita ranges from 10 to 35 litres per day in the rural areas of the world to 40 to 300 litres per day in the areas with high standards of living (WRI, 1986). Over the period of the International Drinking Water Supply and Sanitation Decade (1981-1990) an estimated 1348 million people globally received adequate water supply services while another 748 million received satisfactory sanitation services. The number of people left unserved with drinking water supply declined from 1.8 to 1.2 billion over the decade while sanitation coverage was just able to keep ahead of population growth. The unserved population continue to be at the mercy of water-related diseases (particularly infant and child diarrhoea and malaria which exact a heavy death toll annually in the developing countries; WHO, 1990). However, many large cities of the developing world lack sanitation systems at present and with the growth in urban population this situation will worsen. Consequently, pollution of rivers, lakes, groundwater and the marine environment will grow.

1.7 Non-consumptive water uses

Water use for non-consumptive purposes like hydropower generation, navigation and fisheries has also brought significant benefits to many economies. According to Turner *et al.* (1991), the global capacity of all hydropower plants in 1970 was 290 GW (1 gigawatt = 10^9 W) or 24 per cent of the capacity of all electricity generating plants. The capacity rose to 542 GW in 1984 but its share of the total number of plants dropped to 23 per cent. In 1988 hydroelectricity provided 7 per cent of total global energy (WRI, 1990). The opportunity for developing hydropower is considerable in the developing countries as their reserves have hardly been tapped. Compared with North America and Europe which by 1980 had developed 59 per cent and 36 per cent of their respective potential, Asia, Latin America and Africa had developed only 9, 8 and 5 per cent, respectively, of theirs.

In the area of transportation river navigation provides an important means of transporting goods and people and in meeting communication needs. The volume of traffic on rivers such as the Mississippi, the Rhine, the Nile, the Ganges and the Mekong attest to this. In 1985 the total length over which the world's inland navigation was carried out was estimated at 500,000 km (Turner *et al.*, 1991).

1.8 Threats to water use

Freshwater fisheries and fish farming contribute to the protein resources of the world. Since 1950, global freshwater fish catches have grown by a factor of six, from 2.2 to 13.4 million metric tonnes in 1988 (WRI, 1990). The freshwater catch in 1988 formed about 14 per cent of the total global fish catch, with Asia accounting for the major part (67 per cent) followed by Africa with 15 per cent. The estimated sustainable annual yield of freshwater and marine fisheries is 100 million tonnes. Present catches are approaching this limit. However, sustainability of yield is threatened by eutrophication, chemical pollution, and destruction of nursery grounds.

In spite of the many benefits which mankind has derived, and continues to derive, from his use of water in many sectors of the economy, there are also some serious threats that water poses to him. Table 2 presents the evolution of water availability per inhabitant for different continents and sub-regions (from Shiklomanov, 1991). A water availability of between 5,000 to 10,000 m³ per inhabitant per year is adopted as an average amount to meet his needs. It can be seen from the table therefore how continents and sub-regions have moved from average to below-average water availability situations in the 30-year period 1950 to 1980 and also the prospects for the year 2000. The situations of the North African and West Asian countries are worth noting.

Water is a useful and convenient medium for the assimilation and disposal of wastes. Because of population increase, there has been a need to increase production in agriculture and industry, and to build more settlements, leading to a corresponding increase in the wastes discharged into water bodies and the atmosphere. This results in a reduction of the assimilative capacities of water bodies, something which is happening both in developed and in developing countries. The agricultural wastes are mainly agrochemicals (fertilizers, pesticides, herbicides). They are laden with heavy organic loads, sediments and high concentrations of major nutrients — nitrogen and phosphorus — required for plant growth.

The wastes discharged from industrial sources include waste heat, liquid effluents, garbage, toxic substances, effluent gases and particulate matter, consisting of organic chemicals and heavy metals. The wastes from human settlements come first from non-point sources, such as drainage water from urban areas and then as point sources from treated and untreated sewage (including human excreta), garbage and liquid wastes which contain significant quantities of nutrients (WHO/UNEP 1989). It is obvious from the above that the discharge of increasing amounts of wastes into finite water resources poses considerable danger to human health and to the survival and diversity of biological life within the terrestrial and aquatic ecosystems.

A further threat is the environmental degradation of agricultural lands by erosion and also the loss of reservoir capacity through sedimentation. These are the results of bad farming methods and uncontrolled harvesting of vegetation for fuelwood, timber, food, medicine, building materials, etc. The impact of these practices is felt more in the tropical

Table 2 Water availability per inhabitant (source: Shiklomanov, 1991)

Continent	Area	Water availability $m^3 \times 10^3\ y^{-1}$ per capita				
Region	M km^2	1950	1960	1970	1980	2000
Europe	**10.28**	**5.9**	**5.4**	**4.9**	**4.6**	**4.1**
North	1.32	39.2	36.5	33.9	32.7	30.9
Central	1.86	3.0	2.8	2.6	2.4	2.3
South	1.76	3.8	3.5	3.1	2.8	2.5
European USSR (North)	1.82	33.8	29.2	26.3	24.1	20.9
European USSR (South)	3.52	4.4	4.0	3.6	3.2	2.4
North & Central America	**24.16**	**37.2**	**30.2**	**25.2**	**21.3**	**17.5**
Canada & Alaska	13.67	384	294	246	219	189
USA	7.83	10.6	8.8	7.6	6.8	5.6
Central America	2.67	22.7	17.2	12.5	9.4	7.1
Africa	**30.1**	**20.6**	**16.5**	**12.7**	**9.4**	**5.1**
North	8.78	2.3	1.6	1.1	0.69	0.21
South	5.11	12.2	10.3	7.6	5.7	3.0
East	5.17	15.0	12.0	9.2	6.9	3.7
West	6.96	20.5	16.2	12.4	9.2	4.9
Central	4.08	92.7	79.5	59.1	46.0	25.4
Asia	**44.56**	**9.6**	**7.9**	**6.1**	**5.1**	**3.3**
North China & Mongolia	9.14	3.8	3.0	2.3	1.9	1.2
South	4.49	4.1	3.4	2.5	2.1	1.1
West	6.82	6.3	4.2	3.3	2.3	1.3
South-east	7.17	13.2	11.1	8.6	7.1	4.9
Central Asia & Kazakhstan	2.43	7.5	5.5	3.3	2.0	0.7
Siberia & Far East	14.32	124	112	102	96.2	85.3
Trans-Caucasus	0.19	8.8	6.9	5.4	4.5	3.0
South America	**17.85**	**105**	**80.2**	**61.7**	**48.8**	**28.3**
North	2.55	179	128	94.8	72.9	37.4
Brazil	8.51	115	86	64.5	50.3	32.2
West	2.33	97.9	77.1	58.6	45.8	25.7
Central	4.46	34	27	23.9	20.5	10.4
Australia & Oceania	**8.95**	**112**	**91.3**	**74.6**	**64**	**50**
Australia	7.62	35.7	28.4	23.0	19.8	15.0
Oceania	1.34	161	132	108	92.4	73.5

water deficient regions where the climatic conditions are harsher.

Floods and droughts are yet another threat that mankind must face in his management of water. The human misery — including loss of life and the destruction of social and economic infrastructures — that occur most often in the tropical regions of the world are evidence of this point.

1.9 The need to assess water resources

It follows from the foregoing that because of population growth and rising standards of living, we are faced with ① declining water availability per inhabitant of population. Secondly, the quality of the available water is being ② progressively degraded because of increasing waste loads discharged into water bodies and the atmosphere. Thirdly, water-related land degradation from loss of vegetative cover ③ is on the increase. All these factors could undermine the development and adversely affect the earth system. Among the measures that can be taken to contain the situation and reverse the trend is to improve information about water resources through thorough assessment.

2 Knowledge about the Resource

A thorough assessment of water in the hydrosphere is necessary if we are to understand its role in the earth system and provide a solid basis for rational water management to meet human needs while at the same time preserving the integrity of the environment.

In the following paragraphs, estimates from various sources will be compared to show that the present level of knowledge of water balance components at global and regional levels, and also of water reserves in the various parts of the hydrosphere — and, in particular, of freshwater resources (rivers, lakes/reservoirs, groundwater, glaciers, etc.) is imprecise and/or adequate. This is followed by an identification and discussion of the reasons why this is so.

The International Hydrological Programme and the Hydrology and Water Resources Programme of UNESCO and WMO respectively have provided important mechanisms by which knowledge of the hydrology and water resources of the Earth and its continents has been acquired, for example the symposia on *World Water Balance* (Budyko, 1970) and *Variation in the Global Water Budget* (UK, 1983). In addition, individual contributions have been made by Nace (1968), Budyko (1970), Lvovich (1974), Baumgartner & Reichel (1975), Shiklomanov & Sokolov (1983), Dooge (1984), Klemes (1988) and Shiklomanov (1991). Probably the most significant and comprehensive contribution to the subject was the monograph *World Water Balance and Water Resources of the Earth*, published in Russian in 1974 and translated into English by UNESCO in 1978. More recent contributions have arisen from General Circulation Models (Grassl, 1991).

2.1 Global water balance

The extent of knowledge of global water is presented in Figure 2 where the results of the water balance components of the global water cycle from three sources are compared. Using the results in UNESCO (1978) it is seen that some $505x10^3$ km^3 is returned to the oceans as precipitation while some $50x10^3$ km^3 is transported to the continents. The amount precipitated, including snow that falls on the continent, is of the order of $110x10^3$ km^3. From this, about $45x10^3$ km^3 is returned to the oceans as runoff. When these figures are compared with those in Budyko (1970) and estimates from General Circulation Models, differences can be seen, particularly with regard to precipitation and evaporation from the oceans. These are said to arise from differences in the objectives for which the studies were carried out, the methodologies used and the data available, and their representativeness.

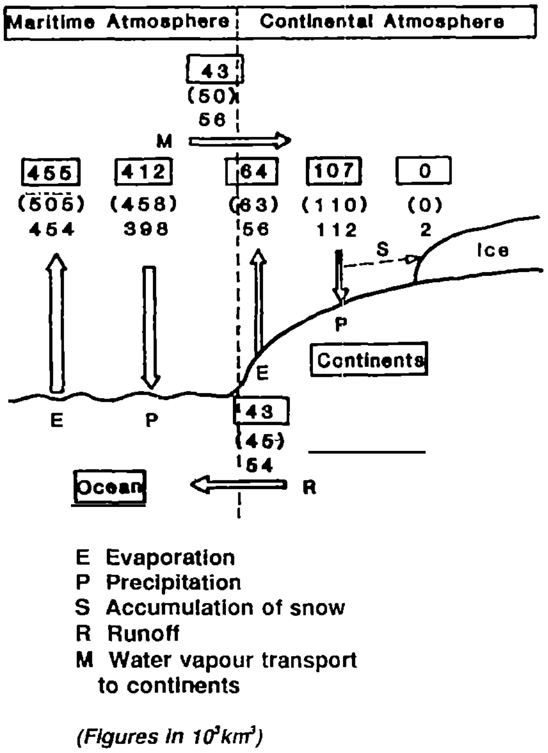

Figure 2 Global water balance estimates: boxed figures from Budyko, 1970; bracketed figures from UNESCO, 1978; open figures from GCMs

2.2 Continental water balance

Data on the continental water balance are presented in Table 3. Here the water balance components of precipitation (P), evaporation (E), and runoff (R) for the continents as computed by Baumgartner and Reichel (1975) are compared with those in UNESCO (1978): it is evident that there are significant differences between the two. While both estimates agree that precipitation is highest on the South American continent, there is no such agreement on either the next highest or the continent with the least precipitation. There is agreement, however, that potential evaporation is highest in South America followed by Africa. There is further agreement that runoff is highest in South America and least in Africa. Discrepancies in water balances are highest for South America followed by Africa, with figures of 86 and 58mm respectively.

2.3 Global water storage

For water stored in various parts of the hydrosphere the estimates of UNESCO (1978) are compared with estimates by Cini (1989) in Figure 3. The difference in the percentage for freshwater resources is striking, since they differ by a factor of two. Using the estimates of UNESCO (1978) it follows that freshwater resources form only 2.5 per cent of the global water resources, the remainder being salt water (ocean and terrestrial). Furthermore, of the total freshwater resources, almost 70 per cent is snow, ice, permafrost, etc., with only 30 per cent available in the liquid form. Of this liquid freshwater, over 98 per cent exists as groundwater, which is only about 0.74 per cent of the total global water storage. But the most important water resources — rivers and lakes — on which much human development depends, form only about 1.0 per cent ofliquid freshwater resources, or less than 0.01 per cent of the total global water storage.

2.4 Continental distribution of freshwater resources

Distribution of River Runoff The surface runoff from the continents, as compiled by UNESCO (1978), is presented in Table 4. From the differences between this table and Table 3, it is evident that the estimates in Table 4 are also approximate. This is borne out by the fact that the estimate of 4570 km^3 for the African continent varies from that given by other workers (including Zubenok, 1970; ECA, 1976; and FAO, 1987) which range from 2280 km^3 to 7826 km^3. It should be noted that at 31 per cent Asia accounts for the

Table 3 Comparison of water balance components (sources: (1) UNESCO, 1978; (2) Baumgartner & Reichel, 1975)

	Europe	Asia	Africa	Australia	North America	South America	Antarctica	Total land area	GLOBE
Precipitation (P mm)									
(1) without corrections	637	670	702	766	635	1503			
(1) with corrections	789	742	742	791	756	1597	177	800	1130
(2)	657	696	696	803	645	1564	169	746	973
Difference (%)	+20	+7	+7	−2	+17	+2	+5	+7	+16
Evaporation (E mm)									
(1)	470	414	533	491	418	850	0	463	1130
(2)	375	420	582	534	403	946	28	480	973
Difference (%)	+25	−2	−8	−8	+4	−10	−100	−4	+16
Runoff (Q mm)									
(1)	306	332	151	267	339	661	165	315	
(2) (Q=P−E)	282	276	114	269	242	618	141	266	
Difference (%)	+9	+20	+32	−1	+40	+7	+17	+18	
Water balance Discrepancy (mm)	+13	−4	+58	+33	−1	+86	+12	+22	
% Precipitation	2	0.5	8	4	0	5	7	3	
% Runoff	4	15	40	13	0	13	8	7	

highest portion of global runoff which, together with South America, accounts for 56 per cent of the global annual runoff from the continents.

Distribution of Lakes/Reservoirs Information on the regional distribution of water in large lakes with a surface area greater than 100 km² is given in Table 5 as compiled from UNESCO (1978). Out of a total of 145 lakes, 92 or 63 per cent have been investigated. Regionally, Africa with 30,000 km³ or 35 per cent of the total, holds the largest volume of the freshwater lake resources. This should be compared with a volume of 36,000 km³ estimated for Africa by Balek (1977). Table 6 presents information on reservoirs with a volume greater than 5 km³ by region in 1972. It can be seen that the highest percentage of runoff-regulation (27 per

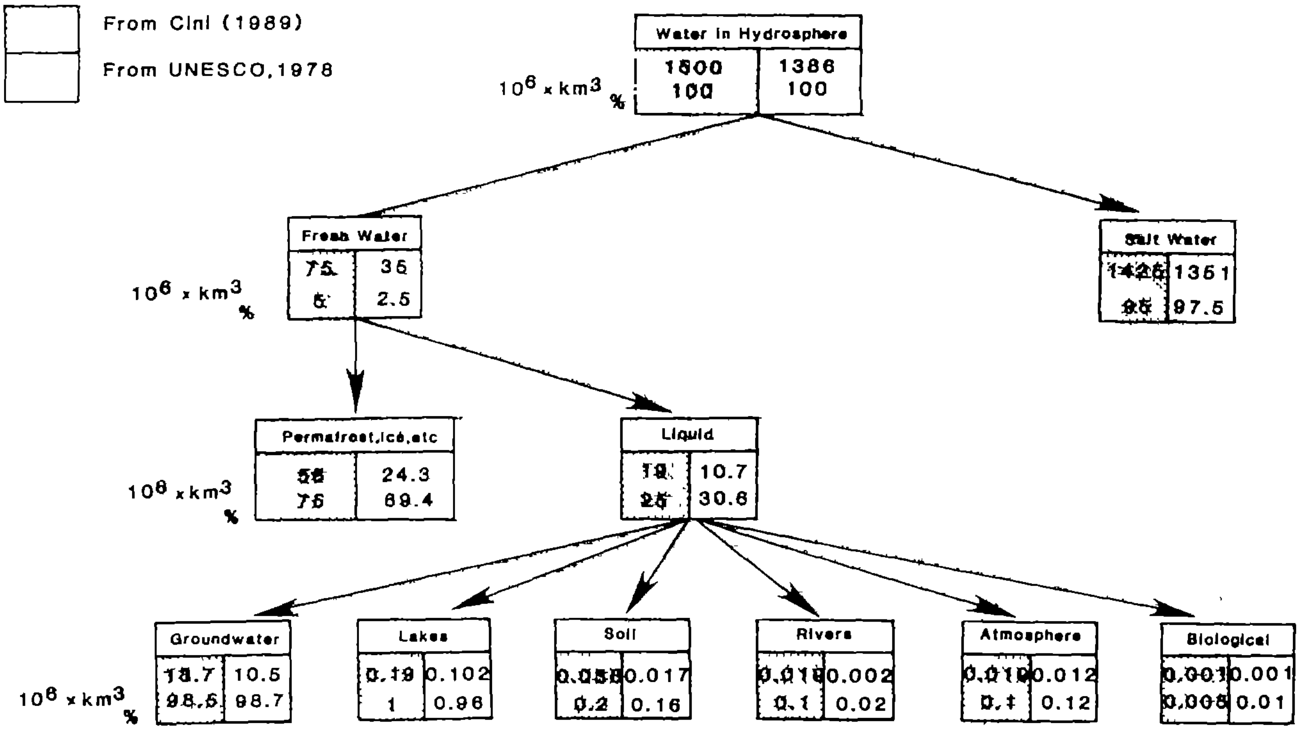

Figure 3 Global water storage

Table 4 *Continental distribution of runoff (source:Shiklomanov, 1991)*

Territory	Annual stream flow (mm)	Annual stream flow (km^3)	Percentage of total runoff	Area (km^2 x 10^2)	Specific discharge
Europe	306	3210	7	10500	9.7
Asia	332	14410	31	43475	10.5
Africa	151	4570	10	30120	4.8
North & Central America	339	8200	17	24200	10.7
South America	661	11760	25	17800	20.9
Australia & Tasmania	45	348	1	7683	1.4
Oceania	1610	2040	4	1267	51.1
Antarctica	160	2230	5	13977	5.1
Total land area	314	46768		149022	10.0

Table 5 *Water reserves in large lakes of the world (source: UNESCO, 1978)*

Continent	No. of lakes with surface water area > 100 km^2		Total area (10^3 km^3)	Water reserves (km^3)	
	Total	Investigated		Freshwater	Salt water
Europe	34	30	430.4	2027	78000
Asia	43	24	209.9	27782	3165
Africa	21	15	196.8	30000	-
North America	30	20	392.9	25623	19
South America	6	2	27.8	913	2
Australia & New Zealand	11	1	41.7	154	174
Total	145	92	1300	86500	81360

Table 6 *Basic information on the reservoirs of the world in 1972 (source: UNESCO, 1978)*

Continent	Reservoirs with a volume >5km^3			Total annual runoff of rivers (km^3)	Ratio of volume of reservoir to volume of river runoff (%)
	Total number	Total volume (km^3)	Useful volume (km^3)		
Europe	25	422	170	3210	13.1
Asia	48	1350	493	14410	9.4
Africa	12	1240	432	4570	27.1
North America	45	950	210	8200	11.6
South America	10	286	123	11760	2.4
Australia & Oceania	3	38	10	2390	1.6
Total	143	4286	1438	44540	9.6

cent) is in Africa, reflecting the annual runoff distribution. The least regulation is in Australia and Oceania with 1.6 per cent. Comprehensive information on large lakes/reservoirs of the world are being compiled by the International Lake Environment Committee (ILEC), to be presented in the publication, *Survey of the State of World Lakes.*

Distribution of Wetlands The areas covered by wetlands or marshlands in various regions are presented in Table 7. The continent with the highest proportion of marshlands is South America with 7 per cent and the least is Australia with 0.05 per cent. For Africa, the estimate of 34,000 km² given by UNESCO (1978) agrees fairly well with Balek's (1977) estimate of 339,200 km².

Table 7 Distribution of marshland (UNESCO, 1978)

Continent	Area of marshland	
	(10^3km²)	% total area of continent
Europe	925	1.8
Africa	341	1.2
North America	180	0.9
South America	1232	7.0
Australia	4	0.05
Total	2682	2.1

Distribution of Groundwater The groundwater resources which are renewed annually are presented in Table 8 as percentages of the annual volume of river runoff. The highest groundwater runoff into rivers is 31 per cent while the minimum is Australia with 4 per cent of the global total. It is obvious that these figures must be considered as approximate only. Through the United Nations Department of Technical Cooperation for Development (UNDTCD) recent data on groundwater have been compiled from countries in the various regions of the world. These have been analysed and synthesized to give more up-to-date information about groundwater resources in the various regions and have been published in their Natural Resources/ Water Series.

Distribution of Glaciers The freshwater contained in surface ice caps, glaciers, polar regions and high mountain regions in the various continents is presented in Table 9 The total surface area of the ice is some 16 million km² and the total volume contained is estimated at 24 million km³. This is much greater than the volume of water in rivers and lakes/ reservoirs. It is seen that Antarctica alone accounts for about 90 per cent of the global freshwater reserves in surface ice. Together with Greenland, the two regions account for 99 per cent of the total reserves. [According to UNESCO (1978) these estimates are approximate.]

2.5 Renewal processes and water resources availability

The discussion so far has encompassed water in all parts of the hydrosphere. From this point onwards it will be limited to the freshwater resources (rivers, lakes/reservoirs, groundwater) that are most readily available for man's use.

Regional distribution of water surplus and water deficit areas The water availability or endowment situation in any region can be assessed using the aridity index (ratio of potential evaporation to precipitation). Where the index is less that one there is a surplus of water (humid conditions). Where it is greater than one, there is a deficit of water (arid conditions). In between the humid and arid areas, where the index fluctuates around one during the year, sub-humid and semi-arid conditions obtain. Figure 4 is a map of the water surplus and water deficient areas of the world, showing the water availability situation to be unevenly distributed in the different climatic regions namely: tropical (low-latitude); temperate (mid-latitude); and cold (high-latitude) regions.

***Table 8** Natural groundwater resources renewed annually (source: UNESCO, 1978)*

Continent	Annual volume of river runoff (km³)	Groundwater runoff as % of river runoff	Groundwater runoff into rivers (km³yr⁻¹)
Europe	3210	35	1120
Asia	14410	26	3750
Africa	4570	35	1600
North America	7450	29	2160
South america	11760	35	4120
Australia	2390	24	575
Total	43790	30	13320

Table 9 Distribution of water reserve in surface ice (source: UNESCO, 1978)

Territory	**Area of ice** (km²)	**Water reserve** (km²)
Antarctica	13,980,000	21,600,000
Greenland	1,802,400	2,340,000
Arctic Islands	226,090	83,500
Europe	21,415	4,090
Asia	109,085	15,630
North America	67,522	14,062
South America	25,000	6,750
Africa, (Kenya, Kilimanjaro, Ruwenzori Mountains)	22.5	3
New Zealand	1,000	100
New Guinea	14.5	7
Total	16,232,149.0	24,064,142

The water deficit areas cover about 33 per cent of Europe, 60 per cent of Asia, 85 per cent of Africa, most of Australia and the western part of North America.

Regional distribution of precipitation The global distribution of precipitation depth has already been presented in Table 5. The regional distribution of mean annual precipitation is presented in Figure 5 where it can be seen that there is a relationship between the precipitation depth over the continents and the water surplus/deficit areas.

Long term variability of precipitation In all climatic regions the annual precipitation shows variations around the long term mean. Depending upon whether the departures are positive or negative, the year is described as wet or dry. Spatially, the variations are higher in the rainfall deficient

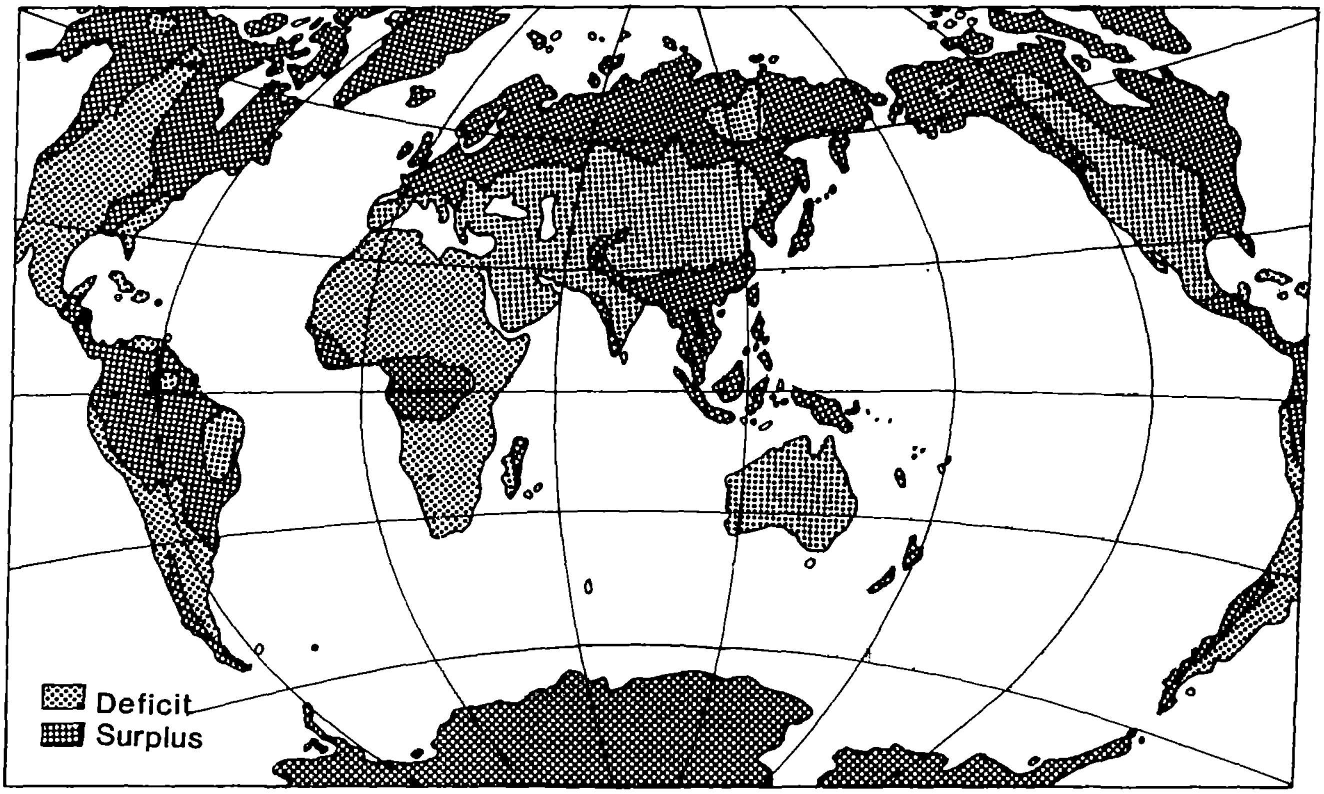

Figure 4 Global distribution of water surplus and deficit areas (source: UNESCO, 1978)

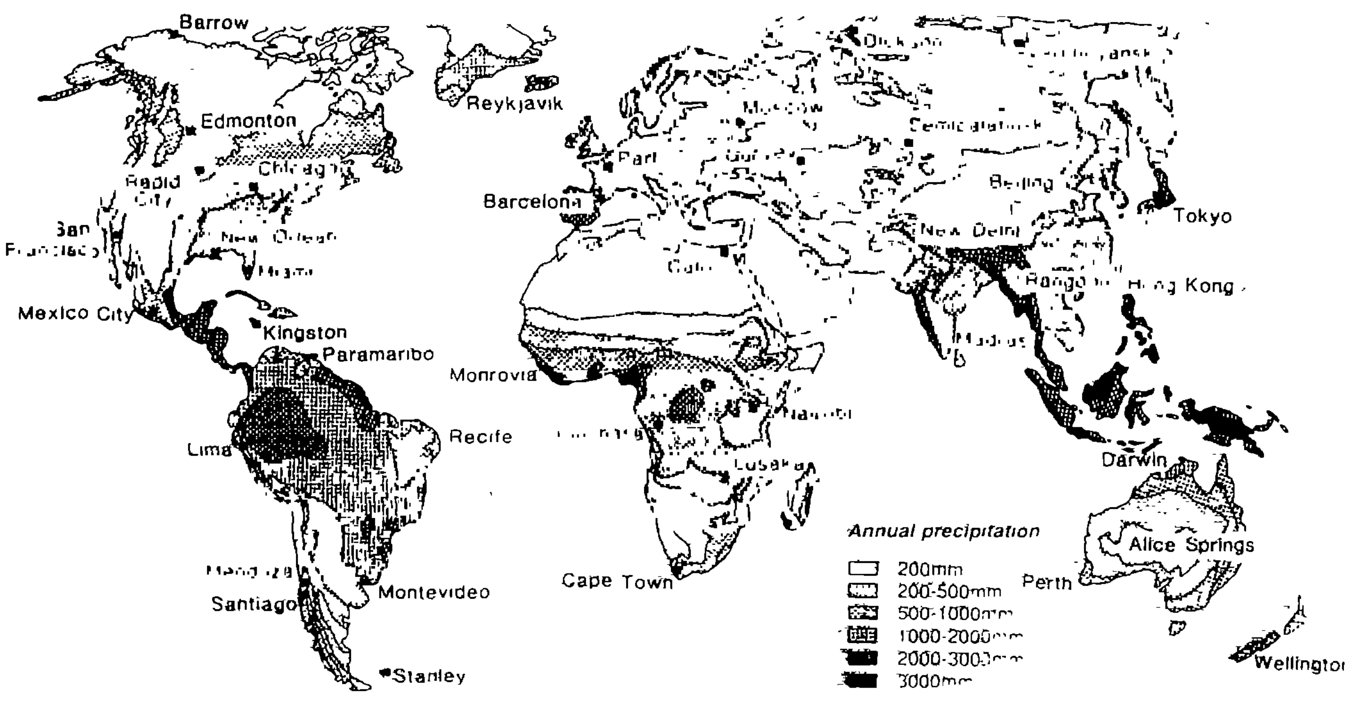

Figure 5 Distribution of annual precipitation (source: Tanke & Gulik, 1989)

(arid and semi-arid) areas than in the surplus (humid) areas, as depicted in Figure 6. Also, variations in the tropics are higher than those in the temperate areas. These are general trends but localised features such as mountains or deserts would show local variations.

Seasonal variability of precipitation The seasonal variability of precipitation in different climatic regions is illustrated with Figure 7 by showing typical precipitation distribution in tropical humid (Recife, Singapore) and tropical semi arid (Lusaka, Lima) areas on one hand, and in temperate

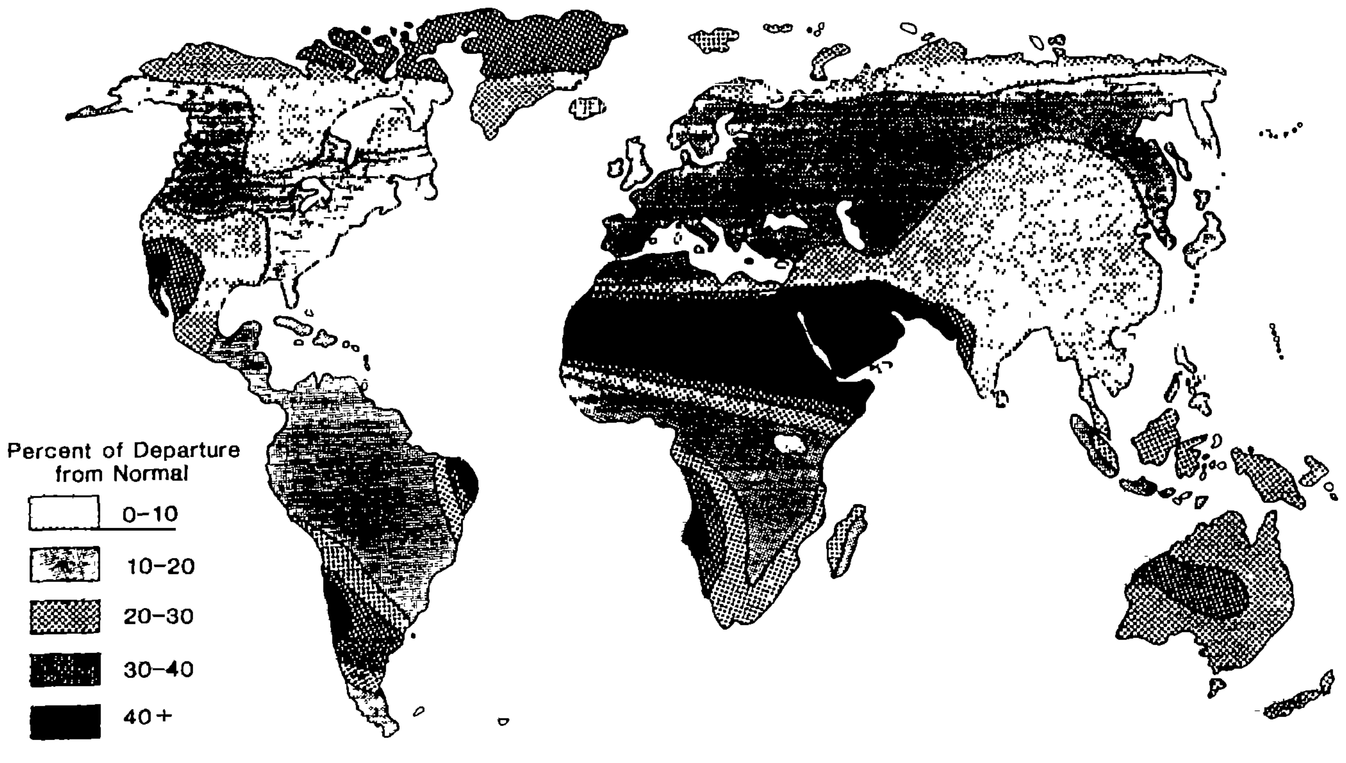

Figure 6 Inter-annual variability of rainfall (source. WRI, 1990)

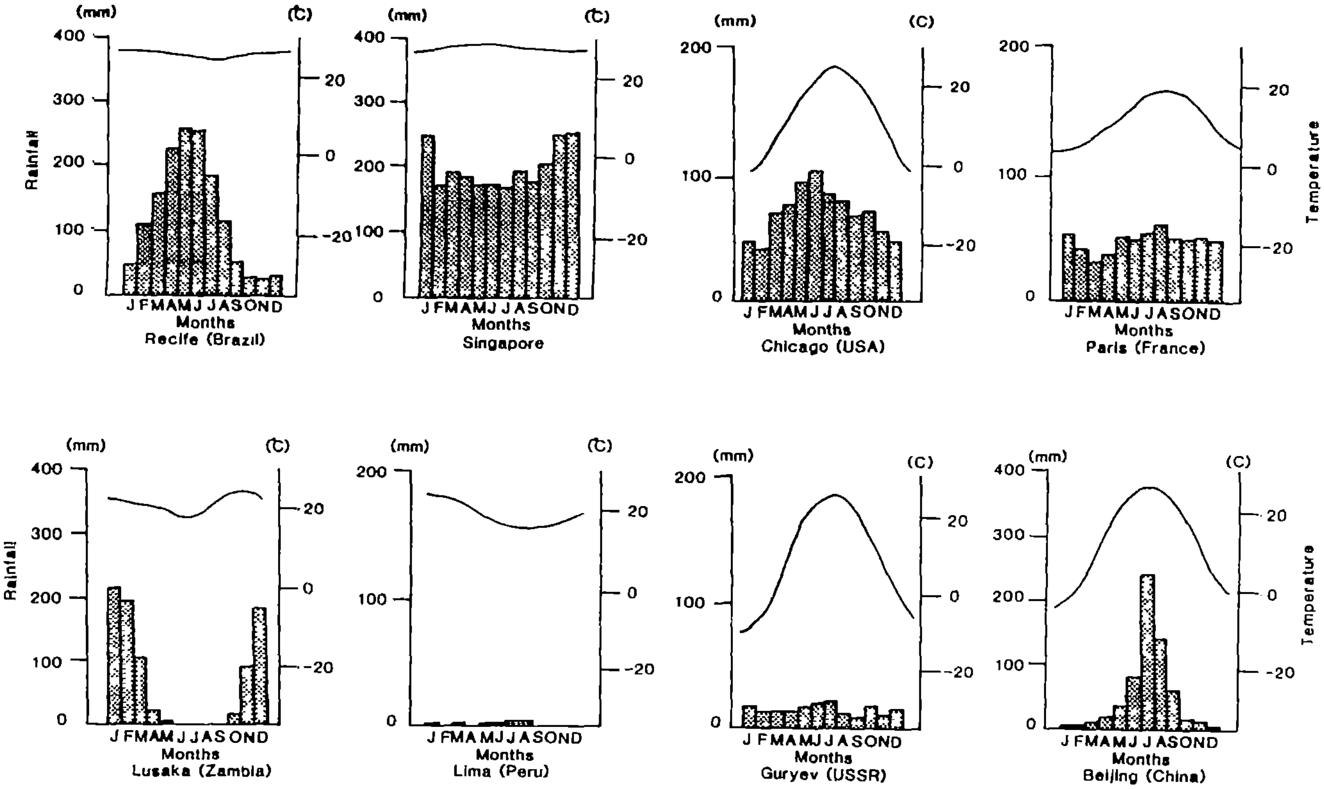

Figure 7 Monthly rainfall distribution at selected stations in the tropical and temperate regions

humid (Paris, Chicago) and temperate semi arid (Guryer, Beijing) areas on the other. Seasonal variation in precipitation can be strong in both tropical and temperate regions (Recife, Lusaka, Chicago and Beijing) or insignificant in humid and semi-arid areas (Singapore, Lima, Paris, Guryer).

Runoff Variability As runoff is a response to precipitation the variability will be similar to precipitation in the regions. In the case of seasonal runoff, there is less variation in the mid-latitude regions compared with the tropical areas. This is due to snow-melt in the warmer months in the mid-latitude regions which tend to even out the flow during the year.

The dependability of precipitation in the tropics, particularly in the semi-arid and arid areas, is very low. This affects agriculture adversely in those areas relying on rainfed conditions for crop cultivation. Again, because of the high variability of runoff, conservation of water through storage reservoirs is highly necessary.

Extremes — Floods and Drought The precipitation that annually renews water resources may be several per cent above or below the long term annual or seasonal mean. Depending on the direction and extent of the departure from the mean, and the intensity and duration, floods and droughts of different magnitude are caused. All climatic regions are prone to extremes but there are some areas which are more prone to one type of extreme than others. For instance, the tropical water-deficient Sahel in Africa, the western part of North America and most parts of Australia are more drought prone than other areas. Similarly, the tropical water surplus south east Asian region (e.g. Bangladesh, India, the Indonesian archipelago) are more prone to floods.

In the case of drought, this may involve the late arrival of rain, or insufficient rainfall during the crop growing season resulting in insufficient soil moisture This deficiency could also last some months resulting in low flows, and the lowering of reservoir and groundwater levels. It could also persist for a few years as in the Sahel drought of 1968-1973 which later spread to the whole of Africa (1981-86).

Unfortunately, statistical models have mainly been used in the past to analyse extreme hydrological phenomena. It has been difficult so far to predict the occurrence of these extreme events in terms of onset, duration, cessation, frequency, severity, spatial coverage, etc. It is now felt that a better approach will be to search for the origins of the extremes, which are linked to atmospheric and ocean circulation processes (UNESCO, 1990). For instance, the floods of South East Asia are being linked with the atmospheric processes leading to cyclones, hurricanes, typhoons and the El Niño southern oscillations.

2.6 Water quality

An assessment of water resources is incomplete without knowledge of the quality characteristics as assessed by their physical, chemical and biological constituents. These constituents may originate naturally from the environment (e.g. soils and geological formation) or from wastes discharged as a result of agriculture, human settlements and industrial activities. They are introduced either from point sources (mostly industrial), which are manageable, or from non-point sources (mainly agricultural), in which case management is more difficult.

The concentrations of the constituents simply express the status of the water in physical, chemical and biological terms, but quality can only be discussed meaningfully when it is related to a specific use. In such cases, guidelines must be given of the concentrations of various constituents which should not be exceeded in order to avoid impairing the water for any particular use.

Global and regional quality of freshwater bodies Until 1987 no attempt had been made to assess globally the quality status of regional freshwaters. This was due to lack of data from most countries, particularly from the developing countries where water quality data were not collected on a regular basis.

To fill this gap, WHO, UNEP, UNESCO and WMO initiated the Global Environmental Monitoring GEMS (WATER) project in 1977. The project was aimed at collecting periodic samples from selected river, lake/reservoir and groundwater bodies, to determine the range of water quality parameters. All member states of the co-operating international organisations were expected to participate. The capabilities of countries in the various regions to take part in the project varied. In the developed countries, where resources were adequate participation was strong. There was least participation from countries within the African region. The Asian and Latin American countries participated to a slightly greater degree.

After ten years of data collection, regional and global assessments were undertaken of the water quality status of water bodies in different regions (WHO/UNEP, 1989). The assessment took into consideration first the various constituents (quality variables or parameters) and the guideline values which must not be exceeded if the water is to be used for domestic water supply, irrigation, livestock and fisheries. The type of freshwater — river, lake/reservoir, groundwater — was also considered where the quality parameters are relevant in determining quality.

A trend was discerned from the analysis of the data that some pollution problems have reached global proportions and are now affecting water resources on several continents. The pollution problems were classified into those that were common to all the fresh water bodies and those that were specific to rivers, lakes/reservoirs or groundwater. The classification is presented in Table 10.

Pollution problems common to all water bodies The common contaminants were found to be heavy metals and organic micropollutants. Globally, the heavy metals lead, copper, zinc, nickel, chromium, cadmium, come from mining operations and from municipal and industrial sources. Such heavy metal pollution problems can be seen to affect both industrialised and non-industrialised countries. The organic micropollutants on the other hand are mainly from the industrialised countries of Europe, North America and the industrialising ones of Asia and Latin America.

Specific pollution problems: (i) Rivers The problems specific to rivers are firstly pollution from disease pathogens. These are common in all regions where urban sewage is discharged into rivers. The problem is more prevalent in the developing regions of Central and South America, Asia and Africa where urban sanitation facilities are inadequate. ①

The second problem relates to organic matter pollution from natural and synthetic matter. The natural sources (nutrients) are found in all regions while the synthetic ones ②

Table 10 Occurrence of major pollution problems in different types of water body (source: WHO/UNEP, 1989)

Type of water body	Water pollution problem	
	Specific to water body	Ubiquitous occurrence
Rivers	Pathogens Organic matter Suspended matter Acidification	Heavy metals
Lakes and reservoirs	Eutrophication Acidification	Organic Micropollutants
Groundwaters	Salinization Nitrates	

Table 11 Water quality at selected GEMS (WATER) stations (source: WRI, 1990)

Rivers	**DO**		**BOD**		**pH**		**FC**		**Hg**		**Pb**	
	Rep	**%< GLV**	**Rep**	**%> GLV**	**Rep**	**%> GLV**	**Rep**	**%> GLV**	**Rep**	**%> GLV**	**Rep**	**%> GLV**
Rivers												0
Africa	3	0	3	33.3	4	0	0	-	0	-	1	
N & C												0
America	7	14 3	4	25	6	0	6	0	2	100	1	0
S. America	12	0	12	0	12	0	11	90.0	1	0	1	0
Asia	24	4 2	24	12 5	23	4 3	23	100	7	85.7	9	0
Europe	11	9.1	5	20	12	0	6	100	0	0	1	0
Oceania	5 3	0		0	4	0	4	75	0	0	0	
	62	4.8	51	11 8	51	1 6	50	84	10	80	13	0
Lakes												
Africa	1	0	1	0	3	0	0	-	0	-	1	0
N & C.												
America	4	0	2	0	4	25	2	100	0	-	0	-
S. America	4	0	3	0	4	0	4	100	1	100	1	0
Asia	7	0	5	0	7	0	6	83.3	1	100	1	0
Europe	6	0	2	0	6	0	1	0	1	0	1	0
Oceania	1	0	1	100	2	0	1	100	1	100	1	100
	23	0	14	7.1	26	38.5	14	85.7	4	75	5	20
Groundwater												
Africa	0	-	0	-	1	0	0	-	0	-	0	0
N & C.												
America	1	0	2	0	3	0	2	100	0	-	0	-
S America	2	0	0	-	2	0	1	0	0	-	0	-
Asia	7	0	4	0	7	0	7	42.9	1	100	1	0
Europe	4	25	0	-	3	66 7	0	-	0	-	0	-
	14	7 1	6	0	16	12.5	10	50	1	100	1	0

GLV = Guideline value
FC = Faecal coliforms
Rep = Noumber of stations represented in region

are to be found more in the industrialised countries of Europe and North America and in those becoming industrialised in Asia and Latin America.

③ Third is pollution from suspended matter which comes from mining and lumbering activities. It is found in all regions, developed and developing; extreme flood flows add to this type of pollution.

④ Fourth is acidification which originates from the discharge of sulphur dioxide and particulate matter into the atmosphere. This has both local and transboundary effects because of the long distances over which these can be transported in the atmosphere. It has manifested itself in recent years in Europe and North America. The sources are from industry, including mining, and thus rivers in both developed and developing countries are affected.

(ii) Lakes and Reservoirs The specific water quality problems are firstly eutrophication which arises from nutrients from human wastes and agrochemicals (fertilizers and pesticides). The problem is prevalent in all regions in both the developed and developing ones. The second problem is that of acidification: the contaminants already identified as causing it in rivers are also responsible for acidification in lakes/reservoirs.

(iii) Groundwater The first specific problem is salinisation of groundwater. This is associated with inadequate drainage and high evaporation in irrigation systems. It also occurs in coastal areas where the groundwater is overexploited and saline water intrudes into aquifers. Salinisation from these sources can be found in all regions

Nitrate pollution of groundwaters is a second problem. It comes from the use of fertilizers in agriculture. This is now known to have become a serious problem in Western Europe, where the level of nitrate concentrations being monitored are above the guideline values for drinking water.

(iv) Global synthesis of water pollution The results of an analysis of selected water quality variables for selected GEMS (WATER) stations in different regions of the world for the three year period (1985-87) are presented in Table 11

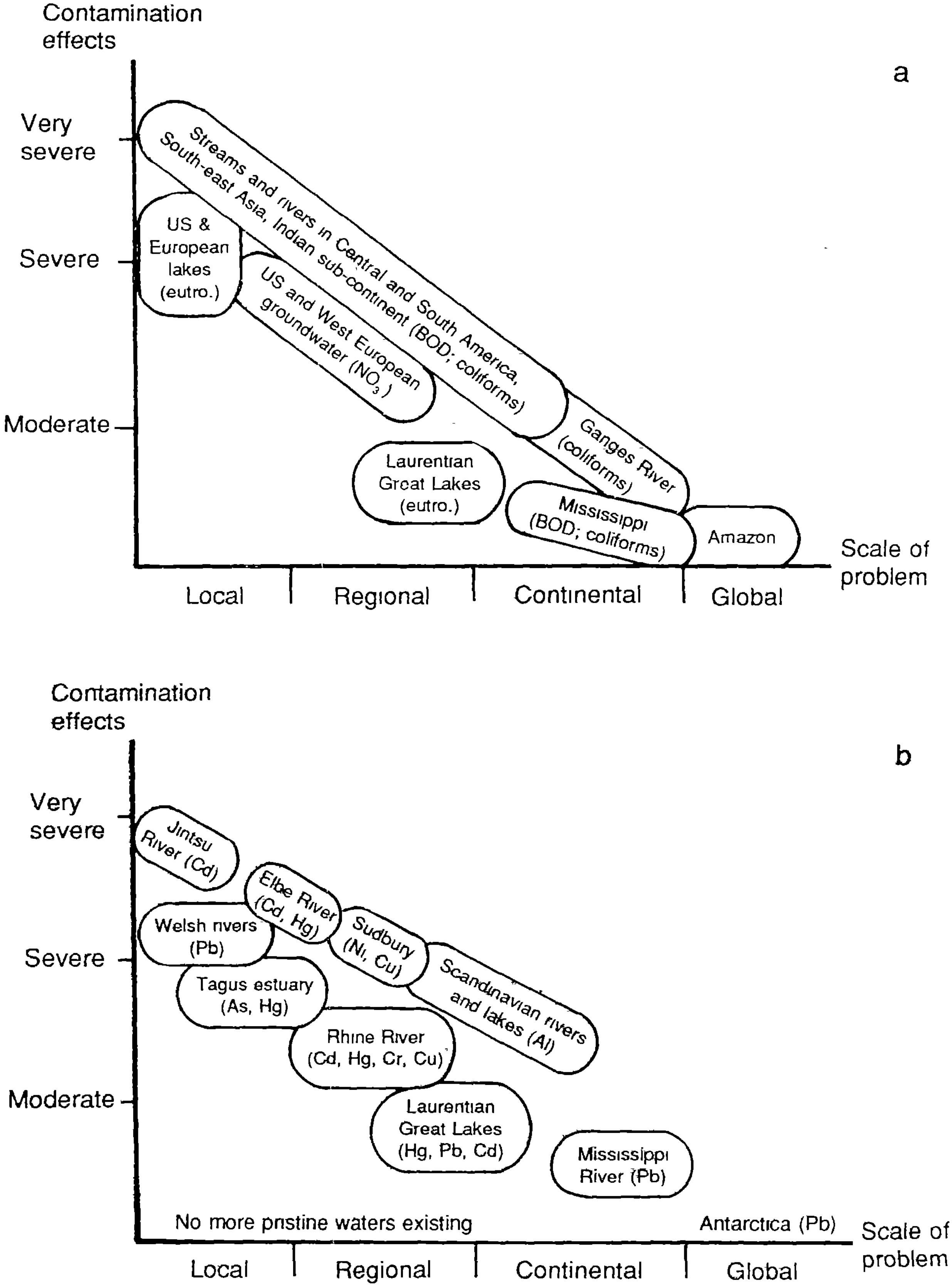

Figure 8 Occurrence and importance of pollution: (a) organic; (b) metals

for rivers, lakes and groundwaters. The variables used are Dissolved Oxygen (DO), Biological Oxygen Demand (BOD) Faecal Coliforms, and dissolved Mercury and Lead. The results show that pollution from faecal coliforms and dissolved mercury were the most serious problems in that period.

In addition, the WHO/UNEP assessment made a global synthesis of pollution problems in the areas of organic, metal organic micro-pollutants, salinisation of surface and ground waters and accidental pollution. It examined the severity of contamination effects against their scale of occurrence at local, regional, continental and global levels. The results for organic and metal pollution are presented in Figure 8. The conclusions are valid for the case studies upon which they are based. There were, however, few studies from the developing regions because of the paucity or absence of data.

2.7 Adequacy of knowledge

The results presented so far show that there is some working knowledge available about the world's water. However, as can be seen from a comparison of the various estimates, differences exist with regard to the water balance components and the water resources at the various levels.

Those scientists who have made contributions to this knowledge have been unanimous in indicating how tentative or preliminary the results are. They have all pointed to the lack of adequate data on the hydrological cycle, the lack of sufficient areal coverage of the data and their representativeness, the gaps in data, the quality of data, and in some cases problems of access to data even if they are available. In addition, there are questions raised about the adequacy of the scientific basis, methods and techniques used in making the assessments.

It must be pointed that both the IHP of UNESCO and the HWRP of WMO have been addressing the problems of the scientific basis and the operational data needs for water resources assessment in their successive phases and medium term plans, with the objective of improving knowledge about hydrology and water resources. The IHP has among other things been responsible for processes to improve understanding and the development of methodologies for the determination of the water balance elements of precipitation, evaporation and runoff; also, for the assessment of water resources in the different climate regions (tropical, temperate and arctic). These have taken account of morphology (mountainous, sloping, low-lying land, including wetlands and coastal areas). The qualitative (physical, chemical and biological) aspects are also being studied. The influence of man on the hydrological cycle and on water resources has also received attention. The HWRP has also been responsible for the data needs of the above studies through network design, standardisation of instruments and procedures, data collection, transmission, processing, storage and retrieval.

To reinforce the above efforts the importance of assessing water resources as a prerequisite for rational and sustainable management of water resources was underscored in 1977 by the UN Water Conference held in Mar del Plata (Argentina). In the Plan of Action that emanated from the Conference the first recommendation was addressed to water resources assessment, and the actions that countries and international organisations should take towards effective assessment at the national, sub-regional and regional levels.

UNESCO and WMO were in particular requested to develop guidelines within the frameworks of the IHP and HWRP that would help countries assess their water resources adequately. In response to this WMO and UNESCO prepared for the guidance of Member States a *Handbook for National Evaluation of Water Resources Assessment Activities* (UNESCO/WMO, 1989). The objective was to identify gaps and weaknesses in the activities that enable water resources to be successfully assessed. The results are expected to provide the basis for actions to be taken to fill in gaps in knowledge and strengthen the framework for assessing water resources. The activities with which the Handbook deals are:

- Institutional framework
- Areal assessment of hydrological elements
- Hydrological data and information required
- Data collection, processing and retrieval
- Workforce education and training
- Research and development

Regional evaluation of water resources assessment On the 10th anniversary of the UN Water Conference, the UN Economic and Social Council (ECOSOC) in 1987 called for a regional evaluation of the progress made in implementing the Mar del Plata Action Plan. Water resource assessment was one of the subjects evaluated. The outcome of the evaluation showed that in the mid-seventies some progress had been made in assessing water resources in all regions. This was particularly the case in the area of network expansion, with installation of new equipment and training of personnel. Due to the economic difficulties of the 1980s, however, such gains as had been made were lost in most regions, even though the pressure to meet the needs of the growing population demanded more precise knowledge about water resources, their availability, variability, reliability and quality. The findings in respect of the three key issues — data collection, processing and retrieval; areal assessment of hydrological parameters; and data and information for planning — are instructive in assessing the regional and global situations.

Network ✓

Data collection processing and retrieval The following are the key problems identified:

- inadequate networks
- incompatible technologies
- little user interaction
- poor data accessibility

Except for North America and Europe, these problems were prevalent in all regions.

The issue of inadequate networks is particularly acute in the African region, which promoted the World Bank/UNDP Sub-Saharan Hydrological Assessment Project to identify the special problems of the region and to propose strategies for solution. A study of the evolution of the data networks (1977-1989) in the various regions of the world shows a general improvement between 1977 and 1987 but that there appears to be a retrogression after 1987. The evolution of water quality stations in Africa — from 123 to 351 — over the period is worth noting, as this unimpressive progress partly accounts for the lack of assessment of the water quality status in Africa under GEMS(WATER); often the networks do not include routine collection of hydrological data, and as such are not reported upon.

In the case of data banks there has been a general trend of improvement in all regions but in spite of this, there is need to harmonise data bank hardware and software in the developing countries, and to process the backlog of data for publication and archiving.

Physiographic data such as topographical, geological, geomorphological, pedological, land cover and land use data are available in one scale or another Regrettably, data in developing countries are often out date as the lack of resources makes updating difficult.

Areal assessment of hydrological parameters The main issue here is that methodologies have not been adopted to extrapolate from the point measurements and observations made for precipitation (including snow and ice), evaporation, runoff, groundwater, sediment and water quality to obtain areal values over basins, regions and continents. The problem was found to exist more in the Latin America, Arab and African States.

Data and information for planning Issues identified are:

- poor network design
- need for other data (groundwater, water quality) and integrated networks
- lack of interpolation methods.

Apart from precipitation measurements, most data are of short duration and thus estimates based on them are not reliable.

3 Changes/Threats to the Resource

In addition to assessing the freshwater resources on the basis of the present climate, it is necessary to expect that changes will occur and hence the capacity to assess the impact of such changes on water resources should be developed accordingly. The changes could be the result of natural geophysical processes, man-induced climate change or man-induced changes on the land.

3.1 Natural geophysical changes

This type of change is long term. It is borne out by the fact that reconstruction of past climate has shown that the present climate in the various regions of the world is different from that which obtained in the past (Liebscher, 1991). The present variability in hydrological elements is therefore part of long term natural geophysical changes. The methodology to assess such changes are being handled under the World Climate Programme (Water) under the project dealing with analysis of historical hydrological and related information. These analyses should help assess any shifts in the long term means of hydrological elements, both in the past and in the future within different climatic regions.

3.2 Man-induced climate change impact

The Second World Climate Conference (SWCC) in its statement on the specific issues of climate change impact stated that "among the most important impacts of climate change will be its effect on the hydrologic cycle and water management systems. Increases in incidence of extremes, such as floods and droughts would cause increased frequency and severity of disasters."

Present water resource systems which have been based on analyses of past climatic and hydrologic parameters will no longer be adequate. Preliminary assessments have been made by the IPCC on impacts on water resources in five regions of the world: North America, Western Europe, the Sahel in Africa, India and Australia. These were based on various scenarios of the increase in concentration of CO_2 and other 'greenhouse' gases in the atmosphere. The IPCC's findings from these preliminary assessments indicate that "relatively small climate changes can cause large water resource problems in many areas, especially arid and semi-arid areas where demand or pollution has led to water scarcity. Little is known about regional details of greenhouse induced hydrometeorological change. It appears that many areas will have increased precipitation, soil moisture and water storage, thus altering patterns of agriculture, ecosystem and other water uses. Water availability will decrease in other areas, a most important factor for already marginal situations such as the Sahel zone of West Africa". The IPCC report goes on to state that "change in drought risk represents potentially the most serious impact of climate change on agriculture at both regional and global levels." (IPCC 1990).

It can therefore be expected that the impact of climate change on water resources will compound the present insufficiently understood long term natural variability of water resources both for the means and the extremes. To be able to predict the impact, UNESCO, WMO, ICSU and IAHS through the WCP (Water), IHP-IV, the OHP and the IGBP are working to develop better Atmospheric General Circulation Models (AGCMs) and also better land-phase hydrological models. These are planned to be coupled together at appropriate scales to predict the changes in rainfall and temperatures that could result from different amounts of CO_2 emission into the atmosphere. The temperature rise will help determine the extent of sea-level rise from melting ice and, as such, the impact on coastal water resources (both surface and underground).

3.3 Human-induced impacts on the land

As a result of population growth more land will be needed for agriculture, urbanisation will increase, and more industries will be established, all in an attempt to satisfy the needs of the population. As the land is involved in water partitioning processes, the changed land use will affect the current proportions into which precipitation is partitioned into runoff, soil moisture, evapotranspiration and groundwater.

In addition, the hydrological regime will change as hydraulic constructions such as dams, diversions, abstractions, and long distance water transfers between basins, etc. take place. Groundwater may be affected by over-exploitation and in coastal areas saline water from the sea would intrude into coastal aquifers.

Also, since water is involved in the transformation and transport of sediment and in hydrobiochemical processes changes in water quality can be expected. This has been indicated by the growing loads of agricultural, household/municipal and industrial effluents that the development process is producing. The quantitative and qualitative changes that will affect water resources must be taken into account in their assessment. Human-induced changes must be differentiated from the natural climate variability in the hydrological cycle. The WCP (Water) Project dealing with distinguishing between the influence of man's activities on climate variability and on the hydrological cycle is expected to take account of this aspect of water resources assessment: Refsgaard (1987) has proposed a methodology.

4 Problems and Constraints

The problems in water resources assessment have already been identified in the discussion on the regional evaluation of water resources assessment, hence this section will deal with the constraints.

4.1 Financial constraints

This has been one of the most serious constraints in all regions even including the developed world. There are however regional differences which are more pronounced in the developing countries. The lack of adequate financial resources has resulted in the inability to maintain field, laboratory and office equipment, purchase new ones or modernise them to keep abreast of new technologies. In many countries, particularly in Africa, Latin America, the Caribbean and Arab States, funds to purchase vehicles and other logistic support to carry out field operations, and to pay observers in the field were badly curtailed if not completely cut out. Where progress was made under bilateral or multilateral assistance projects, the programmes could not be maintained and deterioration set in after the external assistance had been withdrawn.

In the developed regions, financial constraint was due more to a shift in priorities to allocate additional funds to other economic and social activities deemed to be more important. For many of the developing countries, there have been difficulties from the mid-1970s arising from high inflation rates, unfavourable balance of payments, crippling debt burdens, stagnating or decreasing government revenues, bloated public services, and natural disasters like drought, floods, earthquakes, etc.

Even the structural adjustment programmes introduced by the IMF/World Bank to correct the ills of the developing economies had the effect in some cases of worsening the situation as staff strengths and financial resources had to be cut down.

4.2 Technological constraints

Very often the techniques and methodologies developed in the temperate mid-latitude climate are transferred without adaptation to suit other areas. For instance, in the semi-arid and arid areas of the Sahel and North Africa where there are vast distances between non-coastal settlements, it may not rain in these related areas for a couple of years. However, when rains come they do so with very high intensity and last for a few hours. Serious floods accompany these intense rainfall events. Also considerable amounts of sediment are generated which threaten the storage capacities of water conservation structures. Conventional operational techniques cannot be applied in such conditions. Equipment must be able to withstand severe weather conditions, and capture data very infrequently. Automatic data capture will be necessary and remote transmission of the data will be needed. For flow measurements dilution methods would be more practical. Again, the normal methods of computing statistics of hydrological elements cannot be applied to yield meaningful results.

It is also important that in addition to being appropriate to local circumstances they should be affordable in terms of cost and maintenance. Many hydrological services in the developing regions have not been guided on these latter aspects. It is not uncommon to find that equipment has been acquired without ensuring that it can be operated and maintained properly. Hence, the life span of equipment is unduly shortened, thereby wasting scarce resources.

4.3 Institutional constraints

The institutional constraints centre on the fragmentation of the water resources assessment activities among various agencies with no attempt to co-ordinate or clarify mandates so as to reduce duplication and overlapping of functions, and thereby use scarce resources more efficiently.

[illegible]

There are institutional reforms which are not well-considered and these tend to confuse agencies and result in duplication, or in important functions being left unattended. In most countries, the organisational arrangement at national and local levels are skewed in favour of the national, to the extent that the local levels at which basic work is done are starved of adequate manpower and other vital resources. In most organisations technical guidelines and procedures are not properly documented and made freely available for use so as to standardise work. Where they are available, supervision is not adequate to ensure their compliance because of lack of adequate supervisory personnel. Some institutions are knowledgeable about what to do, but their efforts may waste away because the resources are not made available.

4.4 Human resource constraints

The most notable human resource constraints identified in regional evaluation of water resources emanate from:

- Lack of human resource planning in the water agencies to determine numbers for both national and local level operations, and the appropriate level of professionals, senior and junior technicians and observers that are needed for coordinated work. In some countries there is an emphasis on training professionals, to the detriment of sub-professionals and observers.
- Lack of motivation of staff through inadequate remuneration. This is a problem in most developing countries in Africa and Latin America. Hence trained staff are always looking for better financial opportunities elsewhere, either in the country or outside. This leads to high staff turnover.
- Trained staff leaving their organisations for lack of job satisfaction because they are not given the resources (field, laboratory and office equipment and logistic support) to work with so that they can apply the new knowledge they acquire. Ironically in some countries staff who have been on the job for many years do not get the opportunity for periodic training to upgrade their knowledge.

It must not be forgotten, however, that national governments (both local and foreign) and international organisations (UNESCO, WMO, WHO, UNEP, FAO, UNDP, World Bank, etc.) have spent considerable effort and resources in training in the field of hydrology and water resources since the 1965 when the IHD (now IHP) started.

5 Strategies for Assessing Resources in the 1990s

5.1 Institutional component

As institutions are the vehicles by which programmes get implemented it is recommended that at the national level, governments that have not already done so should arrange to carry out careful evaluation of the water resources assessment activities with a view to clarifying functions, coordinating activities and ensuring that there is an agency assigned for every aspect of water resources assessment.

The results of the evaluation should be used as a basis for carrying out the reforms in the WRA institutions. The *Handbook for National Evaluation of Water Resources Assessment Activities* produced by UNESCO and WMO would be useful in this regard.

5.2 Knowledge and technology component

As more precise information about water resources is needed because of growing water demand and pollution it is necessary that knowledge about hydrological processes in the atmosphere, oceans and the land phases (including biogeochemical processes) be vastly improved. In the face of impending climate change, greater attention is being given to the fact that the freshwater resources are part of the hydrosphere within the earth system.

In this connection it is important to recognise the many projects that have been initiated under the World Climate Research Programme (WCRP): the International Geosphere Biosphere Programme (IGBP), the International Hydrological programme (IHP) Phase IV, the Hydrology and Water Resources Programme (HWRP), the World Climate Programme (Water) of ICSU, WMO, UNESCO and UNEP, with the assistance of other international governmental and non-governmental organisations such as the IAHS. These are aimed at gaining a better understanding of the earth system and the role of water and water resources in the system. These projects will involve among other things the development, calibration, validation and use of models at grid, meso and micro scales for Atmospheric General Circulation Models, to be coupled with improved land phase hydrological models, and so lead to better assessment of water resources for development. (Schaake, 1991; Rowntree, 1991).

5.3 Funding component

As already pointed out, this has been one of the serious constraints in the 1980s. It is obvious that more funds must be mobilised for water resources assessment if better progress is to be made. To this end it will be necessary for water resources agencies to demonstrate and convince their governments — particularly those in the developing regions — of the benefits that would be derived for sustainable development through adequate and accurate knowledge. The resources of bilateral and multilateral funding agencies must also be mobilised and in this regard, the present World/Bank UNDP Sub-Saharan Africa Hydrological Assessment should provide an important mechanism for removing the severe constraints which exist in the African region.

5.4 Capacity building component

The capacity to assess water resources involves a wide range of activities: institutional strengthening at various levels of education and training, introduction of appropriate legal instruments, mobilisation of adequate financial resources.

As pointed out earlier, the international organisations particularly UNESCO, WMO, UNEP, FAO, WHO and governments in the developed countries have over the years supported and promoted education and training in hydrology and water resources. The developing countries have been the greatest beneficiaries of the courses. Under UNESCO's IHP alone there are about 34 international courses in hydrology and water resources in four different languages covering various durations from eight weeks to two years. In order to cope with the new demands for hydrological knowledge, it is important to broaden the base of hydrology teaching at undergraduate level to include other aspects of the hydrosphere not presently covered (Nash *et al.*, 1990). Research training also needs to be intensified to meet the new challenges of the next 20 to 30 years.

However, it is recommended that the Delft Declaration issued by the participants to the UNDP Symposium on *A strategy for Water Resources Capacity Building* held in June 1991 in Delft (Netherlands) should receive the attention of national governments, national WRA organisations, and external support agencies.

5.5 Monitoring the state of water resources and environment

In view of human dependence on water resources and the environment, and the current and projected threats to them, it is imperative to develop indicators by which they can be monitored, to obtain fore-warning about adverse trends.

These indicators will relate to the states of the hydrosphere, geosphere, atmosphere and biosphere of the earth system. In the case of water resources, it is suggested that the indicators include precipitation, river water level, lake/reservoir level, groundwater level, dissolved oxygen (DO), biochemical oxygen demand (BOD), salinity, dissolved lead and mercury. These should be accompanied by land surface indicators, for which urban, vegetation and snow covers are suggested. The strengthening and expansion of data collection networks for water resources assessment, as already discussed, would provide a solid contribution to the monitoring effort.

5.6 International cooperation component

Attention has already been drawn to global projects initiated by international governmental and non-governmental organisations to advance the knowledge of the earth system.

In the final analysis the projects will depend upon the efforts of individuals and national institutions. Cooperation in training and strengthening individuals and institutions in the developing world, in particular, will be a prime necessity. The projects will also involve the acquisition of climate, hydrological and physiographic data from all countries so as to be able to develop, calibrate, validate and use the models to be developed.

Data will be required from all countries. Some will be collected from space and some from ground stations. It is recommended that for projects to be implemented successfully, countries should undertake to exchange and use data freely among themselves (Askew, 1991). In this regard, the Global Precipitation Climate Centre, and the Global Runoff Data Centre which have been established in Offenbach and Koblenz in Germany should be supported by all countries. Similar global centres for land resources data should be supported.

The outcome of the recent NATO Advanced Workshop on Opportunities for Hydrological Data in Support of Climate Change Studies held in Lahnstein, Germany, in August 1991 will require the attention of all countries in helping them to know what is required.

With trained manpower and strengthened national institutions it should be easier to improve assessment of water resources at the national level, making it easier to co-operate on sub-regional, and regional and global projects. It goes without saying that financial assistance will have to be provided for countries in the developing regions to participate effectively in these projects.

6 Conclusions

It has been shown that water is a vital part of the earth system without which it cannot function. Human development depends upon only a small part — less than 0.01 per cent — of the total available water in the hydrosphere.

The knowledge we have of the available water, though inadequate in many ways, has proved useful so far. However, in the face of population growth and the increasing demand for water, deteriorating water quality, increasing environmental degradation, and impending climate change, we need more precise information about water resources for rational planning and management to sustain development.

This can be achieved if we overcome present constraints regarding water resources assessment, by strengthening water resources assessment agencies, providing more financial resources to the agencies, and stepping up human resources development and co-operating at sub-regional, regional and global levels to carry out important studies to improve knowledge.

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2

Water — the environmental and developmental dimensions — striking a balance

Janusz Kindler (Poland)

EXECUTIVE SUMMARY

In the last decade of the 20th century, mankind finds itself at a critical point and with very little time — years, not generations — in which it must restore degraded ecosystems and bring water resources to such a state that they can maintain themselves naturally. Water resources planners and managers must now think in terms of sustainable development: using and managing water resources, the natural environment and entire landscapes in such a way as to maintain a strong economy and preserve the natural environment today and in the years to come.

This paper emphasises the need to appreciate fully the interrelationship between water resources development and environment. It argues that the quality of the natural environment should be protected and, when possible, enhanced by water resources development.

A fundamental question is asked as to what are the overall long-term impacts of water resources development on the biosphere. There are no easy answers to this question, especially since the scale of human activities has increased substantially and many environmental problems take a long time to unfold. Thus the author argues that 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 made as to the benefits from risk reduction. Decision criteria must extend beyond engineering and economics.

Everyone must play their part — government, industry, agriculture, interest groups and individuals — in giving due consideration to the environment: we owe it to the generations who will follow us.

CONTENTS

1 Introduction

Water occurs in many different forms — as ice in glaciers, as vapour in the air, and as a liquid in rivers, canals, lakes and seas. These different forms are connected through the hydrological cycle across a wide spectrum of space and time scales. Powered by the sun, the hydrologic cycle involves storage and release of latent heat that drives the atmospheric circulation and globally redistributes both water and heat. These processes are of fundamental significance in shaping climate and weather.

At the other end of the scale, water is essential as blood and lymph. The molecular structure of water makes it an almost universal solvent. Since cell membranes are permeable only to dissolved substances, water is essential both for the nourishment of cells and for the removal of their wastes. In fact, it plays this role at different levels of life's organization: for the individual human, animal or plant, the household, the city, and for the earth itself. This process has profound implications for all efforts toward ensuring the security of water supplies and protecting water resources against contamination.

Furthermore, water has an ecological significance of its own and it contains many forms of life. Wetland and estuaries, for example, are highly valued aquatic ecosystems. Changes in water quality, such as pollution, as well as changes in water quantity have immediate consequences for the ecological functioning of these systems.

The earth is blessed with a bountiful supply of water. Although freshwater is only about three per cent of water on the planet, its total amount (36 million km^3) is more than enough to sustain all life forms on the earth. The total annual world water consumption by the end of the 1980s was of the order of 4100 km^3 and by the end of the 20th century it may increase to 5200 km^3 (Shiklomanov, 1989). About 60 per cent of water consumption occurs in Asia where the major portion of irrigated land is located.

In spite of this global abundance, the availability of freshwater varies widely with geographic location. In high-latitude river basins endowed with temperate climate and good precipitation, water availability is generally much higher than in the low-altitude basins. The latter exhibit a highly seasonal rainfall pattern, high rainfall intensity during the wet season, and natural water supply conditions are difficult. Irrespective of these differences, in many river basins the demands for water and water-related services come close to or even exceed available supply.

Throughout most of history, the interactions between water and its natural environment as well as between water and development have been rather straightforward and of a local character. But the complexity of these interactions is increasing. What were once well understood questions of nature preservation versus economic growth, now involve complex economic and environmental linkages. What was once clearing of land for agricultural development, is now deforestation on an unprecedented scale affecting the global hydrological cycle. What were once river training and regulation practices needed for the development of navigation, now often lead to a reduction in biodiversity.

As pointed out by Clark (1986), humanity has entered an era of a large-scale interdependence between economic development and the natural environment. This interdependence will intensify over the next century as the number of people on earth, industrial production, and the demand for agricultural products increase. A major challenge for the coming years is to learn how to manage our water resources in such a situation. One of the critical issues will be how to avoid development that is only undertaken for short-term benefits, such as the well-known case of cotton development in the Aral Sea basin in the USSR. To increase the prospects for environmentally-sound improvements in human welfare, appropriate institutions are required for the better management of the complex interactions between development and environment.

This paper is concerned with the environmental and developmental dimensions of water resources management. The overall purpose is to show that these two dimensions are not mutually exclusive but complementary and, in the long run, mutually reinforcing. *Our Common Future*, the report of the World Commission on the Environment and Development, states that good development protects and enhances the environment and that a consideration of the environment strengthens developmental progress and prospects. To achieve these goals, water resource projects — structural as well as non-structural — must be planned, implemented and operated in an 'environmentally sound' way. The resource base must be maintained and enhanced over the long term. Water's role in supporting life on the earth must not be impaired and its use has to be consistent with future as well as present needs.

2 Water as a Component of the Landscape

In nature nothing exists alone. Living things relate to each other as well as to their non-living, but supporting, environments. The landscape encompasses all of these interactions. Thus, each body of water is a delicately balanced component of the landscape in continuous interaction with the surrounding air and land. Water is intimately related to all man's activities in the landscape. Whatever occurs on the land and in the air also affects water. If a substance enters a river or a lake the water, to a certain degree, can purify itself biologically. Whether it is in the smallest stream or in the mighty ocean a point is eventually reached where the self-purification process is exceeded.

As pointed out by Falkenmark (1991), man's dependence on the natural life-support systems forces him to manipulate landscapes. This he does to control the circulating freshwater, to make water accessible when and where needed and to mitigate water-related hazards, such as floods and droughts. The intensity of these manipulations depends on the regional characteristics (climate, population pressure, etc.) and on the general level of development. One should distinguish here between more or less natural conditions, a developmental stage where the manipulations are growing in extent and in number, and complete development when water resources are fully controlled in the sense of their redistribution in time and space.

Environmental problems arise if the intensity of landscape manipulation exceeds certain site-specific (or region-specific) thresholds. Unfortunately, identification of these thresholds is a very difficult task. Our understanding of all interrelated natural and social processes occurring in the landscape at different spatial and temporal scales is limited. Extreme prudence must be exercised in all decisions that involve landscape manipulation.

2.1 Water as an ecological base

Ecosystems are composed of biotic (living) and abiotic (nonliving) components. The biotic components consist of three general types of living organisms: producers, consumers and decomposers. The abiotic components of ecosystems include air, water, soil, nutrients, the geological substrata, sediments, and both particulate and dissolved dead organic matter. The boundaries of natural ecosystem are determined by the environment, i.e. by what forms of life can be sustained by environmental conditions of a particular region (Grodzinski *et al.*, 1990).

Within any ecosystem, populations of organisms playing similar roles are joined together in communities and trophic groups or levels. These large groups contain many different species which act and respond to stresses as ecological units. Waterborne and airborne pollutant chemicals are the most common stress factors of concern to aquatic ecosystems.

The main structure of an aquatic ecosystem is provided by the food chain (Hjorth *et al.*, 1991). It starts with the input of nutrients and solar energy which are consumed by algae (microphytes) and aquatic plants (macrophytes). The organic matter and oxygen produced by these primary producers are grazed upon by zooplankton, crustacea and other small animals. These in turn are consumed by various fish species. The small fish are preyed upon by larger fish which are eventually consumed by man or birds. The dead bodies of food chain species drop to the bottom of the water system where they are decomposed by bacteria and re-enter the system in the form of nutrients.

Any change in the input variables caused by the stochastic nature of hydrological or meteorological variables is buffered by the ecological system. Man-made impacts are caused primarily by the exploitation of resources faster than their natural reproduction rates or by the release of waste products in greater amounts than can be integrated into the natural cycle of the system. Any input of non-natural substances puts stress on the ecosystem. If the stress exceeds the biological capacity of one component, at least one functionally duplicate component is recruited to preserve the system's resistance. In general, the functional simplicity of an ecosystem tends to reduce its resistance. Systems with large storage capacities show a high stability. Such systems are rather complex structures with high internal recycling rates and an elaborate food chain.

Ecosystems exposed to major shocks such as large floods or prolonged droughts are usually able to recover. Some of them, such as wetlands, floodplain forests or estuaries, even require such disturbances to maintain their resilience (i.e. the capability to recover from shocks). The recovery period is quite short in cases where the energy and nutrient capture is high but for ecosystems with a high buffer capacity and high internal recycling which therefore exhibit a high resistance, a longer recovery period is required (Hjorth *et al.*, 1991).

2.2 Changes in the hydrological regime in terms of quantity and quality and their effects on aquatic ecosystems

There are many man-made quantitative changes on the hydrologic regime that can impact upon aquatic ecosystems. They are of special concern in the case of storage developments. When regulating river flows, the cumulative value of a river's flood pulse (i.e. the nutrient supply to the floodplain, natural floodwater irrigation, groundwater recharge, fisheries, etc.) has often been underestimated.

Long-term and sustainable economic interests may be better served by building on this flood pulse and locally flood-dependent production systems such as recessional agriculture, floodplain fisheries and grazing, for example, rather than by supplanting them. Relying on the flood-pulse or perhaps by mimicking the flood-pulse through releases from an existing storage reservoir, is also more compatible with biodiversity maintenance and traditional social controls (Warshall, 1989).

Regarding qualitative changes, the primary threats to aquatic ecosystems come from the chemical loading of surface and groundwater by airborne and waterborne pollution. These chemical compounds are in transit to a variety of sinks from which they are eventually removed. Stumm (1987) states that "The major ecological problem is related to the adverse effects of heavy metals and refractory organic compounds on biota. For most inland waters, pollution by algal nutrients, especially phosphates, is of major concern".

There are many ways in which chemicals can enter the aquatic environment and we have limited knowledge of how they are distributed within the environment and on their residence times. The fate of these chemicals needs to be studied within the framework of the natural geochemical cycles of the earth.

2.3 River channels

River channels transport water and sediments from the catchment area to the sea. They are characterised by a continuum of physical gradients and biotic associations, and by longitudinal linkages (both physical and biological). These longitudinal linkages depend on the intensity and scale of erosional and sedimentary processes generated by the hydrological cycle in the river basin, on the nature of migratory species, on the dynamics of species coupling land and water, and on the nature of macrophytes trapping sediments and nutrients.

Flows of water, energy, biomass, sediments and polluting substances are linked in a river through several feedback loops. These loops operate on different temporal and spatial scales and change with the magnitude of the flow. This dynamic nature of the river is not completely understood, making it difficult to predict river response to management and stress.

Structures built in river channels need special emphasis on the fluxes and processes taking place in the interface zones between water, the river bed and banks. Such projects should always try to maintain transition zones (ecotones) within the river and between terrestrial and aquatic ecosystems. In the case of flood control embankments, they should be located at a sufficient distance from the river banks to maintain riverine forests and wetlands.

2.4 Wetlands

The UN Ramsar Convention defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres". Wetlands are of particular importance both economically and environmentally. The most important roles which wetland perform are (World Bank, 1991):

- Production of services: wetlands contribute to local rainfall and can be efficient, low cost water purification systems, recreation areas, buffers against floods, and can provide protection from coastal erosion by storms.
- Preservation of biological diversity: for many species of fish, waterfowl, tidal and freshwater marshes, coastal wetlands are of vital importance as breeding grounds as well as staging areas in their migration routes.
- Production of goods: wetlands are among the most productive ecosystems in the world. They are rich fishing grounds, important grazing areas for cattle and wildlife, and their swamp forests may yield valuable timber.

The wise use of wetlands is their sustainable utilisation for the benefit of man in a way compatible with the maintenance of the natural properties of the ecosystem.

2.5 Coastal zones including estuaries

The term 'coastal zone' describes that part of the continent where the land meets the sea; it includes the estuaries, marshland, and lands adjacent to the shoreline, and the adjacent sea. The term 'estuary' applies to the lower reaches of a river into which sea water intrudes and mixes with freshwater from land runoff.

Coastal zones are subject to multiple, frequently competing demands. Some require changes in the natural environment, while others require preservation. Large parts of coastal zones are often urbanised, industrialised, and densely populated, but they are also the location of delicately balanced estuarine ecosystems where the essential process is that of interchange between the waters of the sea and freshwater from land, with the freshwater inflow and tidal currents primarily determining the circulation patterns.

Productivity and biological diversity are important attributes of estuaries. Rivers deposit sediments rich in nutrients, tides flush the estuarine bays, and the shallow water permits good light penetration and, as a result, the estuarine regions are the most biologically productive areas on earth. The estuarine regions also provide important habitat for waterfowl and wildlife.

One of the major premises of this paper is that water resources planning and management must be integrated with land use planning. This is especially true in the coastal zone and in upstream areas where land use affects the estuaries.

2.6 Protection of the aquatic environment

Since the aquatic environment plays such a vital role in life on earth, good quality water is a precious resource. The quality of water affects the use we make of it, but the reverse is also true. Once we have used water, we affect its quality. Therefore, discharging untreated or partially treated wastewater directly into the aquatic environment for its eventual 'assimilation' is no longer acceptable. The approach to protecting aquatic environments depends on the type of pollutant (is it degradable; persistent; is it a metal; pesticide; dioxin; PCB?), the source (does it come from a specific industry; from agriculture; from the atmosphere?), and the effects (is it harming fish; birds; plants; human beings?).

Measures used to protect aquatic environments include water quality standards and objectives, regulations, and economic incentives. An example of a substance successfully regulated in many countries to reduce contamination of water is the phosphate in laundry detergents. Technology can be used in many cases to reduce or eliminate substances which may be harmful to aquatic environments. Sewage treatment plants, properly operated and maintained, can remove many toxic substances from wastewater.

But what happens when contaminants are not removed, even by the most modern wastewater treatment methods? They may only be present in minimal quantities but because of their persistence, they can build up to dangerous levels. In such cases, preventing pollutants from entering aquatic ecosystems is the only viable solution. Pollution control 'at source' is essential to the survival of all living things - plant, animal and human.

3 Water Use

3.1 Types of water uses

Water use consists of (1) on-site uses, (2) intake uses, and (3) instream or flow uses. On-site uses include all those which deplete water supplies before they reach surface or groundwater as well as water consumed by wetlands, natural vegetation, rain-fed crops, wildlife, and evaporation from the surface of water bodies. Intake uses include water physically withdrawn from surface or groundwater bodies for municipal, domestic, industrial and agricultural purposes. Instream uses include navigation, hydroelectric power generation, minimum flow requirements, and also fish, wildlife and recreational uses.

Water uses are measured by the amount withdrawn and by the amount consumed. Water is consumed through incorporation into a product (e.g. beer production) or lost to the atmosphere through evaporation (e.g. in the industrial cooling processes) and transpiration. Water consumptive uses are of particular importance since some part of withdrawn water can usually be reused, although not always near the point where the first withdrawal took place. Under certain circumstances, therefore, large water withdrawals over a short time may become critical, adversely affecting instream and on-site uses.

Quality determines the usability of water at any time and in any particular location. Over time, water quality in many streams, lakes, estuaries and groundwater aquifers has deteriorated through disposal of wastewater by both water consumers and producers. Much of this wastewater is generated as a result of inefficiencies in the manufacturing processes. Water pollution and its associated human health implications are serious in many river basins. Other problems caused by water pollution include excessive water purification costs, metal corrosion, fishery, agriculture, and recreation losses.

3.2 Overview of water uses

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 litres, depending on climate and physical activity. The daily *per capita* domestic use of water in urban areas is much larger. Taking into account expected population growth, there will certainly be a need for new water supply projects and facilities.

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 per cent, mainly through irrigation. The total irrigated area in the world is of the order of 250 million ha of which about 100 million ha are in developing countries with about four-fifths lying in the arid and semi-arid regions of Asia. In these regions waterlogging and salinity are common where irrigation is not accompanied by adequate drainage. Worldwide, no less than 200 000 ha of irrigated land are lost every year to waterlogging and salinity.

From the development plans of different countries it is clear that the irrigated areas will continue to grow, although small-scale projects seem to be getting more and more attention. There is also a great potential for improvement of water application efficiency through better management practices.

Water is used in many industrial activities, in producing such things as foodstuffs, metals, chemicals, and textiles. It is needed for cooling, for boiler feeds, for processing and for incorporation into end products. Both the volume of water needed and the quality criteria differ considerably from one industry to another. Large amounts of water are needed by thermal power plants. Today, in the industrialised countries, industry claims 40 to 80 per cent of total water withdrawals, while comparable figures for the developing countries are in order of two to five per cent; increased industrialisation in these countries will cause related water needs to grow substantially.

Hydroelectric power generation, is an entirely non-consumptive water use that does not pollute the water. It has been the main purpose of many large water projects undertaken in the developing world. Unfortunately, the benefits envisaged by the planners of these projects have not always materialised. 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 and radioactive substances, hydroelectric generation will most 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 will continue to be one of the important components of multipurpose water resources development schemes.

Recreational activities such as sailing, swimming and fishing also make demands on water resources. They demand a water quality such that public health risks are minimised. With increases in the standard of living, recreational water needs can be expected to grow substantially.

The various water uses discussed so far are sometimes difficult to satisfy, mostly during the low flow periods. But water resources management is equally concerned with combating the effects of excess water. 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 environmental costs involved.

Because of frequent loss of human life and the disruption of regional and national economies, large-scale flood control programmes will be continued in the years to come. The challenge is, however, to design and operate flood control systems in an ecologically sustainable fashion.

3.3 The importance of clean water

It is easy to get rid of waste by dumping it into a nearby water body. In large or small amounts, discharged intentionally or accidentally, it may be carried away but it will never completely disappear. It may reappear downstream, sometimes in a different form or in a different concentration. Rivers have a great ability to degrade some waste materials, but not in the quantities disposed of by today's society. The resulting pollution eventually puts the ecosystem under stress.

Sometimes nature itself can produce similar problems, like water flowing through highly saline areas or water originating from mineralised springs. But most often water resources, both surface and groundwater, are polluted by municipal, agricultural and industrial wastes. Some of the wastes are non-persistent (degradable) and they can be broken down by chemical reactions or by natural bacteria into simple, non-polluting substances. The process can lead, however, to low oxygen levels and to eutrophication. The situation is more complicated when many toxic chemicals are present which cannot be broken down by natural processes. These persistent (non-degradable) pollutants include substances that degrade very slowly and may remain in the aquatic environment for very long periods of time. The damage they cause is sometimes irreversible or reparable over decades or even centuries.

With today's increasing demands for high quality water, pollution leads to conflict among different water uses and incurs serious losses of social, economic and environmental values. Projections of future water demands make it clear that the increased re-use of existing water supplies will be essential to meet these demands. Re-use is possible because the majority of users return water to its source after use. To rely on such re-use, however, the water returned must be of a sufficiently high quality that its usability is not impaired.

It is clear that the problems surrounding a lack of clean water have reached a critical stage in many parts of the world. Involving the people who are the targets of water quality improvements is an absolute necessity if this unsatisfactory situation is to be turned around.

3.4 Water resources development measures

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

- 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 exert positive impacts (reduction of flood risk to downstream populations and economy) as well as adverse impacts (degradation of flood-based downstream economies and degradation of floodplain ecosystems);
- Open channels which may take the form of a canal, flume, tunnel or partly filled pipe. They are characterised by a free water surface, in contrast to pressure conduits which always flow full. Especially important in this category are interregional or interbasin transfer canals. In some cases, they are tens or even hundreds of kilometres long;
- Pressure conduits which often are less costly than canals or flumes because they can 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 less vulnerable to pollution than open channels;
- Diversion structures, ditches, pipes, checks, flow dividers and other engineering facilities necessary for the effective operation of water distribution systems (e.g. irrigation systems);
- Municipal and industrial water intakes, including water purification plants and transmission facilities;
- Sewerage and industrial wastewater treatment plants, including waste collection and ultimate disposal facilities;
- Hydroelectric power plants which are usually classified as storage, run-of-river and pumped-storage plants;
- River channel regulation and bank stabilisation works, navigation locks and other engineering facilities for improving a river for navigation.
- Levees and flood walls for confinement of the flow within a predetermined channel. They are most frequently used for flow mitigation.

Although this list highlights structural projects only, all plausible development measures should be considered - both structural and non-structural, water and 'non-water'. Even a study of infeasible options may yield valuable information, shedding light on the cost associated with existing impediments and indicating specific ways for their removal.

Non-water measures often form an integral part of what is commonly known as a development package; for example, land transportation in combination with navigation developments or combined thermal and hydroelectric power systems. Furthermore, non-structural measures are often available to accomplish the same objective. The best known example is flood protection, which can be achieved by floodplain management (allowing, among other things, for the preservation of natural ecosystems in the flood-prone areas).

4 Environmental Effects of Water and 'Non-Water' Projects

Generally, four types of environmental effects of water projects may be recognised. The first is disruption of human settlements and human activities. Occasionally such disruptions are very large. A second type is the creation of favourable habitats for parasitic and waterborne diseases, such as schistosomiasis, malaria, filariasis and liver fluke infections. This has been especially the case with several irrigation projects in humid tropics and arid regions. A third type of environmental disruption is physical or chemical. It generally results from the alteration of land use and changes in the surface or groundwater regime, usually as a consequence of flow control works such as storage reservoirs and flood levees. Finally, the fourth category concerns the impact on indigenous flora and fauna, including aquatic ecosystems, as discussed earlier in Section 2 of this paper.

It is clear from the foregoing that 'the environment' has a wide variety of meanings and that environmental disruptions can take many forms. We now look at land-water linkages, stressing the importance of watershed management, lack of which often leads to very serious degradation of water and related land resources. Against this background, the environmental consequences of storage and wetland developments are discussed, followed by consideration of the environmental consequences of 'non-water' or 'water-impacting' activities.

4.1 Land-water linkages: watershed management

Development of water and related land resources cannot be carried out effectively in isolation from each other. Watershed management is a process of formulating and implementing a course of action involving the water and the land of a watershed, taking into account related social, economic, environmental, and institutional factors, with special emphasis on the linkages between upstream and downstream parts of a watershed and their respective human and physical endowments (Easter *et al.*, 1985). An integrated approach to watershed management gives promise of including the often ignored land-water interactions in planning and implementing development projects. These interactions are of utmost importance as shown, for example, in several basins of Asia, where high levels of soil erosion in the upper watersheds not only reduce forest and agricultural productivity but also cause sedimentation and water pollution problems downstream.

The rationale for the watershed approach to water and related land resources management can be summarised as follows (Hufschmidt and Kindler, 1991):

- The watershed is a functional region that includes the key interrelationships and interdependencies of concern for water and land management.
- The watershed approach is suitable for evaluating the biophysical linkages of upstream and downstream activities.
- The watershed approach is holistic, enabling planners and managers to consider all relevant facets of resource development including on-site and off-site changes and impacts.
- There is a strong economic logic in the watershed approach since it internalises many of the externalities involved in both land and water management practice.
- The watershed approach allows for ready assessment of environmental impacts including the effects of water and land use activities on ecosystems, both upstream and downstream.
- The watershed approach to water resources management can be integrated with other programmes, including forestry, soil conservation, rural and community development, or farming systems.

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Watershed management has long been recognised as an integral part of river basin development, although few effective watershed management programs have been implemented so far. This was largely because many water projects dealt only with individual river sections, involving the construction of dams and reservoirs, power plants, and diversion facilities. Moreover, in many countries watershed management developed as a separate activity usually administered by ministries of forestry and/or agriculture.

4.2 Reservoir development

Reservoir development provides a good vehicle for discussing the environmental effects of water projects because of the widespread interest they arouse and the controversies they generate. The Narmada Valley Development Project in India, Czorsztyn Dam on the Dunajec River in Poland, Nam Choan Dam in Thailand, Three Gorges Dam on the Yangtze in China, Two Forks Dam on the South Platte in the USA, Kalabagh Dam on the Indus river in Pakistan, are only a few examples from a long list of reservoir development projects which caused serious and emotionally charged debates. But since the earliest days of civilisation man has built reservoirs to adjust the pattern of river flows to his various needs: to capture high flows to prevent floods and to store water for augmentation of natural low flows.

This section discusses the range and magnitude of the potential environmental effects generated by impounding a stream. It does not attempt to discuss the important social and economic values of non-environmental effects of storage reservoirs, such as municipal and industrial water supply, irrigation, recreation, hydro-power generation, navigation and flood control, assets which were reviewed briefly in Section 2. Historically, much emphasis has been placed upon these assets but in order to make a balanced evaluation of reservoir development, it is also necessary to appreciate environmental aspects.

The emphasis here is on the relatively direct, primary effects. It must be remembered, however, that reservoir development and use produce secondary effects which may have great environmental significance. For example, a hydro-power project may require land for long-distance power transmission lines which a fossil-fuelled power plant located at the centre of demand would not need. The transmission lines are a secondary environmental cost that has to be weighed against the environmental benefits of not building a coal-burning power plant and thus conserving non-renewable fossil fuels and curtailing air pollution.

The environmental consequences of reservoir development may ~~be seen in terms of ecological~~ processes such as effects within the impoundment, effects downstream, effects of altered flow, effects of changed land use, aesthetic effects and loss of wilderness (National Water Commission, 1973).

Although altering the pattern of river flows is a primary purpose of constructing a reservoir, water impoundment may lessen total flows downstream because of increased evaporation. More importantly, reservoirs always alter the regime of sediment deposition, both within the reservoir and downstream. Coastal and downstream channel erosion caused by reservoir development have been observed on several occasions (e.g. West African coast retreat caused by Ghana's Akosombo Dam). Since eventually all reservoirs fill with sediments, the opponents of storage reservoirs often claim that this fact alone negates the idea that large dams and reservoirs are compatible with the principles of sustainable water resources development; indeed, there are already several instances where major reservoir projects have had to be abandoned because of sediment build-up. It is certainly an open question whether the water resource community has learnt all that could be learnt from such unfortunate situations.

Regarding ecological processes, within the reservoir the natural stream ecosystem is replaced by a new lake-like one. This means a changed habitat for the local flora and fauna, terrestrial plants and animals replaced by aquatic species. It is important — although usually quite difficult — to predict which species will be eliminated and which species may succeed them. A further ecological effect may be increased primary productivity in a reservoir (the 'nutrient trap'), leading to eutrophication and stimulating the growth of algae, aquatic weeds, and bacteria.

Inundation produces serious effects within the impoundment. First of all a large population is often involuntarily displaced. The objections of the "oustees" often results from a tardy policy on population transfer. Historic, archaeological, and scenic sites may be flooded. Recreational opportunities are altered substantially and there may also be some environmental effects due to fluctuations in the water level of the reservoir.

One of the significant downstream effects may be the stoppage of the upstream migration of anadromous fish. Releases of cold water from the hypolimnion may have either a beneficial or a detrimental effect upon downstream fisheries. By the same token, releases from the epilimnion may be too warm for some species. The supersaturation of gases dissolved in water below high-head spillways and hydro-power installations has been noticed in some cases.

The possible loss of wildness associated with reservoir development is a serious consideration in many countries. In the United States, for example, the Wild and Scenic Rivers Act of 1968 established a system of wild and scenic rivers to be protected from development incompatible with their natural character. Many other countries have introduced similar legislation.

It is much less clear how to assess the aesthetic effects of reservoir development and to identify when these values are significant enough to be considered or even to outweigh other considerations. Although subjectivity will always play an important role in the assessment of aesthetic factors, they should at least be described as carefully as possible and discussed openly with all concerned.

Finally, some of the most serious environmental impacts may come from the changed land use pattern which the reservoir permits or encourages, although it should be acknowledged that these are rather second-order effects.

4.3 Degradation of wetlands

The Everglades, which are the largest freshwater marsh of North America, provide a good example of wetland degradation. A century ago, the region located in the state of Florida encompassed a 400 km long system of lakes, marshes and rivers. Its headwaters began in the swamps south of what is now Orlando and flowed into Lake Okeechobee at the centre of the system. During each summer's rainy season, the lake's water would spill over its southern rim and slide down towards Florida Bay. Although rarely deep enough to cover the protruding blades of sawgrass, the flowing water — the so-called River of Grass — would spread over an area about 100 km wide, drenching almost 8 million hectares of land.

Land speculators, politicians and farmers saw profit in these wetlands. The first effort to drain them began in the 1880s but the main push came after a hurricane in 1947 drove floodwaters over Lake Okeechobee's southern edge, drowning more than 2000 people. The United States Congress ordered the harnessing of the natural system. The Everglades was carved into sections by an intricate network of canals and levees, 2200 km in all. North of Lake Okeechobee the marsh was drained and changed into a prairie that became the state's main cattle and dairy-farming region. A large area south of the lake was designated for sugar-cane plantations. To provide water for farmers and city dwellers, three sections of the marsh were surrounded with dikes and set aside from development, each one a kind of captured remnant of the Everglades, but wholly for man's use. At the southern tip of the marsh, almost one-third of the original 8 million hectare expanse was left in a natural state as the Everglades National Park. But this area, too, was wholly dependent on engineers for its existence.

Typical ✓

By the time the network of canals and huge pumping stations was completed in the mid-1960s, the age-old cycle of wet and dry seasons had become irrelevant. The engineering marvel turned out to be a slow-motion natural disaster. Wading birds, the barometer of any marsh's health, have been devastated. Lake Okeechobee is full of nutrients, most of them traced to cow manure, and algae have all but suffocated it. The sawgrass, which serves as a vital part of the food chain, is being pushed back by cat-tails, a dense plant that thrives on the phosphate-rich water.

The alarm went out and environmentalists began to try to halt, if not reverse, the destruction of the remaining park. The challenge is to restore the flow of clean, fresh water and to recreate the seasons of wet and dry, flood and fire. Beginning this year the water flow into the park will try to mimic nature, but the main question as to who will pay for all the clean-up and restoration operations remains largely unanswered.

4.4 Water resources degradation by a 'non-water' project

A good example of adverse impacts upon water resources of a 'non-water' project is the Dutch 'manure mountain'. Due to intensive methods of livestock-keeping, farmers in the Netherlands have built up a 112 million strong herd of pigs, cows, hens and ducks, far outweighing the human population of 15 million and straining the ability of the natural environment to absorb the resulting manure. In the last 40 year period, the pig herd alone has jumped by 675 per cent to 14 million. The animals generate 80 million tonnes of manure a year, and out of this, 14 million is considered to be surplus because it cannot be spread safely on fields in the same province as it was produced without exceeding the government's manure disposal standards. Water pollution caused by ammonia and phosphate in the animals' excrement becomes a critical problem in the southern provinces of the country. The scale of the environmental damage threatens the survival of the Dutch livestock sector, an industry that generates annual sales in the order of US$ 6 billion.

To ward off involuntary cuts in animal herds, the Dutch agricultural community has joined with the industry to seek ways of disposing of the surplus manure. But most projects are still at the research and pilot stages. The Netherlands first priority now is to export the manure as fertiliser. But in the long term, Dutch companies are also hoping to export their know-how to Taiwan, the Po river basin in Italy and the Brittany region of France, all of which share the Netherlands' predicament of too many animals on too little land.

5 Integrated Analysis of Water Projects

Integrated water resources management is a set of actions that takes appropriate account of the important physical, economic, social and cultural linkages within the water resources system being managed. Examples are the physical linkages between land and water and surface water and groundwater, economic linkages between water uses such as irrigation and hydroelectric power production, and social linkages between water management and people who benefit or are adversely affected (Hufschmidt & Kindler, 1991).

Integrated water management requires, among other things, that water projects are analysed in a similar way. All relevant linkages should be identified but the level of sophistication brought to bear on the analysis should be adjusted, depending on the problem at hand, on the expertise available, financial constraints, time limits and the institutional arrangements. In general, six stages of analysis can be identified:

- Problem identification and formulation.
- Definition of project objectives and evaluation criteria.
- Formulation and screening of alternatives.
- Evaluation of alternatives.
- Implementation of the selected alternative.
- Monitoring and ex-post performance analysis.

5.1 Problem identification and formulation

There is a general agreement that the problem identification and formulation step is of critical importance for the entire process of water resources development and management. As stated by Quade (1980), problem formulation is concerned with such things as 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.

A wide range of different situations may be encountered at this stage. Problem formulation depends on the nature and scope of the problem, and its various technical, political, social and economic aspects. Furthermore, much depends on what the problem is perceived to be by the local population. It has to be recognised that sometimes low social awareness of problem consequences may decide on the primacy of 'development imperatives' over environmental needs.

It is extremely important at this early stage that any activity likely to have significant environmental effect is identified. Checklists, although they say little about the magnitude and the extent or the relative importance of environmental effects, are especially helpful at this stage of analysis. Many types of checklist are available and their use in application to water projects has been discussed, for example, by Biswas & Qu Geping(1987).

If the environmental effects are serious and formal Environmental Impact Assessment (EIA) is required, it is important to plan at this stage how to integrate EIA with cost-benefit and technical feasibility studies.

5.2 Objectives and evaluation criteria

An important step in the analysis is definition of the project objectives and translation of these objectives into evaluation criteria. The environmental objectives are just some of several others that must simultaneously be taken into account. In the USA, for example, *Principles and Standards for Planning Water and Related Land Resources* identifies four objectives to be promoted through project 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 optimised during the 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 politicians and economists and on the part of other participants in the project planning process, especially the environmentalists. In the past, water resources engineers who were responsible for the planning process often 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 rapidly changing.

An evaluation criterion is a rule used to measure the extent to which an objective has been achieved. In water project planning studies there is a natural tendency towards limiting the number of evaluation criteria, and the use of aggregated criteria has often be advocated (e.g. environmental quality index). However, the aggregation process should not be carried too far. Trying to merge too many non-commensurable entities into a single index is usually unproductive and misleading, especially as the aggregation process often calls for arbitrary value judgements. Instead of an index arrived at by a questionable weighting scheme, decision-makers usually prefer a set of explicitly stated evaluation criteria which describe in economic, physical, chemical and biological terms the environmental consequences of a given project (Miser & Quade, 1985).

The sustainability criterion is of particular importance in large scale broad policy decisions. This says that water resources decisions that impoverish future generations in order to enrich current generations are patently unfair. This criterion is already being used in toxic-substance control policy in the USA, where waste dischargers are required to post a bond to cover any financial liabilities that could arise in the future. The costs of posting a bond are born by current users and should prevent shifting the burden to future generations. Other more imaginative options, such as spending more money on research and development, or on education, are also possible (Tietenberg, 1988).

5.3 Formulation and screening of alternatives

In the case of integrated analysis of water projects the proper course of action may not be easy to identify without a 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 uncomplicated and perhaps small projects, this, however, is an exception rather than the rule. Any reasonable-sized water project will invariably have a series of subproblems, each of which is likely to have a series of alternative solutions.

In short, the problem at hand can usually be solved in a variety of ways, and the full range of choices must be explored. The socio-cultural factors are of special importance in the process of formulating alternatives. There are many examples of water projects that have failed because the attitudes and habits of the user community were ignored.

For environmentally-sound planning and design of water projects, special care needs to be taken to ensure that resource development alternatives do not foreclose other options. It should also be recognised that technological progress generally increases the margins of substitution in the use of water, especially in industry and manufacturing, whereas it is generally incapable of augmenting the supply of environmental resources.

5.4 Evaluation of alternatives

After the project alternatives have been reduced in number through the screening process to a few select ones, it is necessary to use the criteria discussed earlier for integrated evaluation of their economic, social and environmental impacts. Current methods for environmental impact assessment are based on the use of matrices, flow diagrams or simulation models.

Most matrix methods are designed to ensure that all potential interactions and impacts are considered, with some indication of their relative importance. One of the best known is the Leopold Matrix (Leopold *et al.*, 1971), which consists of a horizontal list of developmental activities ranged against a vertical list of environmental criteria. Within each cell, the magnitude and importance of each possible impact are ranked on a scale of 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. A major criticism of all these methods 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 address explicitly the dynamics of systems subject to analysis. Many of the ecosystem simulation models developed during the last two decades are mathematically sophisticated and they contain provisions for non-linear relationships. They are useful in conferring a better understanding of ecosystem structure and dynamics, but they do not readily lend themselves to answering specific resource management questions. Their use in the planning and operation of water projects has been rare and steps should be taken to develop a closer tie between ecosystem and water resource system modellers.

Simulation x Optimization

There are several simulation models which concentrate on hydrological and 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 consequences of land use changes. Another example is the water quality model WODA which allows the computation of BOD and DO concentrations in a river stretch under different hydrological and thermal conditions (Kraszewski & Soncini-Sessa, 1986). One of the advantages of the WODA package is an interactive simulation routine that can be of assistance in evaluating the impact of alternative planning or management options. Several groundwater models capable of simulating the transport and dispersion of contaminants in aquifers have also been developed.

It must be remembered, however, that the use of simulation models should never give an impression that all is known and that all impacts can be predicted with adequate reliability. Our knowledge of natural and social processes and relevant cause-effect relationships is still limited: there is always considerable uncertainty associated with impacts evaluated by simulation models.

The choice of the 'best' project alternative when several evaluation criteria must be considered 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 & Freedman, 1975; Cohon, 1978; Chankong & Haimes, 1983, and others). While the growth in theoretical and empirical studies has been phenomenal, there are few water studies that have utilised multicriteria methods throughout the entire course of project planning. Although the complexities and constraints faced by the analysts in applying multicriteria methods should not be underestimated, they provide a viable framework for analysis for environmentally-sound water resource planning and management.

5.5 Implementation of the selected alternative

One of the pervasive major weaknesses of water resources management in many countries has been ineffective implementation of projects plans and programmes (Hufschmidt & Kindler, 1991). Failures in implementation are revealed in the construction or installation stage by delays in project completion and cost overruns, and in the operation and maintenance stage by shortfalls in planned outputs, such as irrigated agricultural production, hydroelectric energy production or sedimentation reduction. Other failures arise, for example, in the relocation of people displaced from reservoir areas.

Some major causes of implementation failures are (1) inadequate attention to implementation constraints at the planning stage (e.g. adoption of inappropriate capital intensive and sophisticated systems that are difficult to operate and maintain); (2) inadequate financial allocations; (3) lack of involvement of local communities with the consequent lack of feedback from project users and beneficiaries.

5.6 Monitoring and ex-post performance analysis

While there is still only a limited amount of literature on monitoring and ex-post evaluation of water projects, such techniques have to be seen as an integral part of project analysis. They are aimed at determining the extent to which the objectives of the project or a policy are being achieved. Such analysis may, for example, ascertain how much water from an irrigation project is actually used, what are the originally unanticipated responses of project users, or what is the impact of the project on the downstream floodplain. Such a performance analysis is indispensable for assessing the effectiveness of the project or policy initiatives and it may prevent mistakes in the future.

Unfortunately, there tends to be a reluctance to examine past experience, simply because of a fear that objectives have not been attained or that unanticipated effects have appeared. While such reluctance is understandable, especially when analysts may share some of the responsibility for the past decisions, the future is better served by a system that creates positive incentives for the pursuit of this kind of feedback. A cost-effective monitoring, evaluation, and feedback system is crucial for the identification of project deficiencies and for the development of necessary corrective measures.

6 Striking the Balance

Striking a balance between environmental and developmental dimensions of water resources management is a complex task. There are, however, some issues of special importance for its accomplishment.

6.1 Institutional arrangements

All over the world, water resources management takes place in complex planning and policy settings. Indeed, the tasks of water resources planning and management are most often divided among many national, provincial and local agencies, such as ministries of agriculture (for irrigation), energy (for hydroelectric power), public works (for water supply, water quality and flood control) and forestry (for watershed management). Sometimes there are national or provincial coordinating commissions or councils, but the basic institutional pattern is diffuse (Hufschmidt & Kindler, 1991).

As pointed out by the former Secretary of Irrigation in India (Padhye, 1987), most of the existing institutions do not function effectively. If they function effectively, their recommendations are ignored or not read. If they are read, they are not acted upon. If acted upon, usually when it is already too late.

There are two principal trends in the institutional arrangements for water resources management, although they never appear in their pure form (O'Riordan, 1985). One is towards centralisation in an attempt to internalise the effects of decisions. The establishment of national authorities responsible for managing both water quantity and water quality typifies this approach. In such cases, however, public involvement and inputs originating from local initiatives tend to be reduced. Moreover, the information barrier typical for all large, centralised institutions adversely affects the overall quality of the decision-making process. Indeed, centralised water authorities are usually well informed about structural supply augmentation alternatives such as storage reservoirs, interbasin transfers, etc. but have much less information about water conservation options available to individual water users and their related costs. This deflects the attention of central authorities away from the demand management alternatives which are usually less disruptive environmentally than the large-scale supply augmentation schemes.

Many water resource and environmental problems are caused by a divergence between individual and collective (societal) incentives and in the past it was quite common to hear that centrally planned economies avoided these problems. The argument suggested that centralised decision making allowed collective decisions to be made right at the outset. The experience of the centrally planned economies shows, however, that this expectation was completely false. The central plans which set the priorities and production goals to be followed by the state-owned enterprises simply emphasised production over the environment and efficient resource use.

A second trend is towards decentralisation, but this example needs some instruments to influence and coordinate the actions of each and every independent water user. The principal objective is to achieve an efficient allocation of water resources among competing users. To be efficient, the allocation must (a) strike a balance among all competing users, and (b) handle the year-to-year variability of water resources (in some years there is less water to be allocated than in others).

With respect to the first requirement, the efficiency criteria are quite clear — water should be allocated so that the marginal net benefit is equalised for all users. Concerning the second, water users who can most easily find substitutes or conserve water should receive proportionately smaller allocations when supplies are diminished so that those who have few alternatives receive proportionately more.

The practical implementation of these rules is difficult. The transfer of water amongst various users is restricted, preventing its gravitation to the highest valued use. Moreover, the level of water prices and the rate structure most often preclude efficiency of use (the same applies to effluent charges). For groundwater, 'common property' problems arise. All these deficiencies combine to discourage conservation of water to the detriment of potential future users (i.e. non-sustainable resource use).

As pointed out by Tietenberg (1988), reforms are possible and badly needed: "Allowing conservers to capture the value of water saved by selling it would stimulate conservation. Creating separate fishing rights that can be sold would provide some incentive to protect streams as fish habitats. Pricing systems can be changed to better reflect costs". To the extent that more fundamental change is politically possible, a set of transferable water use and pollution rights can be instituted to increase efficiency in the use of water and its protection against contamination.

But centralisation and market-controlled decentralisation should not be seen as two mutually exclusive options. The most efficient water management schemes, such as those developed in the UK, Germany or France, feature strong national and/or regional water authorities combined with innovative systems of regulation and economic incentives.

It is important that institutional arrangements are capable of motivating all parties involved in water management decisions towards their effective implementation. There are situations where administrative structure seems to be ideal, laws and rules look perfect, but things do not work as expected. This is often caused by the lack of adequate motivating mechanisms. This difficulty has been most evident where water authorities have relied chiefly upon regulatory process to achieve policy objectives.

To summarise, it is important that institutions charged with water resources planning and management should not be too narrowly concerned with only the physical aspects of water resources protection and control. They should be sensitive to social preferences, ecological objectives, human desires and aspirations as well as to local management abilities. Decision makers must also be accountable to those who are affected by their decisions. River basins should be seen in the context of coherent hydrological units relevant to water resources planning and management.

6.2 Demand management

Rapidly increasing population coupled with economic growth will place increasing pressure in the future on the supply of fresh water. But most of the cost-effective reservoir sites have already been developed and new supply capacity development is extremely costly, and may often have adverse effects on the natural environment. Groundwater is increasingly subject to contamination from municipal, industrial and agricultural sources and new resources are costly to exploit because of high pumping costs.

All of the above trends point to the need for major changes in the approach to water resources management if the challenges of the future are to be met. One of the fundamental changes required is a shift from preoccupation with development of water resources by major construction programmes toward a more balanced approach which emphasises more efficient use of available supplies, water conservation and demand management. This approach does not rule out the continued development of water resources in those parts of the world where it is socially justified, environmentally sound, and cost effective.

A persistent trend in water resources planning has been to project future water uses under a continuation of present policies, leading to extremely high estimates of future water requirements. There are, however, only few water 'requirements', such as relatively small amounts for drinking, cleaning, fire fighting and some other non-substitutable social and environmental purposes. Generally, there are rather 'demands' for water and water-related services that are affected by a host of different factors and policy decisions, some in areas far removed from what is generally considered to be water policy.

6.3 Conservation and pollution control measures

Satisfaction of future water demands is to a large extent the problem of rational resource management. There is lots of scope for rationalisation of water use in virtually every sector of the economy. Present efficiency of irrigation systems is prodigiously low and there is also much room for water conservation in industry and municipalities. There is a vast under-utilised potential for stepping up agricultural and industrial production, primarily through more efficient utilisation of existing water management infrastructures. Conservation of living natural resources requires the same kind of control measures.

Historically, policies for controlling water pollution have been based mostly upon subsidy of municipal waste treatment plants and legislating ambient water quality standards set by national or regional water authorities. More recently, several countries have introduced effluent standards for industrial sources but the control of non-point pollution is still in its infancy worldwide.

Future pollution control policies should go far beyond direct regulation. Marketable emission permits, emission charges and other economic incentives are more flexible and should be applied as part of the comprehensive control strategies designed with the characteristics of each of the multiple sources of water pollution taken into account.

6.4 The problems of developing countries in arid and humid tropical zones

In arid, humid tropical, and mountainous areas information is often too scarce to predict ecosystem responses to water projects with the required accuracy. Moreover, potential conflicts between development and preservation of environmental quality are often particularly difficult to solve.

The problem can be illustrated by the case of India (Padhye, 1987). Every development project in this country is being examined for its impact on the environment, which is now mandatory following the 1986 Environment Protection Act. In the recent past, however, large water resources projects have come in for considerable criticism on the charge that they have contributed largely to the destruction of the environment, the ecology and the habitat of particular areas.

Environmental objections are directed mostly against large irrigation and hydro-power projects; drinking water supply projects, even large ones, rarely come under such criticism. Nevertheless, India will need 200-300 million tonnes of food grains alone to feed 1000 million population by the year 2000 and by 2050 the population is expected to increase to about 1500 million with grain requirements in the range of 400-450 million tonnes.

This all happens in a country where about one-third of its area is drought-prone and about one-eighths flood-prone. The monsoon season lasts for barely 90 days and is erratic in time and space. To afford protection against floods and to make water available to drought regions, large reservoirs have to be built in hilly areas where rainfall is abundant. Stored water has to be transported through long-distance canals to serve drought prone areas.

Numerous instances of such large projects may be cited, such as the Hirakud Reservoir, Govind Sagar, Thein Dam or Mettur Dam. All of them have contributed significantly to India's achievement of self-sufficiency in food production. However, to put existing achievements in perspective, it should be noted that it is planned to provide about 40 per cent of the cultivable area with irrigation facilities, that is 50 per cent of the double cropping area; the rest will remain as rain-fed agriculture.

The implications for water resources management are that local or regional water resources plans and programmes need to be closely tied to the local, regional and national plans and programmes for other sectors. Multiple objectives and multiple purposes, including both developmental and the environmental aspects, are typical in such a complex management setting.

6.5 The role of research

Research plays an important role in striking a balance between development and preservation of natural life-support systems.

Among others, the current phase of the International Hydrological Programme of UNESCO (IHP) and Operational Hydrology Programme of the World Meteorological Organisation (WMO) are expected to yield important research results for sustainable water resources development and management. Here, close collaboration with the Man and Biosphere Programme (MAB) of UNESCO is of particular importance. Within the framework of these programmes, a general critique of water resources development projects by environmental groups needs to be addressed (e.g. Goldsmith & Hildyard, 1984). This critique, although sometimes not entirely objective, should call the attention of the water research community to specific problems and the deficiencies in some water projects and programmes.

Regarding sustainability of growth, it should be recognised that the compensation to be paid to future generations does not necessarily have to be monetary: among other options it could also be in the form of spending more on research oriented towards better use of water and its conservation.

7 Concluding Remarks

In the last decade of the 20th century, mankind finds itself at a critical point and with very little time — years, not generations — in which it must restore degraded ecosystems and bring water resources to such a state that they can maintain themselves naturally. Water resources planners and managers must now think in terms of sustainable development: using and managing water resources, the natural environment and entire landscapes in such a way as to maintain a strong economy and preserve the natural environment today and in the years to come.

This paper has emphasised the need to appreciate fully the interrelationship between water resources development and environment. It has argued that the quality of the natural environment should be protected and, when possible, enhanced by water resources development.

The fundamental question must always be asked as to what are the overall long-term impacts of water resources development on the biosphere. There are no easy answers to this question, especially since the scale of human activities has increased substantially and many environmental problems take a long time to unfold. Thus, 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 made as to the benefits from risk reduction. Decision criteria must extend beyond engineering and economics.

Everyone must play their part — government, industry, agriculture, interest groups, individuals — at home, at school, at the work place, while working, while playing, while travelling. It is time for people to re-examine their values, and make thoughtful although sometimes difficult choices, and adjust their lifestyles to give more consideration to the environment. This includes changing their water use habits in ways that will help the resource sustain itself and maintain its quality.

It is important for each one of us to act — not only for ourselves and our children, but for future generations and for the other living things sharing the earth with us.

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3

Water for the people — community water supply and sanitation

Aminata Traoré (Mali)

EXECUTIVE SUMMARY

1 Against the backdrop of the economic crisis of the 1980s the International Drinking Water Supply and Sanitation Decade (IDWSSD) has not only been unable to achieve its, admittedly ambitious, goals, but is has also seen its original target lose its well-defined focus on the improvement of the human health situation.

2 Currently, there is a renewed awareness that human health problems associated with the lack of safe drinking water supply and inadequate sanitation can only be successfully combatted in integrated, essentially community-based control efforts, that are geared to local conditions and needs, and in which the provision of drinking water supplies and sanitation is a crucial component.

3 As sources of good quality drinking water diminish at an alarming rate, there is an urgent need to protect the still usable sources from degradation and to discover new underground resources. Where water quality has dropped below acceptable levels, water treatment will be needed, and in rural areas this can only be done on a sustainable basis if existing appropriate technology is used and new technologies are developed.

4 The formulation and application of sound cost recovery and cost containment policies and practices in the drinking water sector will need to be stepped up in the face of increasing scarcity of good quality drinking water, if the sector is to expand or even maintain its present level of coverage.

5 New legislation should not only form the firm basis for successful cost recovery and cost containment programmes, but it should also regulate the allocation of water resources to the various interested sectors: drinking water supply, agriculture and industry.

6 The *de facto* involvement of many rural communities and especially of rural women in water supply and sanitation activities should convince governments and External Support Agencies alike of the need to review and, where necessary, revise their policies and programmes in the sector.

7 Operation and Maintenance (O&M) of existing irrigation schemes is probably the most crucial determinant of a WSS system's sustainability; in the coming years, this area will require substantial support for rehabilitation projects as well as more realistic *ex ante* assessments of the O&M implications of new WSS projects.

8 New and more effective mechanisms for intersectoral collaboration between the water supply and agriculture sectors will need to be developed and implemented to ensure the optimal use of scarce water resources. Collaboration is particularly desirable in water quality monitoring and national Geographical Information Systems should be set up with databases provided by the various sectors involved.

CONTENTS

1 Community Water Supply and Sanitation in the Context of Sustainable Development

1.1 Introduction

The global environmental concerns, which have their roots in the pioneer green movements of the 1960s, and the development crisis of the 1980s found their synthesis in the report of the World Commission on Environment and Development, *Our Common Future* (WCED, 1987). For the first time the causative links between development approaches that are not sustainable on the long term and a deteriorating environment in both industrialised and developing countries were demonstrated in a comprehensive way.

Water is a recurring topic in the WCED report, as one would expect, considering that life on earth is essentially based on water. The importance of water in human life is pervasive: it is as necessary as food and needed more regularly than food for survival; it has a role in cooking, food preparation and personal cleanliness only a little less crucial than survival. Water resources are in many places a determinant of and often a limiting factor in food production, whether of crops or livestock. As a resource, good quality water is becoming increasingly scarce. The public sectors dealing with this common good are therefore forced to review and update their position vis-à-vis water use and join hands for its optimal use in a coordinated and sustainable manner in the years to come. The use of available water resources for the present five billion plus world population should not be at the expense of future generations.

Community water supply and sanitation is, traditionally, a cornerstone of community health. The promotion of safe drinking water and sanitation, especially out in the rural areas of the developing world, is in transition from its earlier emphasis on the expansion of service coverage to a broader role involving water resources management, environmental protection and human health.

The International Drinking Water Supply and Sanitation Decade (IDWSSD), conceived at the United Nations Water Conference at Mar del Plata in 1977 and launched with great hopes and expectations by the United Nations General Assembly in November 1980, was a global symbol of concerns and responsibilities of the development community for this traditional emphasis. The Decade served both as a rallying point for action and as a constant reminder of the inadequacies of the development community in meeting the water and sanitation needs of all people. Because its goals — safe water and sanitation for all — far exceeded its limited responses, many of the needs and problems faced at the start of the Decade still continue today.

First and foremost of those needs is an improvement in the deplorable state of environmental health in many of the poorer countries of the world. Facilities that provide safe and potable water supplies and give people protection from the pathogenic organisms found in human excreta and other solid and liquid wastes are the primary elements in improving the situation. Health parameters (child and infant mortality, life expectancy, specific causes of morbidity and mortality) are significant indicators of overall development, and the provision of safe drinking water and adequate sanitation is arguably the most important single contributor to a population's improved health status.

It should not be forgotten that the basic purpose of the Water Decade was, indeed, to provide these elements - safe water and sanitary disposal of wastes - because of health needs. Other objectives, including time savings, household convenience, and an improvement in the status of women, have been used to justify the Decade, but the fundamental rationale for mobilising a worldwide effort to expand water and sanitation coverage was, and still continues to be, to improve human health, and, as a consequence, socio-economic development.

In the 1970s it was clear that the magnitude and importance of the water and sanitation needs could not be adequately met with general development programmes. In the early part of that decade, it was estimated that only one out of three persons in the developing world had adequate access to potable water supplies and sanitary excreta disposal. The situation was particularly acute in rural areas, where it was not uncommon to find less than ten percent of the population served with acceptable water and sanitation facilities. The health impact of these inadequate services has never been fully established, but WHO now estimates that diarrhoea, for example, at that time killed six million children each year and that parasitic worms infected nearly one-half of the entire population of the developing countries. To those who worked in water and sanitation at the time it was clear, even without good health statistics, that urgent action was needed!

What developed was a radical departure from the past and should be seen in the light of the Basic Needs philosophy, which dominated development thinking at that time.

In 1977, the World Health Assembly called upon the governments of the world to set, as their main social target, the attainment of a level of health that would permit all people to lead a socially and economically productive life by the year 2000. The following year, at the International Conference on Primary Health Care at Alma Ata, representatives of governments around the world stated that primary health care, which includes the adequate supply of safe water and basic sanitation, is the key to attaining health for all. These two concepts, Primary Health Care and Health For All by the year 2000, became the intellectual underpinning of the 1980s.

By the time the United Nations General Assembly formally launched the IDWSSD in November 1980, there was widespread agreement that the improvement of health was the goal of the overall effort. Thus, the idea of the Decade was accepted, not because people lacked water and sanitation facilities, but because many people were ill. It was not until after 1980, when the grim realities of limited resources became evident, that Decade justifications other than health were advanced.

An interesting parallel can be drawn between the perceptions of the Decade's health objectives and the health dimension of the present wave of intensified interest in environmental matters. In the early 1980s health objectives apparently did not suffice to create an adequate funding base. Presently, global issues such as ozone layer depletion, the greenhouse effect and the reduction of biodiversity, and also the deterioration of fresh water resources, are mostly considered from a conservationist viewpoint, with a very low profile for human health aspects. When Mrs Brundtland, chairman of the WCED, was asked why health was not discussed as one of the major challenges in *Our Common Future*, her reply was that ultimately the entire WCED report was about health.

It may be concluded from the above experiences that, while everybody agrees that health protection and promotion is a noble cause, it will need to be emphasised explicitly and emphatically and presented as a cross-cutting issue that transcends traditional sectoral boundaries if financial support for it is to be mobilised.

It should be clear that much has been done by the world community during the IDWSSD in attempting to deal with problems that have plagued mankind since time immemorial. We should not be overly discouraged by our inability to solve them in only a few years. The Decade has taken place during an extraordinary period of economic and political difficulties. Indeed, many people now refer to the 1980s as the "lost decade" because of the effect of these difficulties on overall global development. The 1990s, on the other hand, could become the "decade of opportunity" if current trends in arms reduction and democratisation continue. The question that faces the development community now is what are the lessons to be learned from the Decade experience and how can they be applied in the present climate of a rapidly changing global political landscape and the increasingly important environmental issues?

1.2 The health dimension of water supply and sanitation

Given its ubiquity, it is not remarkable that water can act as a conduit of disease and that many pathogens are transmitted, either facultatively or of necessity, by water, or are otherwise dependent on it for their survival. This results in a varied and often complex relationship between water, as a commodity or a habitat, and human health.

The classification of water associated diseases proposed by Feachem *et al.* (1977) is still valid today. It uses their relationship to water as the main distinctive criterion.

1 Water-borne diseases

This is the first of the four categories. Water-borne diseases are caused by organisms that can survive in water and be ingested when contaminated water is drunk. They are therefore the classical diseases associated with the lack of safe domestic water supplies — typhoid, cholera — and which are of great concern to those responsible for piped water supplies in human settlements, since contaminated water could reach many people simultaneously and lead to an explosive common source epidemic.

2 Water-washed diseases

More recently, it has been increasingly realised that other infections, some diarrhoeal diseases and contagious skin and eye infections, are prevalent where the scarcity of accessible water supplies make washing and personal cleanliness difficult and infrequent. These can conveniently be called water-washed diseases since they diminish once an adequate supply of water for washing is made available and used.

3 Water-based diseases

A number of parasitic helminths (worms) pass part of their life cycle in intermediate host organisms that live in fresh water. Guinea worm is one example: its adults live under the human skin in the limbs and cause a disabling arthritis. The female creates a blister on the skin, which bursts when wet and releases myriads of small larvae which further develop inside small water crustaceans called Cyclops. People get infected by drinking water containing infected Cyclops.

Most water-based diseases are, however, due to trematodes or flukes which have developmental stages in aquatic snails. The eggs of these parasitic worms leave the human body in urine, faeces or sputum, hatch in water and the first larval stage penetrates the appropriate snail species. Inside, they undergo development for several weeks. Many more larvae of a second stage are then released daily from the infected snails and find their way back to man either by boring through the wet skin (schistosomiasis), or by infecting crustaceans or fish which may be eaten inadequately cooked (other liver flukes causing opisthorchiasis and clonorchiasis, and lung flukes causing paragonimiasis).

4 Water-associated vector-borne diseases

The fourth way in which water may affect communicable diseases is by providing a habitat for insect vectors of disease. Mosquitoes need water for part of their life cycle: eggs are laid in it, and larvae and pupae are aquatic life forms. The adult mosquitoes that emerge may transmit malaria, filariasis and a number of arboviral diseases such as yellow fever, dengue fever and Japanese encephalitis. Different mosquitoes vary in their preference for different water bodies, but are usually very specific in their requirements.

Bradley (1991) recently distinguished a fifth group, which he calls water-dispersed diseases. These diseases are emerging as an important public health problem in the developed countries. The causative agents may proliferate in fresh waters and enter the human body through the nose and nasal passages. Some freshwater amoebae, usually not pathogenic, can proliferate in warm water and if they enter the nose in large numbers may cause a fatal meningitis. Bacteria of the genus Legionella have demonstrated a capacity to grow in the water of complex air conditioning systems from where they may be dispersed as aerosols to infect substantial numbers of people through the respiratory tracts.

The traditional four groups all contain diseases whose incidence can be prevented or minimised by the introduction of safe water supply and adequate sanitation facilities, or by an effective intersectoral planning of water resources development for drinking water purposes.

From an environmental health standpoint, the end of the Decade finds 1200 million people without safe water supply and almost 1800 million people without adequate sanitation (WHO, 1990). While these statistics are shocking in themselves, they mask a large number of equally shocking health conditions. There are many ways in which unsatisfactory water and sanitation conditions can result in poor health.

From the above categories, three diseases or disease groups stand out because of their strong linkage to water supply and sanitation: the classical water-borne diseases include cholera and typhoid fever, as well as infectious hepatitis and shigellosis. More common, and in the long run more deadly, are the diarrhoeal diseases due to poor hygiene and faecal-oral transmission. Of the water-associated parasitic diseases schistosomiasis and dracunculiasis are the most important. The infrastructure for water supply (reservoirs) may have an impact on malaria prevalence and that for sanitation (pit latrines, sewage drains) filariasis. And now, one must include a fourth major category; illnesses resulting from the nitrates, heavy metals, and pesticides that constitute the noxious side products of the industrialised societies and, unfortunately, too often the pollutants of drinking water sources.

What challenges do water-related diseases pose to the world in the 1990s? It is estimated that diarrhoea currently causes between four and five million deaths annually in children under the age of five years in the developing countries. In the first two years of life as many as 15 of every 1000 children will die from diarrhoea (WHO, 1989). Recent studies indicate that water and sanitation improvements can reduce the overall incidence of infant and child diarrhoea by one-quarter and, more importantly, total infant and child mortality by more than one-half (Esry *et al.*, 1990). The message that water and sanitation is an effective intervention is beginning to affect diarrhoeal disease control programmes around the world. Increasingly, country programmes are shifting their emphasis to the prevention of these diseases with improved water supply and sanitation as an essential component of primary health care.

People contract dracunculiasis, or Guinea worm disease, by drinking water which contains the minute crustacean, Cyclops, infected with Guinea worm larvae. Approximately 10 million people are infected by the disease each year and over 100 million more are at risk of infection in some 21 countries of Asia and Africa (WHO, 1990). Since the disease is transmitted only by drinking contaminated water, it can be eradicated through the provision of safe drinking water. Indeed, over the past century, improvements in general sanitary conditions have eliminated the disease from most areas in Asia, the Middle East, and large portions of Africa. Current control programmes in a number of countries, especially Ghana, India, Nigeria and Pakistan, show very promising results.

A third debilitating disease related to water supply and sanitation is schistosomiasis. It is found in 76 countries, where it infects some 200 million people and places another 400 million at risk of infection (Doumenge *et al.*, 1987).

Although schistosomiasis has been known for thousands of years, expansion of irrigation systems and water resources developments in modern times has led to an explosion of the disease to many new areas. Schistosomiasis is not normally contracted through drinking water, but the provision of adequate supplies of uncontaminated water and safe excreta disposal can break the main transmission routes of infection. Studies of improved water supplies with related facilities, such as showers, show that reductions of 60 percent or more can be achieved in schistosomiasis prevalence rates. When such interventions are coupled with the introduction of latrines, hygiene education programmes, environmental management for snail control and selected drug therapy, the prevalence reductions can be even greater.

1.3 A first look to the future

The lessons learned from the IDWSSD efforts will have to be applied in the new policy framework constructed around the concept of sustainable development.

Freshwater supplies available for human use constitute a limited natural resource which may be renewable in principle, but which can only be exploited in a sustainable manner within the boundaries set by the global hydrological cycle. In many countries, the provision of domestic water supplies of acceptable quality and quantity is often constrained by the competitive and usually much greater stress on water resources, both in terms of quantities withdrawn and of contamination, exerted by the agriculture and industry. Because this type of conflict is bound to become a major issue in an increasing number of countries as per capita and total demands for domestic water supplies expand, water resources planning and management will need to be addressed in a much more integrated manner than is currently the case.

In the following sections several aspects of 'Water for the People' will be considered in the light of the above: water quality issues, financial and institutional aspects, the role of governments and of the community and the place of sanitation in overall environmental management.

2 Achievements and Constraints of the IDWSSD with Respect to Drinking Water Supply and Sanitation in Rural Areas

Improvement of the quality of life of rural populations of the world's developing countries was the major focus of the drinking water sector's strategies during the International Drinking Water Supply and Sanitation Decade.

The reason for this priority for the rural areas is clear when levels of service coverage are examined. In 1980 globally only 29 per cent of the rural population of the developing countries were estimated to have access to an adequate and safe water supply compared to 77 per cent of the urban populations. The corresponding values for sanitation were 35 per cent rural people with access to a system compared to 66 per cent urban people.

The reduction of the disparity of levels of service between the rural and urban population of the world's developing countries was a stated objective of the Decade.

Although globally representative, these figures mask the fact that in a large number of the developing countries the disparity was (and often still is) much greater, particularly in the least developed countries and in drought ridden areas of Africa south of the Sahara where the plight of the rural people is often extreme.

Regionally, water supply was provided to the smallest proportion of the rural poor in the countries of Western Asia, with only 22 per cent of service coverage, and in Africa South of the Sahara where only an estimated 23 per cent of the rural populations had access to water supply services. This latter figure is significantly lower than the value of 30 per cent for Africa as a whole.

The lowest level of rural sanitation coverage in 1980 was reported from southeast Asia, and in the eastern Mediterranean region only nine per cent of the population was estimated to be served.

In absolute terms this meant that in 1980 globally some 1650 million rural people were without access to an adequate and safe water supply and a total of 1470 million rural people were without access to good sanitation.

In the course of the IDWSSD the special efforts made to improve conditions are clearly demonstrated by the acceleration of rural water supply and sanitation programmes and the expansion of service coverage. This was particularly notable in South Asia, where India, the most populous country, specifically oriented its sector programme in that direction. In East Asia initially more people were without water supply than without sanitation, because of the high levels of sanitation coverage in China.

Overall 60 per cent more rural people were provided with water supply during the 1980s than during the 1970s, while 140 per cent more were given access to appropriate sanitation.

Problems encountered in implementing programmes to achieve Decade goals expressed in term of constraints identified by governments include the lack of sufficient funding, inadequate cost recovery to ensure sector sustainability, not enough trained manpower, poor operation and maintenance of systems, and lack of community involvement. In addition, improper utilisation of systems resulting from lack of awareness of the health consequences of unhygienic services has often led to a less than satisfactory level of health benefits achieved after commissioning of a system. The lack of appreciation of the health rationale behind safe and adequate water supply and sanitation has in many instances prevented these services from being identified as a perceived need and hence a priority for development. In some countries there is an increasing interest in formulating policies that will prioritise areas and regions for water supply extension based on specific health parameters. The Government of Nigeria, for instance, has a policy to develop water supply systems in those part of the country where Guinea worm infection is most predominant as a public health problem.

An underlying constraint to the development of services in rural areas has been the diversity of agencies responsible, or in many cases the lack of any agency or ministry having specific responsibility for the sector. This tends to be more of a problem in the case of rural sanitation which is frequently seen as an individual community or household responsibility. To overcome this difficulty some countries have developed national rural water supply and sanitation programmes with established targets.

Since diarrhoeal diseases wreak their greatest havoc in terms of infant morbidity and mortality in the rural areas of developing countries, this is the most vulnerable group whose health status and life expectancy can best be affected by improvements in service.

Other vulnerable groups are women and young girls who bear the brunt of water drawing and carrying in developing countries. They are exposed to contaminated water through contact during collection, particularly in the case of parasitic diseases such as schistosomiasis. In addition, they are exposed to the risks of accidents, and pregnancy/post-natal complications through the carrying of heavy loads and may also develop, over the long term, deformities of the skeleton.

Seasonal agricultural workers are another risk group since they are usually amongst the poorest of rural society, often living in temporary accommodation erected close to their work, cotton fields or other harvest areas, without services and hence take water from the nearest water source, such as an irrigation or drainage canal which also receives their wastes.

At the start of the 1990s, thanks to the efforts made during the decade, the proportion of the rural population with access to an adequate and safe water supply has increased significantly and as a result the number of people unserved has dropped by 700 million to 960 million. Much of this achievement can, however, be accounted for by the major programmes having been implemented in China and India, two countries with a major part of the world's rural population. In many of the developing countries less significant progress has been made and conditions are still unsatisfactory with levels of coverage under 20 per cent being not uncommon.

In the case of rural sanitation the efforts of the 1980s have made little apparent impact on reducing the number of people in rural areas without access to an appropriate means of sanitation, which remains at around 1400 million.

3 Trends and Projections

At the end of 1990 it is estimated that there were still over 1000 million people in the world's developing countries without access to an adequate and safe water supply, and around 1750 million without access to an appropriate means of sanitation. This is despite an estimated over 1500 million who have been provided with water during the 1980s and 750 million having been provided with access to sanitation.

The difficulty in closing the gap during the 1980s between served and unserved was due to the population increase, which amounted to around 750 million. This is a challenge also to be faced during the 1990s when the population increase is expected to be almost 900 million.

Those unserved by water supply and sanitation are the group most at risk and suffering greatest from morbidity and mortality in developing countries. Any action taken to reduce the numbers unserved, and hence reduce the number at greatest risk, will impact favourably on this situation.

4 Water Quality Issues

In the remainder of this century water quality issues will become increasingly important, and monitoring and environmental management measures to preserve the quality of existing groundwater and surface water resources will take a prominent place on the agenda of overall water resource use planning. Recently, different views have been expressed concerning the relative importance of water quality versus water quantity for health improvement, and this ongoing discussion will have to result in a balanced view on the issue, taking into account local epidemiology, ecology and economy.

4.1 Surface water versus groundwater in terms of quality

Depending on contributions from various sources (including soil leaching, active volcanism, landslides, decomposition of plant litter and the occurrence of rare rock types) water quality may, under natural conditions, be extremely variable. Pollution of human origin may change the quality of natural water resources to such an extent as to preclude their use for drinking water purposes. Deterioration of water resources belongs to the group of global environmental problems and particularly affects drinking water supply.

Surface waters are usually more seriously affected by human activities than ground water resources. Human interventions include changes in the hydrological cycle (river damming, water diversion from one river basin to another and wetland drainage or filling), enhancement or slowing down of natural biogeochemical cycles, deforestation and erosion, dumping of organic and inorganic waste contained in industrial or agricultural drains and others.

Groundwater sources are, in a way, more protected from pollution than surface waters. This has led to a widespread complacency about the risks of groundwater pollution, and there is an urgent need for a change in attitudes, as this type of pollution represents long-term damage that can only be reduced at great cost and with technical measures of considerable sophistication.

Because of its vital role in drinking water supplies of both urban and rural areas around the world, groundwater must be protected from pollution primarily through preventive measures directed against the infiltration of wastes through the soil surface.

There is a wide range of threats to groundwater. Sources of contamination are listed below:

Urban settlements:
- leaching from sanitary landfills
- leaking sewers
- stabilisation ponds
- wastewater irrigated fields

Industrial and mining activities:
- leaching of toxic materials
- leaching tanks and pipelines
- contaminated drainage waters
- infiltrations from quarries

Agricultural production
- livestock production
- fuel and chemical storage
- latrine discharge
- pesticide and fertiliser use
- leaching from cultivated soils

From an economic viewpoint, groundwater compares positively to surface water as a drinking water source. Due to the presence (or potential presence) of suspended solids, organic and anorganic compounds and pathogenic organisms, surface water needs expensive treatment systems. The development of groundwater resources has a relatively low capital cost and in most cases little treatment is needed to attain the standards recommended in the drinking water quality guidelines of the World Health Organisation.

4.2 Feasibility of improving drinking water quality

In rural areas and small communities it is very difficult to enforce national drinking water standards for a number of reasons. There is a general lack of financial resources and trained personnel, and existing institutional structures are also not conducive.

Specific action plans need to be formulated and implemented to improve the protection of water supply systems from bacteriological contamination. Such plans will only yield positive results if there is a strong political will and commitment to the improvement of rural systems and if the delivery at regional and local level is linked to overall Primary Health Care. Basic components of the action plans include appropriate technology, community education and involvement and well focused training.

Appropriate technology will be needed for:

- the *protection of water resources* from direct faecal contamination and from secondary pollution caused by leaching from pit latrines, septic tanks etc.
- *water treatment*: disinfection has been the most recommended treatment process in many rural areas of the developing countries, especially in Africa. In many cases long-term results have been very poor, often because of a lack in chlorine supply. In a number of situations water with a high turbidity or a high organic content has been chlorinated without a significant reduction in coliform count. For reasons of efficiency and for environmental considerations other treatment methods, such as slow sand filters, should be considered in the coming years. They can be constructed with local materials, do not need chemicals and are very easy to operate and maintain.
- *routine surveillance* for quality control on sanitary infection to be carried out by basic district laboratories. Field kits for on-site water sampling and analysis have been shown to be very effective in rural areas. Water quality control responsibilities should be shared between water supply agencies and health authorities in an intersectoral manner.

4.3 *The relative importance of water quality and quantity in the determination of health risk factors*

It has been unequivocally demonstrated that a safe and adequate water supply is generally associated with a healthier population. These health benefits are, however, almost impossible to quantify because of the difficulties in separating the impact of water supply from those of physical, environmental, economic, cultural and educational factors affecting community health as well. It is important that in addition to safe drinking water, sufficient water is also available for hand washing, bathing, laundering and cleaning. Keeping up adequate quality standards of drinking water will help reduce the prevalence and incidence of water-borne diseases, while the provision of water in sufficient quantities (a minimum of 30 l per caput per day has been suggested) is especially effective in controlling the water-washed diseases.

While there is, therefore, no doubt that water quantity is an important factor in health promotion, it is a fallacious argument that it would be of over-riding significance in comparison to water quality. In most of the developing countries, where only a limited number of water supply points per community are affordable, these must provide water both for drinking and hygiene. Good source selection and protection (preferably a groundwater source) will yield microbiologically safe water so that quality at least is ensured. Large quantities of less safe water will not satisfy both health requirements. Obviously, situations will vary according to local conditions, but environmental measures will have to be promoted to secure safe water sources in the largest possible quantity and a feasible balance will have to be struck between both parameters.

New technologies will need to be applied to detect and monitor water resources in an integrated manner. Water quality is being checked through the Global Environmental Monitoring System by a network of national institutions. These data may be complemented by Remote Sensing (RS) observations of watersheds and river basins, and they will be increasingly analyzed with the use of Geographic Information Systems (GIS). It is of great importance to create intersectoral frameworks in which countries can apply these new technologies for a sound and integrated management of their natural resources. Ministries of health will have to step up their health monitoring and epidemiological assessment activities to provide such systems with adequate data so as to elucidate the linkages between environmental change and human health status.

5 Institutional Development

Institutional development of the Water Supply and Sanitation Sector (WSS) involves the technical elements of management, finance, and legislation which should be analysed in terms of planning concepts and methods, institutional arrangements, development mechanisms and resource requirements. New approaches will be required for the sector to achieve sustainable development within the limitations set by a growing world population and decreasing water resources.

In the areas of organisation and management, the current focus is therefore on decentralisation and intersectoral action, financial management addresses cost-containment and cost-recovery issues, and current topics in WSS legislation are water resources allocation, waste water use and water supply management.

There is some overlap between these groups, in particular the cost containment and cost recovery. Improved measures in Operation and Management, such as community and human resources development, will result in increased community involvement and a reduction in cost. Legislative measures discouraging water wastage and fraud, optimising resource allocations or encouraging waste water recycling and use similarly result in cost containment.

On the cost recovery side, improvements in Operation and Management such as decentralisation and intersectoral action will help bridge the gap between agencies and communities. They facilitate water quality surveillance, hygiene education and health impact appraisals, which in turn motivate governments and external support agencies to invest in the sector, communities to contribute to WSS development and maintenance and agencies to recover costs.

The current trend therefore, in a situation of growing scarcity of resources, is to plan, implement and evaluate institutional development with due attention to its cost recovery and cost containment effects which constitute a common denominator of improvements in all four areas.

5.1 Decentralisation, intersectoral action and privatisation

Decentralisation can be an internal or an external process. Internally in the WSS sector it will imply the shift of responsibilities from the central level to existing or newly created units at regional or district level. Externally, it means the devolution of responsibilities from government institutions to the community. Ideally, both elements are part of the process. While WSS agencies have known limits to their decentralisation potential, software providers such as public health agencies are usually better organised that way. Integration of WSS with the latter agencies can therefore facilitate decentralisation.

Devolution of authority and responsibility to self-reliant community structures with continued support from software providers is probably the most effective decentralisation arrangement. It requires important recurrent budget increases. In many instances, even though decentralisation of WSS institutions takes place, there is little increase in actual spending for the rural subsector. Constraints in the process are compounded by the lack of motivated and qualified personnel.

Community management provides opportunities for reducing costs in less-privileged areas. In many cases WSS services have been made more accessible to the poor through improved participation, varying from voluntary labour to operation and maintenance (O&M) of communal facilities by user groups and autonomous operation of small installations such as hand pumps.

The decentralised provision of hardware often increases unit costs to such an extent as to offset the benefits, particularly because of constraints in logistics. There appears to be a limit beyond which construction, operation and maintenance costs increase sharply. Finally, in many of the least developed countries, the potential for decentralisation is very limited in general, because of the lack of support and contact structures at provincial and regional level, and therefore the possibilities to decentralise the WSS sector are virtually non-existent.

In many instances decentralisation will rely more on community development than on the creation of an institutional network at regional and district level. However, whenever the latter approach is used, it must be ensured that units coordinate their resources and efforts with those of other sectors which are already very decentralised, for example public health, agriculture and education.

From the community perspective the cooperation of WSS and health workers is required at village level, because water supply and sanitation are integral parts of Primary Health Care and essential to the success of health programmes. Qualified public health workers are generally easier to find than teams specialised in the O&M of infrastructure works; decentralisation of such teams is usually not feasible below the regional level.

The IDWSSD has provided a challenge to intersectoral action for health in connection with WSS and PHC. The experience from the Decade will have to be further strengthened, in the light of sustainable development, with increased attention to mechanisms for water quality surveillance, health education, health benefits appraisal, the use of epidemiological data for WSS planning and dissemination of relevant health information to motivate and guide WSS providers and users.

The other sector with which collaboration will have to be strengthened is agriculture. Further irrigation expansion for agricultural production will have to be planned on the basis of integrated water resources development. All too often in the past schemes have been developed without a WSS component, with detrimental consequences for health. It has not been uncommon for water resources to be developed in a way that provides irrigation water to the rural community and drinking water to urban centres, totally overlooking the WSS needs of the rural people. Irrigation development may also result in environmental effects such as a deterioration of groundwater resources because of contamination with pesticide residues and fertiliser or because of salinisation through leaching. Thus rural communities have no other option but to use water from irrigation or drainage canals, and to be exposed to severe risks of water-borne and water-based diseases.

In the sequence input-output-outcome-impact, public institutions are often seen as most concerned with the maximisation of their inputs (e.g. their development budget) and of their outputs (e.g. the number of systems constructed) on which their performance will be evaluated. The intention behind divestiture of responsibilities is to further improve the output/input ratio, and to maximise outcome and impact, thereby expanding the companies' markets.

Matters of public interest cannot easily be put into private hands in the absence of strict regulatory mechanisms, especially in sectors like WSS which have direct public health implications. Government interventions are required to ensure that services will be extended to the less privileged, that best use will be made of the resources, especially those which can be provided locally, and that the company can remain viable without charging exorbitant prices to other sectors of the economy (e.g. industry or tourism).

Water supply agencies, whether public or private, have a high proportion of fixed costs, and must devote the largest part of their (variable) income to meet payroll and debt-service obligations. The income structure of private agencies should be such as to allow for maintenance of existing assets and for depreciation, and to meet service expansion needs if this can be done without tariffs becoming excessive. New requirements that may need to be met in the light of environmental legislation will, in future years, put further pressure on the agencies.

5.2 Financial management

WSS services are provided in most countries at prices which are unrelated to financial and economic costs. Large consumers sometimes including government agencies may not pay their water bills. Industries often enjoy the benefits of private supplies and discharge untreated effluent without any pollution charge or penalty. For those who must pay, tariffs are high. Utilities have irregular incomes and sometimes cannot meet fixed obligations like debt-service or payroll: subsidy is the rule. Inadequate tariff setting is but one reason for this state of affairs: more important reasons are users' unwillingness to pay, lack of qualified staff and lack of political will and commitment to contain and recover costs.

The need for managerial and financial improvements is critical, due to budgetary constraints and the necessity to optimise water utilisation. Service levels deteriorate for lack of provisions to cover replacement, maintenance and even operational needs, so that it has become essential to improve the allocation, size and timing of application of investment funds, as well as take all possible cost containment measures, and diversify and increase the sources of recurrent income.

Water tariffs that reflect future needs may exceed the means of the poor. The compensation possibilities are reduced due to the imbalance between the low-income population which grows rapidly and the stagnating group of large consumers. Efforts to extend services to rural areas are often in vain, because of the growing need to subsidise those who already have access to water. A large part of the water is lost in distribution, and the remainder is often sold at less than the cost, while the poor who are not served are charged high prices by water vendors. There is a need for the less privileged communities, irrespective of size or location, to organise themselves to construct, operate and maintain WSS facilities, and to derive maximum benefits from them, while ensuring that all costs are met. The reduction of non-revenue water (all water which is unaccounted for or otherwise unpaid) remains the most cost-effective cost containment measure in most water supply systems.

5.3 Legislation

The increasing depletion and pollution of water resources, and the dramatic expansion of population groups at high health risk make the provision of water supply and sanitation services difficult and costly. Communities as well as government agencies are faced with managerial and technical constraints, compounded by the lack of adequate human and financial resources. In this connection, there is a need for forward-looking legislation which can be easily implemented and enforced.

Developing countries have tended to adopt imported standards and practices resulting in reliance on central public systems. The role of local administrations and communities and the support activities of the private sector have been limited. In addition, water supply and sanitation are, in most countries, subject to excessive fragmentation of responsibilities, with some overlap of jurisdictional powers between several of the numerous agencies involved.

Many countries have yet to elaborate fundamental legislation and regulation required to cover matters pertaining to the preferential allocation of the best resource to domestic water supply, the use of waste water for agricultural and industrial or municipal purposes, water resources protection and conservation and the recovery of costs from WSS users.

The issues currently addressed are the following:

- allocation of a share of water resources for community water supply, which should be decided using water quality, quantity and access of the resource as criteria;
- regulations concerning the use of waste water for agriculture and aquaculture with respect to environmental and human health protection;
- regulations which govern the institutional framework of the WSS sector to improve its management, and to ensure that community water supply and sanitation costs are adequately recovered.

Legislation can be considered a fundamental issue in institutional development, and improvements in operation, management and finance can only be achieved if regulatory measures are adopted and enforced.

6 The Role of the Government and that of the Community

6.1 Lessons learned from the IDWSSD

Ironically, it was the lack of financial and human resources needed to promote rapid expansion of coverage which eventually forced governments and external agencies to adopt radical new approaches to Decade promotion. Changes arose from the realisation that many more facilities could be built with existing resources, and their use and maintenance could be improved, if the intended beneficiaries were involved at all stages of development and operation. Water and sanitation agencies also began to be sensitive to the key roles that could be played by women, community leaders and other groups with recognised competence and authority.

Community-centred concepts became increasingly important over the course of the Decade as emphasis regarding the leading role for water and sanitation development shifted from the outside development agency to the community and the individuals within it. This shift is clearly illustrated in the development terminology used in water and sanitation programmes. Twenty years ago the term 'community development' was used to describe the generation of local contributions. By the start of the Decade, however, emphasis had shifted to the concept of 'community participation', which stressed local involvement. Current terminology refers to 'community management' as a process in which there is local acceptance of responsibility for and control of water and sanitation services.

For the communities to fulfil their roles efficiently and effectively, they had to be motivated and adequately supported. Considerable strengthening of hygiene education was needed to orient users of water supply and sanitation facilities to the potential health benefits associated with these systems and to promote proper practices for the beneficial and economic uses of water. Through an understanding of health benefits, it was believed that communities would more willingly become involved in project implementation. Similarly, through the proper care and use of facilities, the users would be maintaining a healthy environment and would be contributing to the long-term sustainability of their water and sanitation system.

In practice, a strong incentive for local contribution to project development was the realisation on the part of the users that their efforts were a necessary first step to complementary (financial) investments by outside agencies. Overall water and sanitation improvements, therefore, required both local support activities and the timely provision of hardware.

The strategy of community-based development requires that the chosen technology be appropriate to local conditions. This has encouraged local institutions, national governments, and outside donors to communicate better with each other during the Decade. The result has been an unprecedented move towards closer coordination of governments and external support agencies active in this sector. In turn, this has facilitated improved practices for planning, monitoring, and evaluation.

6.2 A shift from a technical to a participatory role

The roles of governments and communities in water and sanitation varies according to the perceptions of different groups involved. Groups include communities, directly interested individuals who are in need of water and sanitation facilities, political groups including local and regional officials, NGOs (national and international), ESAs and, of course, the official of the different ministries in the central government of the country concerned.

In the past, in most developing countries governments have been expected to provide WSS facilities to their populations and have organised themselves accordingly. The expectations of populations were high, but the investment required in terms of local currency and foreign exchange for the materials and trained manpower proved too high for adequate, let alone full coverage. Nevertheless, great efforts have been made as the IDWSSD statistics demonstrate (see section 5.2). With the realisation of the enormity of the task and the need for community involvement to ensure adequate maintenance and sustainability, many governments are transforming their roles from providers to facilitators of water and sanitation services. Moreover, many communities, not seeing the government active in their areas, have mobilised themselves, generally around some dedicated and energetic individuals (often women) to ensure daily water supply and the minimum of adequate sanitation facilities. There are numerous examples of the excellent work of such individuals carried out, for example, in Zimbabwe and Malawi. Furthermore, many NGOs have been active in mobilising communities to improve their water and sanitation conditions. Their impressive records of success in achieving sustainable systems have served as a model for governments' future role in the sector as a facilitator rather than a provider.

Previously, problems in the WSS sector were considered to be purely technical and economic. Now the role of the community, and especially the role of women, is appreciated for planning, design, operation, maintenance and collection of funds. Previously, the WSS facilities were rarely considered from the user's viewpoint, especially with regard to water quality (taste, smell and softness for washing), quantity, disposal of waste water, requirements for animals and gardens and last but not least their willingness to pay and contribute to the realisation of the facilities. Lack of sustainability of rural WSS facilities was not so much for technical reasons, but more because of inadequate provision of maintenance. The lessons learned from the IDWSSD in this connection advocate a package of measures to ensure successful schemes and lay particular emphasis on the participation of the community and within the community of women who play an increasingly important role.

This role was particularly favoured by the participants from 45 African countries at a sector conference held in Abidjan, Côte d'Ivoire on 10 and 11 May 1990. In the Strategy for the 1990s formulated by the Conference, the sixth recommendation reads:

"Community and women's participation must be an integral part of all project development and implementation varying only in degree between conventional urban and peri-urban or rural projects. Institutional decentralisation and restructuring should be implemented to bring decision-making closer to the user. Privatisation should be part of this restructuring, as appropriate."

In a new order of operations there would be a consequentially different relationship between the Government institutions (plus its regulations) and the participatory communities. This new relationship is called 'community partnership in development'.

Water supply and sanitation has, as mentioned earlier in this paper, important social and health dimensions. Time and energy are saved when women and children no longer have to walk long distances to collect water. On the sanitation side, latrines provide both privacy and health safeguards. Different groups have come to the fore in communities to manage these facilities, or special arrangements have to be made by community leaders.

In the new set-up, there will be a need for a modified method of consultations between Government authorities on the one hand, and between central Government officials and the ESAs on the other. NGOs could also assume an important role in such consultations at the community and government levels. The new modus operandi entails striking a balance between donor policies, government policies and community needs and demands during all phases of WSS development. As a result, self-reliance in terms of water supply and sanitation would be ensured and will contribute to the sustainability of the facilities.

7 Hardware and Software

It is now widely recognised in the WSS sector that achieving broad coverage in rural areas is not simply a question of getting the hardware 'out there'. The needs, desires and ability of the people to be served to pay for the services and maintain the facilities must receive equal attention.

Engineers in charge of projects have little knowledge on how to achieve community participation, women's participation or how to do hygiene education. Equally, the great majority of anthropologists and sociologists contacted to assist in projects have little or no experience, on the whole, of water and sanitation projects and have difficulty understanding both why their help is required and what sort of skills they should apply to each situation. Funding and timing are not suited to having communities involved, and it is hard to imagine how every community can be consulted when there are thousands to be covered.

The primary focus in meeting hardware and software needs in the coming years will be on improving operation and maintenance (O&M), which turns out to be both a hardware and a software issue. In many rural areas it falls on community operators, men and women alike. As for software, the greater part of the challenge still lies ahead, for it is now accepted that the only way to achieve good O&M and, thus, sustainable systems and health benefits, is for communities to be fully involved in the process of their development.

7.1 Appropriate technology

To ensure the feasibility, acceptability and sustainability of a planned water supply service, the adopted technology must be responsive to the needs and constraints imposed by the conditions of the community concerned. Thus, design criteria involve technical, health, social, economic, financial, institutional, and environmental aspects which determine the characteristics, magnitude, and cost of the planned system.

In rural areas, great emphasis has been put on the use of hand pumps and construction of latrines as suitable technologies for the achievement of the targets of the Decade. Although there has been great progress in the development of adequate types of hand pumps and other types of technology, it continues to be an issue of great concern. It is felt that there is a need for further studies and research aimed at improving the quality and sustainability of low-cost technologies used at present in developing countries.

To be appropriate, a technology should:

- be as inexpensive as possible without jeopardising the effectiveness of the improvements sought;
- be easy to operate and maintain at the village, community or municipal level;
- be reliant on locally-produced materials as far as possible;
- make effective use of local labour;
- facilitate and encourage the local manufacture of equipment and spare parts;
- facilitate the participation of village communities in operation and maintenance; and
- be compatible with local values and preferences.

7.2 Promotion of innovative technologies

Currently, a number of different activities related to technology development are being implemented under the aegis of the World Health Organisation:

- Preparation of chemical guidelines for the safe use of domestic/industrial wastewater and sludge in agriculture;
- Study on the effects of human viruses on public health in association with wastewater use;
- Organisation of regional workshops on technical and health aspects of wastewater use;
- Investigation of wastewater treatment technology for reuse;
- Translation of documents on technology into Arabic;
- Investigation on steep gradient sewers;
- Activities for upgrading of water treatment plants;
- Research on natural coagulants for water treatment in developing countries.

7.3 Strengthening Operation and Maintenance

The Operation and Maintenance (O&M) of water supplies and sanitation in developing countries has been badly neglected. Many schemes have fallen into disrepair and no longer provide the services for which they were constructed. In the rural areas, where supply is frequently provided through point sources fitted with hand pumps, a high percentage of facilities are reported as being out of order. Figures of 40 per cent, 50 per cent and 60 per cent have been reported but this is an area where, perhaps not surprisingly, reliable data are not readily available. The deterioration of these valuable physical assets is a major loss to national economies which should be avoided in order to minimise the need for costly rehabilitation projects.

Several factors have been identified as contributing to or bringing about the failure of proper O&M for water supply systems. These range from poor organisational structures in the responsible agency, lack of spare parts, inappropriate technology, lack of trained staff, tied aid, absence of career opportunities in the O&M sector, insufficient funds, legal framework problems, lack of motivation by sector personnel, non-involvement of the users, the low profile of O&M in the sector, inadequate tariff and collection systems and political interference. These causes tend to be interrelated.

It is encouraging to note that as a reaction to the initiatives of bilateral and multilateral agencies in this field, O&M and rehabilitation projects have increasingly become part of many national and externally supported programmes, particularly during the second half of the Decade. The level of O&M activities and the volume of financial resources dedicated to its development are, however, still far from what would be required for the achievement of the efficient use of the installed capacity of water supply and sanitation systems.

In order to rectify this situation and improve O&M a number of fundamental changes are being promoted and are in the process of implementation by the agencies responsible for providing these services. Four major lines of action have been adopted: mobilisation of international resources for operation and maintenance; development of guidelines for operation, maintenance and optimisation of water supply and sanitation facilities; support for the formulation, implementation and monitoring of operation and maintenance programmes; and the development of training activities.

The American region has been at the forefront of developments during the Decade with a new strategy developed in partnership with the Latin American water and sanitation agencies. This strategy places special emphasis on the management of O&M of drinking water supply and sanitation as part of an institutional development process and has been promoted as a guide for the development of projects in several countries within the Region (Brazil, Colombia, Mexico, Venezuela, Guatemala, Honduras, Peru, Costa Rica, Bolivia, Cuba). This initiative is progressively expanding to other parts of the world. *The Management of Operation and Maintenance of Drinking Water and Sanitation Systems* will soon be published by the World Health Organisation.

The implementation of O&M programmes usually involves huge changes in organisation and management and engineering procedures in water agencies. The implementation of these programmes should be accordingly supported by activities directed towards motivation, creation of awareness and training of personnel. One of the key activities to be developed in this area is therefore the organisation of national workshops on O&M for senior managers and engineers. In addition, in order to facilitate and provide a uniform level in personnel training, basic instructional material for engineers and technicians should be developed. This instruction material needs to be grouped into specific training packages, embracing the different areas which are usually of great priority in the development of an Operation and Maintenance programme. These will facilitate the conveyance and comprehension of the information and skills which are related to a better performance which should be expected from the water agencies.

The courses/workshops/seminars will be intended for managers, engineers and technicians. This initial target group is expected to become a core of trainers, which would exert a multiplier effect in disseminating the proposed knowledge to national water agencies and other users.

7.4 Capacity development

One of the achievements of the Decade was the collection of a small body of experiences and key guiding documents on how to achieve community participation and women's participation. Likewise for operations and maintenance, guidance materials and a new approach for the sector came out of the Decade. Both of these developments should lead to far greater sustainability of water and sanitation systems. The challenge ahead lies in how to incorporate these approaches into institutions, to make them a part of their everyday practice in the field.

While the potential contribution of sociologists and anthropologists is well recognised, their main contributions in the future will be in the area of research on how to improve on the techniques we are applying. However, the need for expanded coverage of water and sanitation systems is so great, that it is only realistic to assume that the dearth of professionally trained social scientists will continue to be a serious constraint in meeting the needs of the sector.

Social scientists must be recruited to help institutions evaluate and identify how they can operate more sensitively and effectively by putting people first, rather than the hardware first. Methods of planning have to be changed. Communities have to be consulted before plans are made for their water and sanitation facilities. Many of the ESAs now have adopted standard policies to consult communities in the planning and design stages of WSS projects.

For the time being it is existing personnel in institutions who will carry out the new approach, and they will require re-training in software, so that it becomes part of normal operations. Those who work at field level must be able to assist communities in identifying their priorities and involving women in the decision-making. Likewise, participatory approaches to hygiene education will need to become a normal part of the same process at community level.

7.5 A focus on hygiene education

The inevitably strong focus on hygiene education in the 1990s has already begun. The hygiene education of the future will place even greater emphasis on understanding existing hygiene beliefs and practices and on communities participating in the design of their own programmes.

A landmark workshop on measuring hygiene behaviour took place at Oxford University in April 1991, and its soon to be published handbook for mid-level implementing agency personnel leads the way toward an overall effort to understand *existing* hygiene practices and beliefs before trying to impose *new* ones. Participatory tools developed to involve women are being expanded to be used by agency personnel for participatory hygiene education.

Special attention will be given to hygiene education of school children. Efforts are now taking place to design comprehensive health education curricula, while at the same time less formal approaches through children's curriculum comics are gaining popularity. Health education through schools will emphasise actions that children can take in their communities and teachers will be encouraged to help children reach out to their parents and communities to bring about change.

8 Sanitation and Environmental Management

8.1 The need for adequate sanitary facilities: options and priorities

Appropriate disposal of excreta, waste water, sullage water and solid wastes is of fundamental importance for the maintenance of acceptable levels of public health in both rural and urban settlements.

With the exception of mosquito-borne and a few other diseases, the infective agents of most water-related diseases come into the environment in faeces or urine and unless there is a satisfactory and efficient removal of wastes there is an ever-present source of disease in the community. In fact, unless proper measures are taken, the provision of water can contribute to increased risks as it increases the volume of liquid to be disposed of. In many developing countries institutional, economic and sometimes environmental factors are the major constraints for the provision of water carriage sewerage and waste water treatment systems.

The most practical and direct method of breaking this transmission chain is the adoption of excreta disposal systems that do not utilise water carriage at all. They rely on separate collection and disposal in ways designed to minimise dispersion of wastes in the environment. The four types of systems employed for this purpose are:

- *Pit latrines*, the cheapest and simplest on-site disposal systems, made up by a hole in the ground which is replaced by a new pit when 2/3 full. The siting of pit latrines is important in view of possible percolation to groundwater sources used for drinking water supply. In tropical areas with high rainfall, pit latrines may overflow leading to contamination of the immediate environment. Cleanliness is of the utmost importance. Otherwise the installation of pit latrines may become counterproductive: they will become a site of disease transmission. Special measures should also be taken for insect control to prevent the proliferation of flies and, in case of flooded latrines in particular, mosquitoes. The Ventilated Improved Pit latrine has been designed to prevent insect breeding.
- *Composting latrines* require the addition of a carbon source to adjust the carbon/nitrogen balance. Continuous composting latrines have only a limited application in the developing countries, while batch latrines are popular in China and Vietnam. Compost from these sources is usually applied to agricultural land as fertiliser. The efficiency of pathogen destruction depends on the detention time and temperature. Anaerobic composting systems rarely rise above 35°C but aerobic units may have temperatures up to 70°C. The minimum detention time required to produce a compost free of pathogens is about three months (with the possible exception of hookworm eggs).
- *Cartage systems* involve the collection of nightsoil from homes and its transportation to appropriate sites for treatment and disposal. Health hazards depend on the sanitary safeguards in the various components of this process. The use of bucket latrines, as is customary in many countries in Asia, always involves a level of health risks, but collection by vacuum trucks from vaults can be hygienic and risk-free.
- *Thermophilic composting* is an aerobic process at temperatures of 55°C or higher which is capable of producing a safe fertiliser after two months of maturation. Fly breeding is the main problem in the management of compost systems, and the attainment of a temperature over 51°C in all parts of the compost is essential to prevent this.

Water carriage systems are usually more expensive to construct and more difficult to operate than the dry systems discussed above. They should be carefully evaluated against other alternatives by the community involved. Frequently, a more cost-effective approach can be to improve the system for collecting, treating and disposing of nightsoil. When limited quantities of carriage water are utilised a system of septic tanks and subsurface drainage or soakaways can provide good results depending on soil characteristics. Septic tanks are designed to receive all waste waters from houses, both excreta and sullage, and to provide an average detention time for the liquid of about one to three days. After anaerobic digestion the effluent from a septic tank may be discharged to a soakaway or an underground tile field for subsurface disposal through leaching.

Full carriage systems require the construction of a sewerage network which conveys the wastewater to treatment plants. They are not of great relevance to the rural situations in most developing countries.

8.2 Drinking water source contamination because of bad sanitation

In many parts of the world water is fast becoming the most critical limiting factor for socio-economic development and risks becoming the origin of social conflicts and international disputes. Protection of water sources is of primary concern to water basin authorities and inadequate disposal of waste waters is a major risk to their pollution. Many factors may be of importance and have to be taken into account when planning a sewerage system: infiltration from open ditches, waste lagoons and open sewers, leaching from sanitary landfills, seepage from latrines as well as discharge of domestic and industrial waste waters and drainage from agricultural fields. Proper siting and construction, and an effective system of water quality monitoring with the possibility of investigating the source of contamination if it is detected, are all important contributions in the prevention and control of this problem.

9 Future Trends in Water Resources Development and Management

9.1 Demand for water

The available fraction of the world's freshwater resources forms part of the roughly 41,000 cubic kilometres annually returning to the sea from the land to compensate for the atmospheric vapour transport from the sea to the land (WRI, 1990). Estimates on the proportion exactly available for human use world-wide vary according to the source quoted. This is due to the fact that exact estimates on the amounts of water retained by vegetation, or on the proportion running off in essentially uninhabited areas, are unavailable (Maurits La Rivière, 1989).

The largest share of total global water withdrawals, 68 per cent, is used for irrigation, industry comes second with 23 per cent and domestic uses last with seven per cent (WRI, 1990). About 43 per cent of all water withdrawn is returned to the hydrological cycle as wastewater. Most of this is contributed by industry, where 87 per cent of all water withdrawn is converted into wastewater, after varying degrees of treatment. Relatively speaking, the agricultural sector produces little wastewater, but because of the large water consumption in this sector the absolute amounts are quite considerable; most of the emissions are diffuse and often percolate into groundwater without any treatment whatsoever.

The use of water for irrigation is bound to grow, but at rates below those experienced in the past century, as most land suitable for irrigation is already in use as such and stricter water pricing will tend to increase water efficiency in agriculture. Industrial water use for processing, cleaning, cooling and the removal of wastes, will increase in the next few decades as the economies of developing countries are making the transition to industrialisation. As a consequence, the overall amount of industrial wastewater discharged will also go up, although tougher sanctions and higher prices may bring wastewater discharges down in developed countries. In domestic water use, higher standards of living tend to lead to increased use of drinking water and higher demands in respect of its quality (WRI, 1990). The World Resources Institute (ibid) estimates these changes as shown in Table 1.

Based on a different methodology, World Bank projections of global water uses in the year 2000 by sector are considerably higher:

Application	*Use* (m^3 x 10^9 y^{-1})
Agriculture	7,000
Domestic water use	600
Industrial water use	1,700
Waste dilution	9,000
Other (mostly power generation)	400
Total	18,700

It should be noted that the above projection of 0.6 km^3 for domestic water consumption in the year 2000 is based on a per caput consumption of 274 litres per day and a world population of six billion people, which represents the 'low' variant in the most recent United Nations population projection (UN, 1990). In addition it should be pointed out that 18.7 km^3 equals 46 per cent of the total amount of global runoff water annually available as an absolute maximum, that world population growth will continue for several more decades and that in many developed countries the average daily domestic water consumption already exceeds 274 litres per caput.

Table 1 Estimated changes in water use (WRI, 1990)

	1980s use (m^3 x 10^9 y)			**Estimated use in 2000** (m^3 x 10^9 y)		
Sector	consumptive use	waste water	total use	consumptive use	waste water	total use
Agriculture	1,623	583	2,206	1,920	665	2,585
Domestic	110.2	152.9	263.1	174.5	282	456.5
Industry	98.1	661.8	759.9	225.5	993	1218.5
Total	1831.3	1397.7	3229	2320	1940	4260

The situation is fast becoming quite pressing in many parts of the world. In many developing countries both organic and inorganic river pollution are on the increase as decontamination efforts do not keep up with expanding industrialisation. Over wide areas, the degradation of water resources already constitutes the gravest environmental problem, as for instance in several countries in eastern Asia (Maurits La Rivière, *op. cit.*). Elsewhere, the impact of expanding irrigation is felt in the form of domestic water shortages and lack of sanitation, while salinisation and desertification processes reduce the surface area of arable land for food production. Indeed, the severest problems occur where demands exceed supply. Groundwater is already being depleted at unsustainable rates in large parts of the United States, China and India. The resulting drawdown phenomena affect river flows and the productivity of artesian wells. Sometimes, saline or contaminated water intrusions from adjacent aquifers or groundwater reservoirs render further water extraction less attractive, while in the absence of such spontaneous recharges serious subsidence problems may occur.

9.2 Action plans needed

Notwithstanding different projections, it is clear that increasing trends in water withdrawals and wastewater production cannot be sustained indefinitely and that the severe water shortages already felt in several arid and semi-arid areas will aggravate and spread to other areas unless drastic policy changes are made. Water shortages and water pollution may well become the number one constraint to economic development in many countries by the year 2000.

What is clearly needed with varying degrees of urgency, depending on the trends presently in force, is to declare water resources as intersectoral assets and to start planning for their exploitation for whatever purpose at the level of the total watershed. In many instances, this will require the establishment of inter-district, inter-state, or even international authorities with the power to control all water use planning and monitor and control water quality in a complete hydrogeological geographic entity. In fact, several developed countries already have water quality boards and water management authorities with similar responsibilities on a sub-national scale, which could serve as models for decision-making institutions at the higher level.

In terms of water quantity management, the greatest need for intersectoral coordination is between health and agriculture in all countries with important and expanding irrigation programmes, particularly in arid and semi-arid climate zones. Quality management mechanisms need improvement in a variety of situations, ranging from the newly-industrialised developing countries where the treatment of industrial effluent does not keep pace with the rate of surface water pollution and countries with agricultural economies which increasingly depend on wastewater use for irrigation on the one hand, to heavily industrialised countries with serious surface and groundwater contamination problems on the other.

Solutions that are bound to emerge from such intersectoral planning are the following:

- environmental impact assessment (EIA) to become mandatory for all water exploitation projects and policies and to have human health impact assessment incorporated in such EIA at all levels;
- introduction of realistic disincentives to combat excessive water withdrawals and polluted discharges into water resources;
- integrated water resources management structures, financially carried by all economic sectors dependent on water supplies and responsible for enforcement of minimal water quality standards;
- promotion of improved water economies in industry and agriculture, including the recycling and treatment of wastewater and water-saving production systems;
- novel technologies which will provide sustainable access to water sources hitherto untapped or little used (sea water, fog and dew, rainwater).

International aid agencies and financing institutions have a very important role to play in assisting countries with the transition to integrated water use planning, in the investments needed for applied research into some of the technological areas indicated above and in training of human resources in dealing with the complicated issues involved. A special role may be identified for the UN system and its specialised agencies, as the international, or even global, dimensions of the water supplies problem gain prominence.

Within the WSS sector also a number of new policies and approaches will have to be developed. To promote a healthy environment, water and sanitation programmes should be formulated around a variety of supporting elements. Technologies should be designed to foster a healthy environment through, for example, improvements in water quality, reductions in disease transmission, or lessening the human (usually women's) burden of water hauling. Training programmes which incorporate both technical and health issues are needed at all levels from university professionals to community workers in order to orient water and sanitation personnel to be sensitive to the overriding health objectives of these services. Similarly, schoolchildren need health education to understand the reasons for hygiene practices and adults need user education to understand their responsibilities towards their water and sanitation systems. A related element is the importance of community involvement, especially that of women, in the overall planning, implementation, and operation of their systems.

Two additional elements supporting health objectives in water and sanitation development are the complementary roles of government and external agencies. On the national side, governments need to find better ways to integrate the various ministries and local organisations in coordinated development efforts that require consideration of health strategies and objectives. On the external support side, donor agencies can support health-related issues in countries by promoting sustainable projects, expanded community involvement and management, effective coordination among government agencies, and the integration of technologies, training, and health education.

Health-related strategies for the 1990s should not be limited by any misconceptions that there are profound mysteries masking the linkages between water and sanitation services on the one hand and health on the other. We understand these linkages sufficiently well to be able to bring about improved health status through water and sanitation interventions. There are, nevertheless, many areas where research can be fruitfully undertaken. These include, for example, the effects of specific water contaminants upon health, the effectiveness of school curricula in changing the personal hygiene practices of children, and the relative effectiveness of integrated programmes of water supply, sanitation, hygiene education, oral rehydration therapy, and other aspects of primary health care. There is need to move ahead simultaneously on both the operational and the research fronts.

Several areas of consensus are emerging within the development community on questions of coordination. First, developing countries must become more involved in global and regional efforts to meet sector needs. Sector development cannot be allowed to remain a one-way street whereby donor countries and external support agencies identify needs, plan strategies, and formulate programmes, while developing countries act primarily as acceptors and implementors of decisions made elsewhere. Means must be found to incorporate developing countries in the councils, planning sessions, and networks of the global development community. This involvement should be as co-equal partnership, but one that recognises the special insights and responsibilities of the developing countries. International coordination will be truly collaborative only if it includes active participation of the developing countries.

A second need is to generate political will and commitment for sector development within the developing countries themselves. Governments should be encouraged to review sector needs and assess priorities accordingly. High level officials must be brought into this review and encouraged to formulate national policies in line with sector needs. Various coordinating bodies could assist in this process by using high visibility external fora to involve the leaders of the developing countries in discussion of sector problems. Once the leaders are committed to sector development, the successful establishment and implementation of programmes is much more assured.

Another need is to effectively promote sector development among the general public and key officials of donor countries. This will require the development of appropriate messages to each of these groups and the establishment of effective means of delivering these messages. Both will involve new approaches since the messages of the Decade and the medium of communicating them have proven to be inadequate. We have talked to each other too long and too often; we are preaching to the converted. It is now time to reach out to the rest of the world and show it why and how the sector must be given greater attention.

A fourth need is to create operational linkages to other sectors. Water and sanitation development do not occur in a vacuum, nor should they be viewed in narrow sectoral terms. By linking water and sanitation issues with associated concerns in other sectors, most notably the environment, irrigation, agriculture, urban development, population, and health, a series of mutually supporting alliances with a wide range of development-oriented audiences and organisations can be established. These alliances should enrich the water and sanitation sector by providing it with a better understanding of the process of development and with potential allies in the promotion of the sector.

And finally, there is need to increase the magnitude of investment in the sector. Unless more resources are devoted to the construction of new facilities, the rehabilitation and maintenance of old systems, and the strengthening of supporting activities, the level of coverage will not increase and the sector will remain unhealthy. To some extent, the level of investment available to the sector is a function of the degree to which both donor and developing countries believe investment can make a difference. In other words, resources are more readily available when goals are well defined, proven methods are in place, and participants are willing to work together. This relationship holds true at the community and project level, and it should be true at the country level. A collaborative framework of both donor and developing countries could do much to foster the relationships leading to greater sectoral investment by all parties.

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4

Water for sustainable food and agricultural production

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EXECUTIVE SUMMARY

Formal interest in sustainable development began some twenty years ago, the first key event being the UN Conference on the Human Environment in 1972, followed later by the Brundtland Report in 1987, which emphasised the economic and political aspects of sustainable international development. In the context of rural development, the aim is a secure, sustainable livelihood.

The population of the world is expected to pass the 6 billion mark by the end of the century and reach 8.5 billion by 2025. The rate of increase in developing countries will be 3½ times that of developed ones. Projections of demand for and production of agricultural produce for developing countries indicate a shortfall in production especially when expressed on a per capita basis.

Water is the binding constraint in agriculture, with 83 per cent of the world's cropland being rainfed. Productivity of rainfed agriculture can increase through better retention of soil moisture and drought-resistant varieties, but there is a limit to what can be achieved without the technical intervention of irrigation. Fish production within individual catchments can also be significant.

Irrigation has risen from 94 million ha worldwide in 1950 to 260 million ha today, of which two-thirds is in developing countries. Figures are presented for 93 developing countries and their rates of increase, which show a marked slow-down in the last decade.

The demand for irrigation water is a function of crop water requirements and of the efficiency of delivering the water from its source to the crop. Overall efficiencies can be of the order of 30 per cent. Productivity of water for major crops ranges from 0.4 to 2.0 kg m^{-3} of water.

Water resources for irrigation come predominantly from surface water sources, usually regulated by reservoir storage. The latter can be threatened through siltation of the reservoir if degradation of the catchments is not arrested. Groundwater is also a very important source, especially for projects on a smaller scale. Standards for quality of irrigation water are mentioned, as is the use of domestic and industrial wastewater.

Overwatering and lack of drainage facilities have produced land degradation through waterlogging and salinisation, affecting some 24 per cent of irrigated land in the world. Provision of drainage is essential to protect the often high investment in the irrigation facility.

Water management requirements depend on the scale of the operation. They are divided into (i) resource management within the catchment, (ii) conveyance to farming units and (iii) on-farm. It is questioned whether the typical structure of management of public sector projects is conducive to efficiency. Modern water application techniques can be beneficial if introduced with care. Monitoring of project performance can provide management with indications of how to search for improvement.

Productivity is the result of the farming enterprise: the farming system adopted for a project has to be judiciously selected. Innovation will not be easy when farmers are always at subsistence level where risk avoidance is their sole objective. The scale of development is often dictated by the relative disposition of the land and the water resource. Where there is a choice, smaller-scale projects are likely to be more sustainable by being more easily managed. They also tend to show a better return on investment.

Water resources and irrigation development have their environmental effects. Health hazards from water-borne vectors (e.g. schistosomiasis, malaria) have to be taken into account. Withdrawals of water from the catchment for consumptive use in irrigation reduce downstream flows, affecting various economic and ecological activities in the floodplain. Inundation of land by dam reservoirs may cause hardship for the people displaced. Excessive use of agrochemicals can be detrimental to water users downstream.

The costs of modern irrigation projects have increased while the prices for agricultural commodities have tended to fall. The result is a poor showing of irrigation projects under the economic efficiency criterion of cost-benefit analysis. This is a characteristic of all slow-maturing, but long-lasting, projects. Attention is drawn to multi-criteria analysis, especially if environmental objectives are included. The question of cost recovery is raised and coupled with that of subsidies which should, if they have to exist, be as open as possible.

Development planning at national level has to be holistic and must have strong commitment from politicians and the full support of the bureaucracy. To be sustainable it must also be attractive to the people. Sector plans, such as that of water use, must be integrated into the overall plan. Institutional adjustment may have to be made for managing what are increasingly multi-disciplinary problems. The user, here the farmer, should be seen as the principal agent of production. Action plans have to be drawn up within the realm of possibility. The FAO International Action Programme on Water and Sustainable Agricultural Development, giving priority to five action programmes, is outlined.

Water management for food and agricultural production has had its successes, notably in making the Green Revolution possible. Failures can be reduced if more attention is paid (in both time and money) at the planning stage, incorporating lessons from the past. Competition for external funds is keen and factors such as national resources management and budgetary priorities are of increasing concern to aid agencies.

CONTENTS

1 General Introduction

Development and the environment are rarely seen to be so closely interrelated as in the case of water for agricultural and food production.

This paper provides a brief background to the present state of the use of water in food and agricultural production, indicating the main issues involved and the ways in which they can be faced. The subject area is so wide and interrelated that the format adopted was considered best suited to this purpose. It is intended to set the scene for an exhaustive discussion in the working group, when plans of action, backed by case studies, will be presented.

Since the hydrological cycle, with its natural and man-induced variations, enters into most discussions on water and the environment, attention has been focused on the water resources close to their use in agriculture. As a result, topics such as catchment management have been given only cursory treatment.

Given the present state of world development and the thrust of activity by the UN Food and Agriculture Organization, it was felt that the paper should concentrate on the problems as they affect developing countries.

2 Sustainability and Development

Interest in sustainable development has arisen as a corollary of national, regional and, subsequently, global concern about the environment and in particular its natural heritage. It began to be articulated in Europe and North America in the 1960s and 1970s, key events being the UN Conference on the Human Environment in Stockholm in 1972 and UNESCO's *Man and the Biosphere* projects. The latter have a good claim to be the forerunners of 'sustainable development' thinking (Adams, 1990). In the 1980s the views of statesmen like Willy Brandt (*North-South: a programme for survival*) and Olaf Palme (*Common Security*) drew the attention of the general public to the issues involved. In 1983 the UN General Assembly established the World Commission on Environment and Development and received from it in 1987 its report *Our Common Future*, commonly known as the Brundtland Report (Brundtland, 1987).

The Brundtland Commission unequivocally linked sustainable development to economic and political aspects of national and international development. It defined sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. In economic terms this can be stated as *the welfare of people alive today should not be increased by development activity if as a consequence the welfare of future generations would be reduced* (Turner, 1991), i.e. it aims at non-declining human welfare over time.

Brundtland emphasised the satisfaction of 'basic needs' and thereby the importance of development action for the poor. This is taken further by Robert Chambers (1983) in the principle of '*sustainable livelihood security*', defining livelihood as '*adequate stocks and flows of food and cash to meet basic needs*'; security is defined in terms of ownership of, or access to, resources and income-earning activities.

From the outset, these principles were applied to their operations by the FAO, the Council of which in 1988 defined sustainability in the context of agriculture, forestry and fisheries as follows: *Sustainable development is the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fishery sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable.*"

Of all the qualifying conditions in the last sentence the final one, social acceptability, dominates over all the others. It is now recognised that projects, however well conceived, which rely on the 'command and control' principle of operation will not succeed if the local population perceives no advantages accruing to themselves. In the present context, the concern is with the rural population and, in particular, the rural poor.

3 Population and Demand for Food and Agricultural Produce

The essence of the concept of sustainability is the legacy the present will leave for future generations. This immediately raises the questions of what numbers one is to cater for when considering the future and from what base level of '*satisfaction of human needs*' one begins.

The projections of population in the world as made by the UN (1991) are presented in Table 1. The most striking fact is that, of the population increase up to the year 2000, about 90 per cent will happen in developing countries. The rates of growth show great disparities between regions, with sub-Saharan Africa prominently high. But this average contains rates of over four per cent for Côte d'Ivoire, Kenya and Zimbabwe (Pearce, 1991).

Rural development programmes in the tropics must often strike a realistic balance between agriculture, forestry and other land uses to meet rural needs. Forests and trees can supply a variety of benefits that are often crucial to rural well-being. The global value of the production of forestry and primary forest industries in 1985 amounted to 300 billion US dollars (FAO, 1987). Many non-wood forest products, both plant and animal, add directly to food production, and some are of considerable local nutritional importance.

Wood and tree biomass is a major source of energy for developing countries. Most importantly, in terms of environmental sustainability, natural forests provide the best protection to soil and conserve water and natural resources.

Table 1 *Projection of population and growth rates (UN, 1991)*

	Population (million)				Growth rates % per annum		
	1985	1990	2000	2025	1985-90	1990-2000	2000-2025
World	4851	5292	6260	8504	1.87	1.86	1.54
Developing countries	3677	4086	4996	7150	2.26	2.21	1.76
Africa	553	642	866	1597	3.05	3.13	2.87
Latin America & Caribbean	404	448	538	757	2.14	2.01	1.65
Asia	2605	2981	3420	4569	2.05	2.04	1.42
Middle East	115	132	172	288	2.91	2.86	2.46
Developed countries	1174	1206	1264	1354	0.60	0.60	0.53

When population figures are linked to per capita calorie intake, as recommended by FAO and WHO, rough estimates of the carrying capacity of the earth and its various sub-units can be made (FAO, 1984). A broad indication of the relation between demand (of basic needs) and production in agriculture is shown in Table 2 for the 93 developing countries (listed in Table A-1 in the Appendix) considered in the FAO study (FAO, 1988a). It shows the growth in demand exceeding that of production, this not taking into account increased expectations of future generations. At the same time it is only fair to add that data and their projections are carried out for areas based on geographical and political boundaries, not allowing for mutually beneficial trade in agricultural products (food and non-food).

Another indicator used is the *carrying capacity of the land*, obtained by dividing food output (expressed in calories) by the minimum requirements for an individual's survival. Much depends on the level of technology used in food production, so it does not represent a static situation. In fact, population pressure often forces up the technology level.

Changes in dietary habits may lead to rice being replaced by cereals less demanding of water and to vegetables and fruit gaining in importance. Food self-sufficiency is a concept closely linked to that of independence, itself changing its meaning in today's world.

One cannot leave the subject of food and water without mentioning fisheries. World fish production rose from 20.8 million tonnes (85 per cent marine, 15 per cent freshwater) in 1950 to 100 million tonnes (86 per cent marine, 14 per cent freshwater) in 1989. The value of the 14 million tonnes of production from freshwater is relatively high because it all goes directly to human consumption, whereas a high percentage of the marine catch is converted into other products, such as fishmeal. It is expected that the total demand in 2000 will exceed 100 million tonnes, most of the increase being from developing countries. Within freshwater fish production, the subsistence sector is important, but the greatest potential for increased production would be within the artisan sector, often closely linked to peasant farming activity.

The economies of countries now listed as developing rely heavily on agricultural production, in which the majority (on average over 60 per cent) of the population is engaged. It is their prosperity that will give impetus to establishing an industrial base and thereby raising the overall prosperity of the country. (*"Unless agriculture is given a boost, nothing else works."* said Mr Majid Malik, Agriculture Minister of Pakistan, 14 May 1991.) Intensification of agricultural production, in a sustainable manner, is therefore a matter of urgency.

Table 2 *Demand for and production of agricultural products over the period 1985-2000 in 93 developing countries (% per annum)*

	Demand		Production	
	Total	Per caput	Total	Per caput
93 Countries	3.1	1.2	3.0	1.1
Africa (Sub-Saharan)	3.5	0.2	3.4	0.1
Near East/N Africa	3.1	0.6	3.1	0.5
Asia	3.1	1.6	3.0	1.5
Latin America	2.8	0.7	2.7	0.6
Low income countries	3.1	1.4	3.1	1.3
Middle income countries	3.0	0.8	2.9	0.6

4 Water in Food Production - General

FAO's "*World Agriculture Toward 2000*" (1988) emphasises the importance of water as a key input by stating: *Notwithstanding the fact that land is indispensable for agricultural production, it is water rather than land which is the binding constraint. It is only when this water constraint is released that other technical constraints such as nutrients and pests become important.* Since water is a finite resource, it is central to this discussion to consider how it is employed in agriculture at present and what the prospects are for the future.

Most of the world's cropland (83 per cent) receives its water directly from rainfall. Man's control over natural precipitation is at present minimal. However, improved weather forecasting should remove some of the risk associated with failure of rains in the sowing or planting stage of the crop cycle. Improving the soil texture so as to increase its water-holding capacity and mulching to lessen surface evaporation can help to bridge the uneven gaps between rainfall.

Land degradation through erosion should be prevented by carefully constructed contour ridges. The agricultural land itself should be protected from inundation by excessive direct rainfall through surface drainage and from flooding by protective bunds. On floodplains the latter can become part of control for flood recession agriculture, traditionally and quite effectively practised in West Africa.

Good advisory services (extension) are very important in introducing farmers to short maturation and drought-tolerant crop varieties, as well as to cultural practices, such as intercropping.

But the basic variability of rainfall places a limit on the increase in yields that can be expected from rainfed agriculture in the future. Where an increase in agricultural land is either impossible or undesirable, increased production has to come from intensification, requiring the introduction of irrigation. Water harvesting - the collection and concentration of run-off - is sometimes discussed with rainfed agriculture, but it is basically a form of small-scale irrigation.

Fish production within the catchment comes roughly half from capture fisheries (wild stock) and half from aquaculture. The latter can be divided broadly into three categories (Balarin, 1984):

Semi-aquaculture/fishery, analogous to 'ranching' or 'range-management', where fish are introduced into a water body (e.g. dam reservoir), breeding is uncontrolled, feeding is intermittent or negligible and fish are harvested by normal methods. In small dams, with good management, yields of up to 1.5 t ha^{-1} y^{-1} are possible.

Extensive aquaculture, similar to 'pasture agriculture', where fish are in artificial ponds or rice paddies and productivity depends on natural production, possibly supplemented by manure or fertilizer, with fish generally foraging for food. Again, yields can go up to 1.5 t ha^{-1} y^{-1}.

Intensive aquaculture extends to highly intensive use of modern inputs and management and has been known to give yields as high as 200 t ha^{-1} y^{-1}.

Of particular interest is the integration of aquaculture with irrigation, especially in the Far East, but of increasing interest in Africa, where many village-level schemes are based on small dams. Rice paddy stocking has been a success in countries like Indonesia and Thailand.

5 Irrigation

Irrigated agriculture can be seen as a special case of intensive agriculture in which technology intervenes to provide control of the soil-moisture regime in the crop root zone. The relevant water management practices must ensure that the fertility of the soil is improved, or, at the very least, maintained — the sustainability criterion. Historically, the practice of irrigation goes back at least 5000 years, with the Nile system in Egypt providing the best example of continuity.

The irrigated area in the world has risen from an estimated 8 million ha in 1800, through 48 million ha in 1900, to 94 million ha in 1950 (Postel, 1989). Since then it has nearly trebled to reach 260 million ha today, of which two-thirds is in developing countries. Just two countries, India and China, contributed 40 per cent of that increase (Rangeley, 1990). In the period 1950-80 the annual increase in irrigated area was 4 to 5 million ha, but since 1980 this has been halved, largely because of increased construction costs and lower commodity prices. Figure 1 illustrates the rates of increase of irrigated lands which clearly show the declining trend of irrigation development worldwide and in the regions since 1980. The present situation for the 93 developing countries is set out in Table A-2 in the Appendix for every country in the four regions. It gives the cultivable commanded area (CCA) and its percentage of the arable land in use. Table 3 summarises the information by region, but also includes cropping intensities and forecasts for the year 2000.

The importance of irrigation in the four regions is highlighted by its relation to arable land: Asia 33 per cent, Near East/North Africa 21 per cent, Latin America 8.5 per cent and Africa 2.7 per cent. Within regions there are great variations: for instance, Egypt is 100 per cent and Pakistan 78 per cent dependent on irrigation. Figure 2 illustrates the major irrigators of the world, with India as the leader and China occupying a very close second place.

The forecasts for ultimate potential for the irrigated area in developing countries indicate that it could be as high as double the present figure, i.e. rise to over 300 million ha, but such estimates are usually based only on availability of land and water resources and they become less optimistic when social and economic factors are introduced.

Taking a broad historical view, one can say that, with 36 per cent of total crop production coming from the 17 per cent of the arable land which is irrigated, the practice of irrigation has been a success in providing for the world's

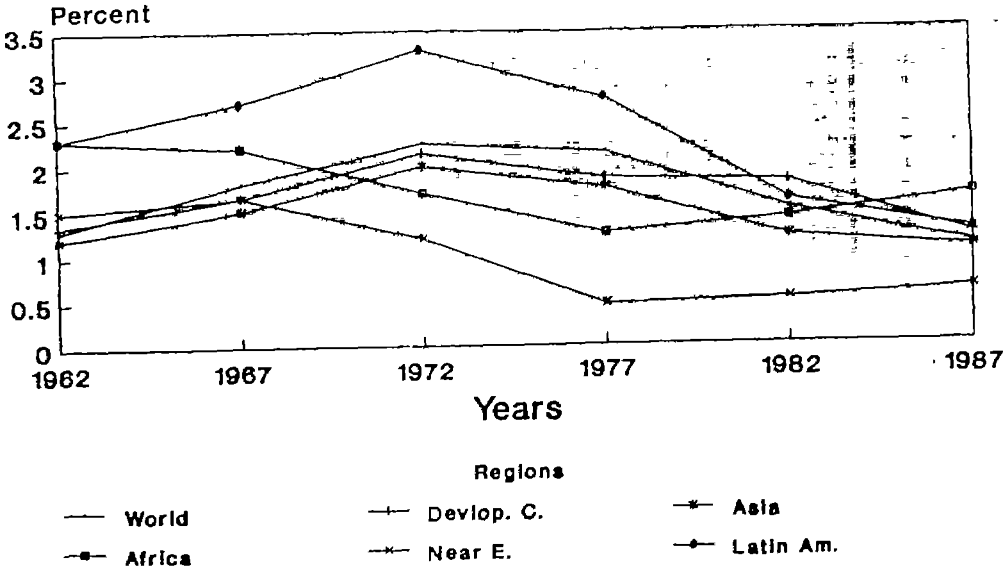

Figure 1 Rates of increase of irrigated land

Table 3 Irrigation in 93 developing countries by region: for the present and for the year 2000

	Irrigated area - CCA (Million ha)		Cropping intensity (%)	
	Present (1987)	2000	Present (1987)	2000
93 Countries	164.7	220	118	123
Africa (Sub-Saharan	5.5	6	84	89
Near East/N Africa	18.8	21	98	109
Asia (including China)	125.2	174	129	129
Latin America	15.2	19	102	106

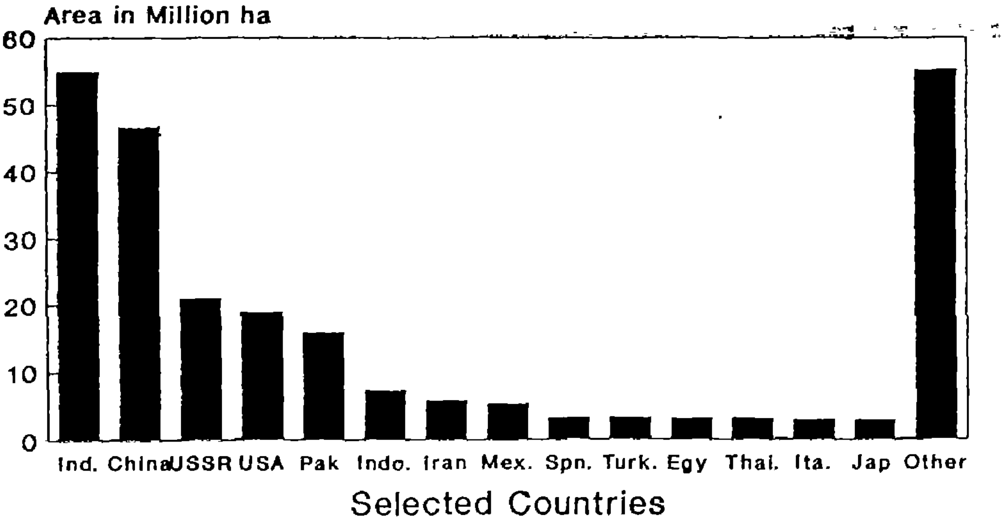

Figure 2 Irrigated area in selected countries (Million ha)

increased population. Looking into the future one sees constraints which should, if lessons from the past are learnt, be within our reach to overcome. These constraints relate to the sustainability of the water and land resources under prevailing socio-economic conditions.

6 Water Resources for Irrigation: Demand

With competing demand for water, it is useful to remember that crop water use is consumptive, i.e. it is lost to the catchment. In developing countries 80 per cent of the water used is for irrigation. Table 4 illustrates the quantities of water involved and its productivity for some major irrigated crops. The quantities of water consumed by the crops on an irrigation project are considerable. But the volumes of water handled by the project system have to take account of system efficiency, a product of efficiency during (i) conveyance, (ii) distribution and (iii) field application. Typical figures for large projects in Asia (Rangeley, 1986) would be (i) 65 per cent, (ii) 75 per cent and (iii) 60 per cent, making the overall efficiency just under 30 per cent. It is thus not difficult to see that something like 2500 tonnes of water may have to be diverted to produce one tonne of cereal.

Table 4 Typical water requirements and water use efficiency of some crops (FAO, 1986)

Crop	Water requirements mm/growing period	Water utilisation efficiency for harvested yield kgm^{-3}
Alfalfa	800-1600	1.5-2.0
Cotton	700-1300	0.4-0.6
Groundnut	500-700	0.6-0.8
Maize	500-800	0 8-1.6
Rice	350-700	0.7-1.1
Sorghum	450-650	0.6-1.0
Wheat	450-650	0.8-1.0

During the Indus Basin studies in Pakistan it was estimated that if the application efficiency was raised from 50 per cent to 60 per cent, this would save annually a volume of water nearly four times the live capacity of Mangla Dam (Olivier, 1972). An indication of how water application efficiency and deep percolation vary with method of application is given in Table 5. Obviously there is much room for improvement; especially as industry and mining, where water is much more productive, can become formidable competitors. While water losses on the farm are to be discouraged, they need not necessarily amount to losses to the river basin as a whole if they can be used downstream. This is not always the case, and may also be poor economics if surface water is converted into groundwater which is then pumped back to the surface.

7 Water Resources for Irrigation: Supply

This is a complex river basin — and sometimes inter-basin — problem, involving surface and groundwater hydrology, as well as possibilities of water re-use. If the objective is, as it should be, to provide a statistically reliable (i.e. sustainable) irrigation water supply, then good hydrological data are required on which to base catchment development plans. Historical data cannot just be manufactured, so predictive models will, in many instances, lack precision and lead to conservative (hence expensive) design.

Table 5 Estimated deep percolation losses as related to water application efficiency, irrigation method and soil type (FAO, 1988b)

Irrigation Method	Application Practices	Water Application Efficiency *Ea x 100*		Average deep percolation as percentage of irrigation water delivered to the field	
		soil texture		soil texture	
		heavy	light	heavy	light
Sprinkler	- daytime application, moderately strong wind	60	60	30	30
	- night application	70	70	25	25
Localized		80	80	15	15
Basin	- poorly levelled and shaped	60	45	30	40
	- well levelled and shaped	75	60	20	30
Furrow, border	- poorly graded and sized	55	40	30	40
	- well graded and sized	65	50	25	35

7.1 Surface water

Dams and their reservoirs are created to regulate stream flow and often to generate power. The amount of storage required to produce a given safe yield depends on the catchment hydrology. For instance, a river such as the Vaal in South Africa, relying entirely on rainy season runoff, requires large volumes of storage and therefore more expensive dams, as compared with rivers fed by high rainfall in equatorial regions (White Nile) or snowmelt (Indus).

The cost of providing storage depends largely on topography of the reservoir area and dam site. It can vary widely, as shown in Table 6. The dams listed were constructed in the heyday of such activity in the 1960s. The headline costs did not include the value of the reservoir area in its previous economic and ecological use, nor any disbenefits created downstream. With the best dam sites naturally selected first, future proposals for dams will have to be based on much more rigorous economic, social and resource accounting.

Table 6 Capital cost of reservoir storage

Dam	Relative cost per m^3
Kariba (Zambesi), Zimbabwe/Zambia	1.0
Kainji (Niger), Nigeria	1.0
Aswan High Dam (Nile), Egypt	1.7
Roseiras (Blue Nile), Sudan	13.6
Bhakra (Sutlej), India	14.3
Kashm El Girba (Atbara), Sudan	19.3
Oroville (Feather), USA	20.7
Gal Oya, Sri Lanka	25.0
El Atazar (Lozoya), Spain	53.6
Mangla (Jhelum), Pakistan	56.4

Increasing demand for electricity means that no opportunity should be lost to generate power when a water mass loses elevation. This renewable source of energy is more environmentally sound than the use of fossil or nuclear fuels. Large dams are therefore often built with their hydropower function foremost. This can be of advantage to other users, as the benefits from the sale of electricity begin to accrue immediately after project commissioning. Even smaller hydraulic structures are now being equipped with turbine/generator sets to satisfy local demand, for example to power tubewell pumps.

Whatever the shortcomings at their creation, existing dams and reservoirs should remain an asset to the river basin, provided their live storage capacity is not reduced by sedimentation. This process can be dramatic, as in the case of Tarbela Dam on the Indus, where the live capacity of 10.6 billion m^3 is expected to be reduced by nearly 90 per cent in about 55 years of reservoir life (Olivier, 1972). The sediment load of some major and smaller rivers is given in Table 7.

It is obvious that such problems cannot be solved on a project-by-project basis but have to be part of national sustainable development strategies for river basins, in which the catchment management aspects, including soil conservation and catchment engineering, will be at the forefront. These issues are key to the deliberations of more than one of the Working Groups.

The protection of upper catchments involves costs which should result in long-term benefits, primarily for downstream communities. The latter should recognise this and make it financially worthwhile for those in the upper reaches to embark on soil conservation measures and practices. An interesting adaptation of a technique, originally used in parts of India, Bangladesh and China to assist groundwater recharge, is to use hedges of vetiver grass along contours

Table 7 Sedimentation in large and small river basins

Rivers	Drainage basin 1000 km^2	Average annual suspended sediment load t km^{-2}
Large		
Yellow (China)	673	2804
Ganges	956	1518
Brahmaputra	666	1090
Irawaddy	430	695
Indus	969	449
Yangtze	1942	257
Mekong	795	214
Missouri	13370	159
Amazon	5776	63
Small		
Lo (China)	26	7308
Ching (China)	57	7158
Ikowa (Tanzania)	0.7	200
Matumbulu (Tanzania)	0.02	550

(Smyle & Magrath, 1990). Recent experience of the World Bank in India shows this to be a very effective and cheap method of soil erosion control.

7.2 Groundwater

Mention of catchment management above implies good management, often on a large scale, without questioning whether such a scarce human commodity is readily available, especially in the public sector. Experience that surface water management was not always reliable has turned the users' attention to the exploitation of groundwater on a very much smaller, and hence more manageable, scale. It is estimated that 95 per cent of the total fresh water in store on the earth and available for exploitation using present-day technology, is held as groundwater (Wilkinson & Clark, 1987). But even though it is extensive it is not always easy to locate.

The suitability of groundwater for irrigation depends on its quantity and quality and, with deeper aquifers, the cost of raising the water. Technically, the difficulty is not so much in determining the presence or the quality of the groundwater, but the assessment of the size of the resource, on a sustainable basis, by balancing withdrawals with recharge. Failure to do so results in falling water levels, loss of yield in wells and often failure of agriculture based on them.

This said, our knowledge of groundwater resources in some major areas (e.g. the Indo-Gangetic Plain) is sound, but what is often lacking is control over its exploitation. Introducing enforceable water legislation for surface water is difficult enough — for groundwater it is much more so. This situation should change when the users become educated to appreciate the hydrological issues involved and become participants in the development planning process.

Over-exploitation or even 'water mining' can be practised, provided society is aware of what is being done in relation to the future. A vivid example today is the Great Man-made River Project in Libya, where 2 million m^3 of water per day will be pumped from fossil water deposits in the desert to coastal plains 400-600 km away. Incidentally, the cost of this project may approach the cumulative lending to date for all irrigation by The World Bank!

7.3 Low-quality waters

It must be said at the outset that if there is no restriction on cost, water of the worst quality can be made pure, e.g use of distilled sea water for irrigation in Kuwait. Such cases, usually strategic, are very much the exception: as much as possible has to be done by appropriate catchment management.

In an irrigation system the question of water quality arises not only at entry, but also at exit (seepage and drainage). The quality of irrigation water is conveniently considered under the headings of (i) suspended solids (silt), (ii) dissolved salts and (iii) domestic and industrial waste.

Silt has already been mentioned in the context of reservoir sedimentation. It can significantly add to maintenance costs if siltation of canals and control structures occurs. The serviceable life of pumping units can also be adversely affected. Against this, silt can be a source of plant nutrients.

Surface water quality varies enormously. Some examples of salinity levels are shown in Table 8. Water having TDS between 500 mg l^{-1} (EC 0.78 dS m^{-1}) and 30 000 mg l^{-1} (46 dS m^{-1}) is defined as saline.

FAO (1990b) classified irrigation water into three groups based on Total Dissolved Salts, Electrical Conductivity and other criteria. In terms of dissolved salt the groups are:

(a) no restrictions on use:
TDS < 450 mg l^{-1} (EC < 0.7 dS m^{-1});
(b) slight to moderate restrictions on use:
TDS = 450-2000 mg l^{-1} (EC = 0.7 to 3.0 dS m^{-1}); and
(c) severe restriction on use:
TDS > 2000 mg l^{-1} (EC > 3.0 dS m^{-1}).

Table 8 Salinity levels in some rivers

River	Total Dissolved Salts (mg/l)
Niger	60-80
White Nile	174
Indus	250-300
Colorado	914
Gila (Arizona)	5120

As water resources become more scarce, there will be a tendency to use more saline and sodic groundwater for irrigation. Guidelines for its use are available, so in the hands of good management such practice can be effective, especially as plant breeders develop more salt-tolerant varieties, but the soil condition has to be carefully monitored. Under specific conditions, seawater has been used to irrigate forage crops.

The water supply may be polluted by industrial wastes injurious to growing plants. Increased awareness of environmental issues will no doubt lead to enforceable legislation to prevent this. On the positive side, domestic and some industrial wastewater can be a valuable resource, not least because of its year-round availability. As such it will be discussed separately below.

The intensive agricultural activity associated with an irrigation project can in itself give rise to changes in the quality of the water leaving the land. For instance, fertilizers entering open collector drains can cause excessive weed growth, while pesticides and other agrochemicals can seriously affect aquatic life. The importance of seepage of nitrates into groundwater is still debated (Pereira, 1986). The monitoring of drainage water quality is therefore essential.

7.4 Wastewater

Rising urban population (growing four times faster than rural population in developing countries) and eventually its higher standard of living necessitates the diversion of rapidly increasing volumes of water for largely non-consumptive use. Table 9 gives some idea of the quantities involved.

The effluent discharges are considerable, reliable and often rich in plant nutrients. The main problem is that they are generally seen as presenting a health hazard. This may be true, more on psychological than medical grounds, for vegetable and salad crops eaten raw, unless very technologically advanced treatment processes are used, at a cost which can exceed ten US cents per m^3. Recently, FAO (1991) has taken a more optimistic view on the use of treated wastewater in agriculture, pointing out that pathogenic agents, notably the helminths, are completely removed by settling and stabilisation ponds at about 20 per cent of the above cost, i.e. less expensive than water from most conventional sources.

It should be noted that costs depend largely on availability of land for the treatment ponds and on the distance the water has to be conveyed to the agricultural land; opportunities are therefore very site-specific. Mexico City, for instance, aims to increase productivity of agricultural land near the city to prevent it from falling into peri-urban slums. Artificial recharge of aquifers with sewage effluent can be an effective way of conserving this water resource in a manner which is reassuring to the public.

Table 9 Projected effluent volumes in the year 2000 (Pescod and Alka, 1984)

City	Volume (million m^3 y^{-1})
Mexico City	2600
Sao Paulo	2200
Cairo	1100
Addis Ababa	500

Wastewater re-use is of great interest in arid and semi-arid regions and on smaller islands with limited freshwater resources. In oil-producing desert environments, expensive water is used in the petrochemical industry, the wastewater from which has been seriously considered for irrigation (Al-Shatti, 1989). Indeed, even copper mine tailings effluent has been diverted to grow crops in a barren valley in Chile.

7.5 Conjunctive use

If water is scarce, it is only natural for the user to look at all sources available and make the best use of them. The most common is the conjunctive use of canal and groundwater, especially on large alluvial plains where losses from rivers, canals and fields go into shallow aquifers. These are often exploited by farmers privately, while receiving public canal water.

8 Degradation of Irrigated Lands

The land on irrigation projects is valuable because it is commanded by what often is an expensive system of hydraulic works. For it to lose productive capacity through waterlogging and salinisation is therefore highly regrettable. The reasons are sometimes historic, when, for instance projects conceived as protecting farmers from monsoon failure (i.e one crop per year) become irrigated continuously. For newer projects, economic criteria based on discounting made expenditure early in the project life seem unattractive, so that investment in land drainage, which today is of the order of $1000-2000 per hectare, was not seen as a priority.

The result is that water table levels are rising by as much as 3 m per year (Nubariya, Egypt and Beni Amir, Morocco). In arid regions the consequent restriction to downward flow of water through the crop root zone causes deposition of salts. Taking a typical annual water use of 12,000 m^3 ha^{-1} and a very acceptable quality of water supply with salinity of 300 mg l^{-1}, some 3.6 tonnes of salt per hectare have to be dealt with. Figure 3 gives an idea of the problem worldwide (Postel, 1989).

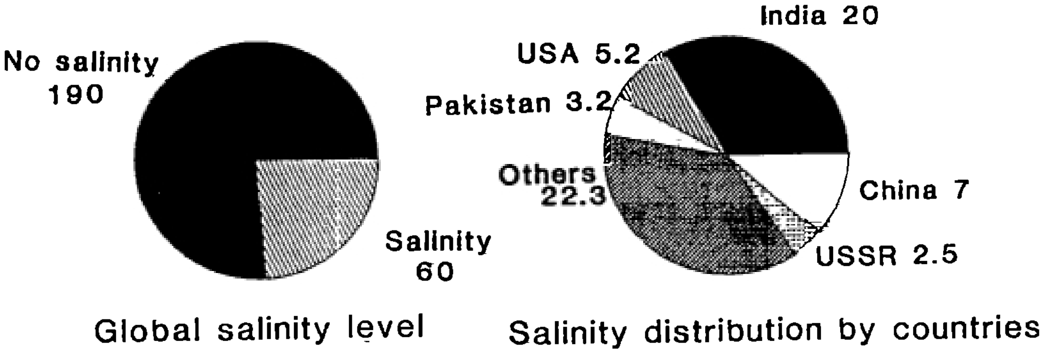

Figure 3 Irrigated land damaged by salinisation (areas in million hectares)

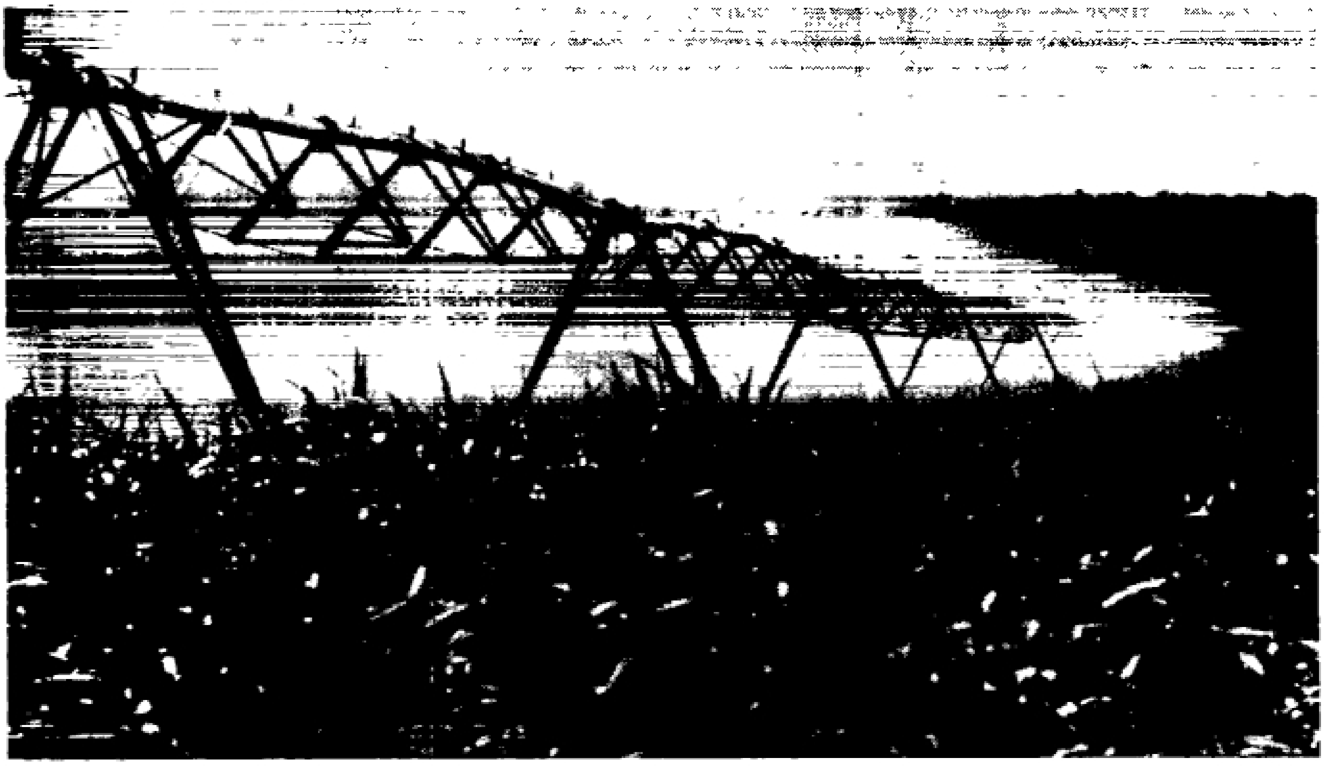

Plate 1 Modern irrigation technology at work: water is applied in the form of raindrops from sprinklers fixed to the rotating arm of a centre-pivot irrigation system. Under such a system water use efficiency is high.

Provision of drainage facilities passes the economic viability test only when the crop yields, though reduced, are at a high level (e.g. cereal. 6-8 t ha^{-1}). With much lower yields typical of developing countries, social and environmental (sustainability) criteria have to be invoked. Considerable effort has, therefore, to be made on the one hand to increase the water application efficiency at field level, and on the other to reduce the costs of drainage installations and hence of reclamation of degraded lands. A good example of the application of modern techniques in this sphere is the Integrated Soil and Water Improvement Project (ISAWIP) in Egypt.

9 Water Management

This can be seen as composed of three elements· (i) resource management within the catchment, (ii) conveyance to the farming units and (iii) management within the farming units. The importance of each depends very much on scale. On large systems (e.g. the Indus Basin) each is a major management task, while a small farmer with a well is largely in control of all three and instinctively appreciates the interaction between them.

The professional bodies which have been responsible for the management and distribution of the water resource should have, for at least a generation, been educated to be aware of the user requirements and, in particular, the problems of irrigation farming. But in some countries certain traditions, which are reflected in professional hierarchies between and within line departments, give little incentive to such awareness. There is a great deal, therefore, that can still be done to provide a more effective interface between the suppliers of irrigation water and those receiving it as an input for agriculture.

While encouraging the suppliers to look downstream at the needs of the user, it is also important for the user to have a broad (non-technical), appreciation of how the supply system works and what are its physical limitations. Whether the system is actually operated efficiently within its physical constraints is, of course, another matter.

From the point of view of the supplier, the easiest system to operate is one of *constant flow*. The user, on the other hand would like to receive water *on demand*. A true *on demand* system (*cf* electricity, domestic water) would be very expensive, as peaks would have to be designed for. It is also unnecessary since water held in the soil acts as a reservoir.

A good compromise is promoted by the National Water Management Project in India, where water is delivered according to clearly defined rules to meet the requirements of the predominant cropping pattern, without attempting to satisfy individual needs of countless farmers. Although not absolutely guaranteed, the water supply can be relied on by the farmers, who arrange their farming activities accordingly. Flexibility is helped if storage low down in the system can be provided to be operated by the farmer or farmer group.

Much has been written about the quality of management of irrigation systems. Since these are usually in the public sector, one often ends up with underpaid civil servants, trained as administrators, assuming management roles. Besides, if the salary is the same, a posting in town is more attractive than one in the field. There is no universal model solution to this problem, but it should be noted that even in Eastern Europe there is a tendency to move from public to private enterprise.

Water management on the farm presents many choices and opportunities to improve water use efficiency. Comments are increasingly being made that research in irrigation technology lags behind that in agronomy and that it is slow in showing results in the field. The impressive, but costly, research that produces new plant varieties or new agrochemicals is not all that expensive to the user, who can try them out without long-term commitment. To change to a different distribution or water application method is quite another thing. Here it is not a question of 'frontiers of knowledge' research, but of evaluating and adapting what already exists and of creating conditions (reliable water supply, credit, produce marketing) which make it attractive for farmers to use. An interesting example of what is called *Advanced Technologies in Traditional Agriculture (ATTA)*, is in the Western Jordan Valley (Rymon & Or, 1990). The success there is not unrelated to the proximity of highly advanced irrigation systems and a competitive supplier market for the equipment Similar developments have taken place in Guatemala, India and Morocco (Keller, 1990). In general, introduction of modern technology should be approached without too many preconceived ideas. If locally made products are available, they may be suitable and economical

Management decisions have to be based on information about system performance. Data collection and processing activities take time and therefore cost money, which should be budgeted for. It should not be the function of separate external monitoring units, but be the routine duty of all

***Plate 2** Small-scale irrigated crop production can meet the food and nutritional requirements of farm families, as well as bringing in substantial income. The picture shows a progressive young couple in Swaziland working together on their irrigated vegetable plot*

Plate 3 Water storage on the farm has multiple benefits. In addition to meeting the supplementary irrigation needs, farm reservoirs can be used for fish culture and domestic water use.

professional and technical staff, assisted by specialists in the management unit. Outside assistance can be obtained to develop methodologies and computer simulation models to help management with sometimes difficult operational choices, for instance, under conditions of water scarcity or equipment breakdown.

Participation by the users in the planning and management of irrigation projects is highly desirable as it encourages commitment. This trend, coupled with better education, will lead to the provider of irrigation water to be perceived as the adequately rewarded servant of the user, as is the case with utilities like electricity, gas or domestic water.

10 Irrigation Farming Systems

The irrigation water supply on its own has no value until it becomes part of a package of inputs at the disposal of the farmer, or farm manager, whose skill and effort, or lack of them, will be reflected in the performance of the farming enterprises and of the project as a whole Sustainability of the project is thus closely linked to sustaining the motivation of the human agents of production, who, with better education, are becoming increasingly articulate.

It is difficult to generalise globally on what is the best system of high-input agriculture, because so much depends on the background and experience of the participants. If the expertise is lacking, or if higher value crops are dominant, then the estate format may have many advantages. It can generate secure employment and the opportunity for farm workers to learn on the job and later to apply this knowledge on their own land.

However, in most developing countries irrigated agriculture is in the hands of people farming small (often too small) units of land. Their interests may not be confined to irrigation, but include rainfed agriculture, animal husbandry, aquaculture, as well as off-farm work. To the small farmer the overriding objective is one of security, i.e. reduction of risk The conservative frame of mind that this encourages is sometimes mistakenly attributed by outsiders to stupidity and laziness But for people living at the margin of subsistence, adopting an innovation that fails may be a matter of life or death (Pereira, 1986).

If farmers, or farm managers, do not have control over their inputs then they have the right to expect those who do have control to manage them in a secure (and therefore sustainable) manner. Since water is the prerequisite for other inputs to intensive agriculture, its timely and reliable supply is the basis for increased productivity through introduction of new varieties and diversification into higher value crops.

It also has a direct bearing on the farmers' willingness to contribute towards the cost of providing the water. This is a controversial subject (Repetto, 1986) which deserves objective airing.

Innovation usually starts with farmers, on adequate land holdings, who can afford to take some risk. It is therefore important for planners to embark on research so as to identify, quantify and aim to remove bottlenecks in the farming systems to give farmers a chance to increase the volume and value of their production Farmers, on their part, should understand the technical possibilities and their associated costs; their decisions must be related to willingness to pay. It must also be realised that changes may be opposed by the privileged, both *traditional* and *modern*, whose position may well be threatened. In the attempt to establish a 'new order' at farm level, one should be reminded that in many parts of the world women take a leading role in agriculture. Given their due status in the eyes of law and commerce and equal educational opportunities, they can become significant agents of rural prosperity.

Holding a title to the land encourages good farming practices and a responsible long-term attitude to the land resource, provided the land is not treated just as a hedge against inflation by the owner, or as a substitute for social security by the state.

11 Scale of Development

Scale here is a relative concept. A project of over 500 ha would be classed as large in Sub-Saharan Africa, while in Southern Asia it would be considered as minor. Disappointing performance of large modern projects has given rise to a debate on what is the most appropriate scale of development. Before discussing these further it may be useful to begin with the assumption that in most developing countries, where intensification of agricultural production will have to depend on irrigation, sooner or later the limit of water and land available for this purpose will be reached. If this limit is still far away, then the question can be asked whether it is better to concentrate now on small-scale projects and leave larger-scale projects for later, provided the choices are not mutually exclusive.

Small-scale projects are attractive for many reasons Notably, they are more likely to be conceived with the participation of the local community and, as such, will tend to be easier to manage and therefore sustain. Their costs are on the whole lower and the time to completion shorter. To illustrate the contrasting economic implications of large-scale and small-scale projects the FAO Investment Centre team (FAO Investment Centre, 1986) considered hypothetical, but not unrealistic, scenarios for cash flows over a project period of 30 years. Taking total investment costs as 'C' and the annual net benefit at full production as 'b', these were taken as shown in Table 10.

The question posed then was: what net annual benefit at full production (b) as proportion of capital cost (C) has to be achieved to reach a given Economic Rate of Return (ERR). The answer for the two cases is:

	Large scale	*Small scale*
b/C ratio = 12 per cent	0.152	0.101
b/C ratio = 7 per cent	0.125	0.082

These non-dimensional results can be given monetary values when translated through crop productivity into net benefits for various crops or cropping patterns. Taking the cases of paddy rice, maize, sugar-cane and seed cotton the indications were that for an ERR of 12 per cent the capital cost per hectare of large-scale projects should not exceed $5000 for seed cotton, $4000 for sugar-cane and $3500 for paddy or maize. For small-scale projects the figures were approximately $1000 higher throughout. Such rough calculations give planners an indication of what level of capital investment could be reasonably contemplated to make the project economically viable.

Small projects can also be very efficient in water use, especially when human power is used to lift water. Hydromodules as low as $0.25\ l\ s^{-1}\ ha^{-1}$ have been observed on vegetable gardens served by shallow wells and hand watering, about three times lower than on formal projects. Animal power, coupled to modern or updated pumping sets, can be appropriate in many countries. Solar powered (photovoltaic)

Table 10 *Hypothetical scenarios of cash flows over 30 years*

Year	1	2	3	4	5	6	7	8	9	10	11	12-30
Large-scale												
Capital cost (per cent of C)	5	5	10	15	15	20	20	10	-	-	-	-
Net benefit (per cent of b)				10	20	30	45	55	75	85	95	100
Small-scale												
Capital cost (per cent of C)	100	-	-	-	-	-	-	-	-	-	-	-
Net benefit (per cent of b)	30	65	100	100	100	100	100	100	100	100	100	100

pumps are beginning to compete on equal economic terms with unsubsidised diesel powered units; developments here are worth watching.

Government departments and NGOs are now being assisted in the design of minor projects by computer software packages (Skutsch, 1991), based on years of experience in the field. This in effect means that the same level of engineering is applied to the design of large and small projects. However, the constraint may be the quality of execution if local contractors are not up to the required standard.

Although government intervention in small-scale development can, and should be, kept to the minimum, good advisory services are essential. On technical matters farmers would welcome an impartial *seal of approval* on equipment, such as pumps, especially when there is no user experience on which to base the selection.

If the reason for advocating small-scale development is to give control to the users over the water supply, which on a large project could be unreliable, then it is important to be sure that the users do not become dependent on equally unreliable distribution of electricity or fuel.

Generalisations are therefore difficult and can be controversial, but if the ultimate objective is to maximise food production, then projects of *all sizes* will have to be introduced eventually, taking account of what type of management is available at the time to sustain a particular type of development. In this context, donor reluctance to fund smaller projects and tendency to favour more prestigious large ones is disappointing.

12 Health Hazards

The aim of improving the quality of life of the rural population obviously encompasses the protection and, whenever possible, promotion of its health status. Irrigation development will contribute to these aspects in several ways. Directly, it will have an effect on the nutritional status by facilitating a better availability of food and more varied diet. Indirectly, the improved infrastructure usually achieved as part of irrigation development will make the contacts between the population and the health services easier; vaccine coverage and drug distribution will generally benefit. Economic strengthening of the area will give the population an increased purchasing power for medicine, mosquito nets and other preventive or curative products.

Inadvertently, however, irrigation development may also create health hazards. These result from the environmental modifications introduced by hydrological changes, habitat modification and increased humidity. The new conditions may favour the propagation of disease vectors (mosquitoes, aquatic snails, etc.) or increase the life span of mosquito vectors. Combined with demographic changes (settlers or people attracted to the economic opportunities offered by the project, who may either introduce a new disease or be non-immune to endemic disease), this may lead to dramatic outbreaks of, for instance, malaria. In some extreme cases in the past, this has jeopardised the operation of the irrigation scheme itself.

Two most important irrigation associated diseases are malaria and schistosomiasis. The distribution of malaria and its occurrence in time are rather patchy, and the most dramatic effects are seen in arid and semi-arid zones where irrigated agriculture is introduced. However, even in areas which already have a certain level of malaria endemicity, irrigation development may mean a shift from seasonal to perennial transmission with severe consequences especially for children.

Schistosomiasis is a chronic debilitating disease. Many cases of sharp increases in the prevalence rates of this disease from 0 per cent to 70-80 per cent in the wake of irrigation development have been documented, particularly from Africa. Case studies showing negative impacts of both diseases on agricultural production have been reported in various parts of the world.

Of more regional importance are lymphatic filariasis (West and Central African vectors which breed in clean freshwater water conditions) and Japanese encephalitis, which is 100 per cent linked to the irrigated rice agro-ecosystems of South and South-East Asia. Onchocerciasis is only rarely associated with irrigation, usually when canals with steep gradients or spillway structures are part of a scheme, and then only in West Africa.

While control of these diseases by whatever medical means is the responsibility of the health sector, the prevention of conditions favourable for mosquito and snail breeding should be taken up in the first instance by engineers and agriculturists who plan, design and operate the irrigation schemes. The successful incorporation of health safeguards into any irrigation scheme requires the establishment of effective mechanisms for intersectoral collaboration at the earliest planning stage.

With this in mind, the WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control (PEEM) was established in 1981. It provides an institutional framework for effective interagency and intersectoral collaboration by bringing together various organizations and institutions involved in health, water and land development and the protection of the environment, with a view to promoting the extended use of environmental management measures for vector control within health programmes and in development projects as health and environmental safeguards.

An awareness by planners of the health implications of their projects is essential, but the biggest and most lasting impact will be made by educating the local population and by the consequent changes in their sanitary habits (e.g the Blair toilet developed in Zimbabwe). Medical research has also produced excellent results, with mass chemotherapy being very effective.

13 Broader Environmental Effects

Irrigated agriculture has a profound effect on the environment including the water bodies, the crop lands receiving it, and the rural environment. The adverse environmental impacts and the means of overcoming them will constitute major determinants in planning future irrigation developments.

Already, mounting concern about waterlogging and salinisation of lands, declining and contaminated aquifers, polluted rivers, lakes and inland seas and the destruction of aquatic habitats is making new large water projects increasingly unacceptable. Another important point is that the links between the damaging environmental effects of irrigated development to non-agricultural sectors and their developmental activities will have to be recognised and dealt with.

The most direct and obvious effect of withdrawals of water for consumptive use is that it reduces flows downstream of the abstraction point. When coupled to storage reservoirs the pattern of flow can be altered significantly. Such knowledge is not new, but its importance may not always have been fully appreciated.

Cases are on record where water, which was efficiently used in a traditional manner on the flood plain, has been diverted to a costly and far less efficient formal irrigation project. Its value in the previous use had not been considered when planning the "modern" project.

Capture fishery activities are broadly divided into one third on lakes and reservoirs and two thirds on rivers. For the latter to be sustainable it is important to maintain connection between the live floodplain and the river channel. Breakdown of the floodplain and loss of channel diversity create serious environmental consequences. The value of wetlands to man, beast, fish or fowl varies enormously. It should always be considered in an Environmental Impact Analysis (EIA).

Probably the most criticised aspect of water management has been the inundation of valleys by dam reservoirs, with resulting loss of land and displacement of people. Again, these are very site-specific problems, which by now have been well documented. Since by exhausting suitable dam sites the pace of creation of such reservoirs is rapidly diminishing, there will be more time to incorporate past experience into future plans.

High-input agriculture and especially that based on irrigation can create problems downstream by releasing excess agrochemicals. This is by far the more serious environmental problem faced by many developed countries whose agriculture is characterised by heavy application of fertilizers and intensive livestock production. In most developing countries, water pollution due to high levels of fertilizer application is not a serious issue, but these countries should learn from their counterparts in the developed nations and take measures to prevent any impending agrochemical pollution problem.

14 Economics of Irrigation

Reference has already been made to the slowdown in the rate of irrigation development in the world in the last decade, largely because of increases in construction costs of modern projects and some legitimate questioning of their performance, especially under low-value crops.

In some major irrigating countries, such as India, the physical limit of land and water resources was being reached. The oil price shocks of 1973 and 1979 were partly to blame, but it must be remembered that modern project appraisal methods will tend to give priority to lower-cost alternatives. So with a limit on water and land resources the economically more attractive projects will be built first. It is estimated that, in real terms, the cost of medium to large projects, supplied by surface water, has more than doubled between 1950 and 1980 (Postel, 1989). Table 11 gives a range of typical costs. Here, too, it is unlikely that environmental costs have been taken into account.

***Table 11** Typical capital costs of large projects (Postel, 1989; Rydzewski, 1990)*

Country	Capital Cost (US $ ha^{-1})
China	1500
India, Indonesia, Pakistan The Philippines, Thailand	1500-4000
Brazil	6000
Mexico	10 000
Kenya	up to 21 400
Nigeria	up to 28 800

Overall, costs can range from a few hundred dollars per hectare for a well and hand-pump irrigated garden to a quarter of a million dollars per hectare for a complete climate controlled system in an arid country. In some regions project costs should be seen in the context of the cost of frequent famine relief operations.

The benefits are, of course, the difference between the *with project* and the *without project* situations: the latter includes upstream and downstream productive activities which the project could have affected. Projects can take up to ten years from the beginning of construction to reach full production, and they do not fare well in standard Discounted Cash Flow (DCF) analyses using discount rates of over ten per cent. It should be recalled that the Net Present Value (NPV) or Internal Rate of Return (IRR) criterion of project viability was initially introduced for industrial investment, where a time horizon of 30 years is quite generous, since product life and manufacturing technology change frequently. So it would seem that the virtue of sustainability is of little consequence from the standpoint of DCF analysis! High discount rates encourage *low initial cost* and high *operations* *and maintenance cost* proposals, without considering whether the latter are sustainable, especially when foreign exchange costs are involved.

Project analysis has two broad functions: (i) to apportion scarce resources in the economy as a whole and (ii) to select the best projects within a given sector, or distinguish between different proposals for a particular project. It can be argued that criteria of acceptability for the first must be the same for all sectors, thus creating difficulties when short-life and long-life projects are compared. But once development of a particular sector (e.g. agriculture) has been willed, then the selection of the best projects from within it can follow lines which take account of its special characteristics.

Irrigation project proposals, be they for new areas or, increasingly, for rehabilitation and modernisation of old areas, have to be appraised from more than just the economic efficiency point of view. The future must also be seen from the position of the farming family, the project management and those affected by, but excluded from, the project. Multi-objective planning, though not a new concept (Rydzewski, 1975), has recently been given a well-deserved intellectual impetus through development of techniques of multi-criteria analysis (Pearce *et al.*, 1990; Petry, 1990; Turner, 1991). In particular, the idea that the degree to which a particular project proposal satisfied the various stated objectives was a matter for politicians to decide is being rightly replaced by one of consultation, formal and informal, at local level.

14.1 Cost recovery

Implicit in any benefit/cost analysis is the assumption that someone will benefit from the costs incurred. This leads to the feeling that those who benefit should contribute to the costs through water charges. If these do not cover the whole project cost, then it is clear that other sectors of society are subsidising irrigation farmers. Whether this is right or wrong is a socio-political question. Since inadequate management of the irrigation water supply is often linked to lack of cost recovery, it is useful, if only conceptually, to separate the two issues in the following scenario. *The irrigation water is supplied to the state by a utility company which charges the state the full cost of providing a reliable and sustained service; the state then sells the water to the user at whatever price it feels is politically right, but realising that the amount of any subsidy is public knowledge.* In some countries the problem is complicated by subsidies on farm inputs being offset by low farm-gate prices, which are not helped by subsidised agricultural surpluses in the First World. More transparency in government financial interventions is to be welcomed anywhere in the world.

15 Policy and Strategy

15.1 General

Development priorities relate to the nation's view of itself in the future. This, in turn, depends on how well evolved is the feeling of *nationhood* (national interest) and also on how the nation, however defined, fits into the region. (Europe today presents some interesting examples of problems arising out of these concepts.) Once national development objectives are formulated by government and people, their implementation should be based on closely integrated sector development plans. These require a strong input from specialists to advise on how best to dispose of natural, human and financial resources to achieve the set aims.

The importance of controlled water resources in agriculture and food production varies enormously from country to country so that global generalities are inappropriate. What is essential, however, is for the degree of its importance and its relation to associated resources to be recognised by the planners and by the politicians they serve. This has to be based on a sound knowledge of the resources (water, land and people) and on their potential in relation to the development of the economy as a whole.

A major objective in building a prosperous rural sector is to stem the alarming drift of population to large cities (e.g Mexico City, Cairo, Bombay) and consequent problems of peri-urban slums. To do this it is necessary to raise the *value added* of produce from this sector. The primary activities, such as agriculture, animal husbandry, aquaculture and forestry, are in the future likely to occupy fewer people. But there is great scope to develop industries based on them, located in the area of production. This, in turn, requires the existence of a physical and social infrastructure which would make both business and personal life there more attractive than in the overcrowded city.

In many developing countries, institutional conflicts and rivalries between agricultural and water ministries have led to inefficiencies and wastage of human and financial resources. As water is a limited and essential natural resource, shared by a variety of users, it is imperative that, for its sustainable use, a holistic approach in its development and management at the national level is adopted. This can only be performed through intersectoral collaboration involving all relevant sectors, and national policies on water use should clearly embody provisions for such collaboration for efficient water management at the national level.

Water resources use, especially consumptive use for irrigation, can be the cause of conflict when it is shared by a number of countries. So before a nation can plan sustainable water resources development it must secure sustainable water rights treaties with other national users. History shows that this is never an easy task.

Such strategic planning has to be backed by strong commitment and leadership from the highest levels. In the first instance, however, this has to work through existing bureaucratic systems. There one often finds single-purpose line agencies, which performed their tasks well in the early days of their existence, but now find that their *rule books* are no longer adequate for a modern multi-purpose function.

The divisions and professional rivalries that frequently exist in the broad realm of water for agriculture have been known for a long time, and it is therefore disappointing that more has not been done to focus the considerable technical talent available on the urgent problems in hand.

The technology for water management is well established, but its selection and application to specific development problems has often been far from effective. Transfer of information is becoming increasingly simple, but mechanisms must exist for it to reach the people who can benefit from it.

Reference has already been made to the high costs of building new projects and rehabilitating older ones. Contractors quote prices which take account of uncertainties in supplies of inputs and have to cover what are often excessive local administration expenses. Removing such constraints would be of general advantage.

International assistance will certainly be needed to fund the projects studies themselves, but, more importantly, to support adaptive research and training programmes for technical staff, as well as the farmers, to raise the performance of water management for food and agricultural production to meet the demands of future generations.

Finally, sight must not be lost of the fact that the user, the farmer, large or small, has to be placed at the centre of the stage of this development activity.

15.2 International Action Programme on Water and Sustainable Agricultural Development

Obviously, not everything can be achieved at once, so priorities for action have to be made. With this in mind, the FAO in collaboration with relevant UN organizations drew up the Action Plan, identifying five major areas for attention, as summarised below.

i *Water use efficiency*: Efficient use of water in the agricultural sector is absolutely critical to improve overall water use efficiency. Positive action is required to transfer existing technologies and to support their implementation. Urgent action is required to educate and train extension staff; strengthen water and soil management research under irrigated and rainfed conditions; monitor and evaluate irrigation project performance; and establish effective demand management procedures and water pricing policies.

ii *Waterlogging, salinity control and drainage*: In rainfed agriculture, surface drainage is required to prevent any temporary waterlogging and flooding of lowlands. In irrigated agriculture, artificial drainage is essential under most conditions. It is also essential to minimise drainage requirements and costs by reducing the sources of excess water through improved system design and on-farm water management practices. Design of appropriate drainage systems, securing funds for their construction and maintenance, farmers' involvement in the management of drainage systems and safe disposal of drainage effluents are important. Groundwater monitoring, water balance studies and conjunctive use of surface and groundwater should be encouraged. Pilot projects in waterlogged and salinised areas need to be established to verify available technologies and train personnel.

iii *Water quality management*: Concerted and planned actions are necessary to establish and operate functional and cost-effective monitoring systems and to ensure that water available for agricultural uses is of acceptable quality. Simultaneously, appropriate steps must be taken to ensure that agricultural activities do not adversely affect water quality and so impair subsequent uses of water for different purposes.

iv *Small-scale water programmes*: Small-scale water programmes can fulfil many local water needs and have considerable global potential for the achievement of sustainable agricultural development. Such programmes should include development of small-scale irrigation, water supply for humans and livestock, improved infiltration to groundwater, soil conservation, water harvesting and flood control. These initiatives should be designed to integrate development and conservation and enhance local involvement in environmental management. The programmes, when properly implemented, would generate employment, promote equity, improve health standards and can help to slow down or prevent migration to urban areas.

It is important that small-scale water programmes should be founded on adequate technical advice and support, improved institutional collaboration and greater involvement of local communities.

v *Scarce water resources management*: Water scarcity conditions require long-term strategies and practical implementation programmes for the development of agricultural water use in ways consistent with limited water resources and competing demands for water. National planning capacities should be developed to formulate policies and strategies to cope with scarce water conditions; appropriate legal frameworks on water rights should be formulated to enable efficient and equitable water use; under certain conditions specialised programmes focused on 'drought preparedness' should be formulated and implemented with special emphasis on food scarcity, environmental protection and improving community resilience.

16 Conclusions

It has become fashionable to criticise the projects built in the past by water and irrigation engineers. There are, just as in any other sphere of human endeavour, some notable failures, but looking back the achievement has been impressive. Without the water management input the Green Revolution would not have taken place.

Recalling that any physical intervention has by definition an environmental effect, it is too much to expect all such effects to be benign, especially when seen from the base of knowledge available at the time of implementation. With advances in science and technology and with increased awareness planners today try to arrive at the best solution possible to the problem. Often they are not given enough time and money to do so to their professional satisfaction. This is not implying that no resources should be spared to seek perfection (Voltaire: 'the best is the enemy of the good'), but there is a need to balance costs of planning and design studies against the ultimate cost (capital and operational) of the final outcome: small savings on the former can end up as vast increases on the latter.

There is, of course, a need to learn from the past, through monitoring of the performance, technical, economic, social and environmental, of existing projects. Given this, the world community can have confidence that projects in the future will be formulated and designed both to be environmentally sound and to be sustainable, fundamentally by being attractive to the local people.

Competition for international funds is keen, and those administering them, on behalf of taxpayers, are showing justifiable interest in the recipient nation's management of its resources and its budgetary priorities. A strong commitment backed by political and administrative action is required to create conditions under which investment of external funds will be seen to be helping those who need it most and, with their energy and enthusiasm, will help to build a sustainable and prosperous rural sector of the economy. This will be seen as a favourable environment for development.

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APPENDIX

Table A-1 *List of 93 developing countries*

Africa, Sub-Saharan	Near East/N Africa	Asia	Latin America
Angola	Afghanistan	Bangladesh	Argentina
Benin	Algeria	Burma	Bolivia
Botswana	Cyprus	Cambodia	Brazil
Burkina Faso	Egypt	China	Chile
Burundi	Iran	India	Colombia
Cameroon	Iraq	Indonesia	Costa Rica
Central African Rep.	Jordan	Korea DPR	Cuba
Chad	Lebanon	Korea Rep.	Dominican Rep.
Congo	Libya	Laos	Ecuador
Côte d'Ivoire	Morocco	Nepal	El Salvador
Ethiopia	Saudi Arabia	Malaysia	Guatemala
Gabon	Syria	Pakistan	Guyana
Gambia	Tunisia	Philippines	Haiti
Ghana	Turkey	Sri Lanka	Honduras
Guinea	Yemen	Thailand	Jamaica
Kenya		Vietnam	Mexico
Lesotho			Nicaragua
Liberia			Panama
Madagascar			Paraguay
Malawi			Peru
Mali			Suriname
Mauritania			Trinidad & Tobago
Mauritius			Uruguay
Mozambique			Venezuela
Niger			
Nigeria			
Rwanda			
Senegal			
Sierra Leone			
Somalia			
Sudan			
Swaziland			
Tanzania			
Togo			
Uganda			
Zaire			
Zambia			
Zimbabwe			

Table A-2 Irrigation in 93 developing countries: Cultivable Command Area (CCA) and its relationship to arable land

	CCA (1000) ha	As % of arable land in use		CCA (1000) ha	As % of arable land in use
93 Developing Countries	164,701	18.6			
Africa (Sub-Saharan)	5508	2.7	Libya	238	12
			Morocco	1255	16
			Saudi Arabia	425	39
Angola	10	0.2	Syria	654	11
Benin	22	0.7	Tunisia	270	6
Botswana	12	1	Turkey	2190	8
Burkina Faso	16	0.2	Yemen	316	11
Burundi	70	7			
Cameroon	24	0.3	**Asia**	125,145	33
Central Afric. Rep.	4	0.1			
Chad	50	0.7	Bangladesh	2199	24
Congo	8	1	Burma	1079	11
Côte d'Ivoire	58	0.8	Cambodia	90	3
Ethiopia	162	1	China	44833	46
Gabon	1	0.3	India	42100	25
Gambia	26	9	Indonesia	7400	35
Ghana	10	0 2	Korea DPR	1180	49
Guinea	70	2	Korea Rep.	1260	59
Kenya	49	1	Laos	120	13
Lesotho	1	0.3	Nepal	338	8
Liberia	19	3	Malaysia	660	28
Madagascar	960	31	Pakistan	16080	78
Malawi	20	1	Philippines	1480	19
Mali	200	3	Sri Lanka	530	28
Mauritania	23	2.5	Thailand	3996	20
Mauritius	17	17	Vietnam	1800	28
Mozambique	105	2			
Niger	32	0.3	**Latin America**	15,227	8 5
Nigeria	855	3			
Rwanda	15	2	Argentina	1700	5
Senegal	175	3.5	Bolivia	165	5
Sierra Leone	55	3	Brazil	2500	3
Somalia	112	9	Chile	1300	26
Sudan	1870	13	Colombia	496	9
Swaziland	62	31	Costa Rica	118	22
Tanzania	146	1.5	Cuba	890	27
Togo	13	1	Dominican Rep	206	14
Uganda	12	0 2	Ecuador	546	21
Zaire	24	0.2	El Salvador	117	14
Zambia	20	0.4	Guatemala	79	4
Zimbabwe	180	4.5	Guyana	128	26
			Haiti	70	8
Near East/ North Africa	18,821	21	Honduras	88	5
			Jamaica	34	13
			Mexico	4900	20
Afghanistan	2660	33	Nicaragua	84	7
Algeria	360	5	Panama	30	5
Cyprus	31	20	Paraguay	66	3
Egypt	2800	100	Peru	1200	32
Iran	5740	39	Suriname	60	88
Iraq	1750	32	Trinidad & Tobago	22	18
Jordan	46	9	Uruguay	100	7
Lebanon	86	29	Venezuela	328	9

5

The importance of water resources for urban socio-economic development

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EXECUTIVE SUMMARY

This paper demonstrates the importance of water in the urban economy. It reviews estimates of existing and future water demands for household, industry and agriculture purposes. Given the likely problems of water availability and water quality arising out of rapid urbanisation, the paper argues for the need to evolve an urban water management policy with particular focus on issues relating to pollution abatement and water conservation. In this context the role of water pricing is stressed since a large proportion of excess use is related to the low price of water.

The paper also emphasizes the need to calculate the relative costs of conserving water and developing new water supply sources. It may indeed be worthwhile to adopt measures for conserving water as it is generally less expensive than developing a new water source. There is however a limit to which this can be done and this limit is set by the marginal cost.

The paper also highlights the crucial role of water in the day-to-day life of the urban poor, especially the squatters and slum dwellers. These people often pay more for water, and spend much more time and energy getting water, than a relatively affluent person. Further, the productivity of the poor worker, through his health and morbidity, is in many ways determined by his access to an adequate and safe water supply.

Historical declines in mortality have been clearly linked to developments in sanitation which are largely water related. Cross-sectional contemporary data also confirm the strong inverse relationship between safe water supplies, sewage disposal, and health and mortality. While information and education can lead to better water use practices at the household level, the municipal supply of better and more water is perhaps more important and cost-effective.

The paper argues that much can be done to improve the overall quality of life of the poor using community participation in water management as an example. Given the constraints on resources in most countries, as well as the demand for these resources by competing priority sectors, the overall assessment of the paper is that low cost technologies for providing adequate and safe water to the urban community need to be vigorously pursued.

CONTENTS

1 Introduction

One of the most important challenges facing policy makers is to reconcile the conflict between the newly industrialising economies and the concept of a sustainable environment. This conflict is clearly visible in the burgeoning urban areas which have, over the years, become dynamic centres of manufacturing and commerce. These centres are far more advanced than their hinterlands in terms of literacy level, productivity and per capita income. However, sustainable development has not been practised, and they have not been able to adequately protect the very resource base which gave birth to their economic enterprise.

Air and water pollution have seriously jeopardised both the health and quality of life that has been made possible through rising incomes. The urban revolution currently under way in developing countries is perhaps irreversible as most government programmes designed to reverse these trends or at least reduce their intensity have generally proven futile. The issue therefore is not to find ways to reverse the process of urbanisation, but to enhance the economy and preserve the environment as urbanisation proceeds.

Urbanisation is not merely an aggregation of growing population in a limited or given area, but an integral part of the development process with significant economic, demographic, social, cultural and environmental dimensions. Urban areas have provided the essential pre-conditions for development beyond subsistence, the external economies of scale so critical for the success of small enterprises, and a disproportionately large and growing proportion of a country's gross domestic product. Further, urban populations are growing about two to three times faster than the total population.

In such a rapidly changing urban scene, environmental factors assume considerable importance. For instance, domestic household waste is highest in urban areas due to both high population density and relatively high income. In a rapidly developing city like Bangkok household waste constitutes about 80 per cent of the pollutant load (Foster, 1989). Many of the environmental problems are often the result of poorly conceived and/or poorly implemented urban policies, especially in the developing countries where environmental protection procedures are lifted bodily from developed countries for implementation. Many of the potential risks associated with environmental degradation as a result of rapid urbanisation can be mitigated or avoided through suitable policies. For instance, higher urban densities have the effect of actually lowering the per capita cost and energy intensity of transportation, water and sanitation, and other public services. Indeed, neither economic development nor urbanisation are *per se* problematic so far as the environment is concerned. Properly implemented, urbanisation can have a beneficial impact on investment opportunities which, in turn, help raise the level of economic activity and contribute to reducing the extent of poverty.

In this paper an attempt has been made to underscore the importance of water resources in socio-economic development in the urban context. Here we focus on the demand and supply issues related to water resources in urban areas, and indicate their relevance to industrial development, poverty alleviation and economic progress.

2 Urbanisation and Economic Development

Before taking up the issues connected with water resources, let us briefly indicate how urbanisation acts as a driving force for national economic development. By now it has been well established that economic growth is accompanied by the declining share of agriculture in total output and employment. This movement out of agriculture is invariably associated with increasing urbanisation and the ascendant role of cities in the development process. The last three or four decades have seen a dramatic growth of urban population in the Third World. From a mere 300 million in 1950, the urban population now exceeds 1.3 billion persons. The population concentration in some urban centres such as Mexico City, São Paulo and Shanghai has reached extraordinary levels and this process shows no sign of abating. The increase in urban population in developing countries is over five times that in the developed world. Up to the turn of the century, the cities and towns in the developing world will have to absorb another 700 million plus persons, or about two-thirds of the total population. Consequently a large and growing share of investment will be directed to urban areas to generate employment and to meet the broad range of human needs.

Urban areas in general and cities in particular are known to make significant and vital contributions to economic growth. Some 60 per cent of the GNP (gross national product) of developing countries is produced in urban areas, although these areas contain only one third of the total population. The growth and specialisation of non-agricultural activities are closely linked to the growth of large urban markets and subsequently reinforce the role of cities as incubators of new enterprises, producers, gatherers and distributors of goods and services. Even if efforts to promote agricultural growth and to remove whatever urban bias might exist in macro-economic policies prove successful, some 80 per cent of GDP growth will come from urban areas.

2.1 Infrastructure bottlenecks to economic expansion of urban cities

As most economic activities are increasingly concentrating in urban centres, it is clear that inefficient and unproductive urban centres with poor infrastructure create bottlenecks for economic expansion. For example, it is estimated that as much as 20 per cent of the initial capital investment by manufacturing plants in Nigeria is made solely to compensate for inadequate supply of power and water in cities. Besides water and power shortages, other limiting factors on economic efficiency and human resource development could be longer travel time from home to workplace, costly transport of goods, lack of basic welfare, education, child care and health services, and environmental decay.

2.2 Importance of water development in the urban economy

The growth of the urban economy, with higher population densities, exerts tremendous pressures on all aspects of the infrastructure, including water resources which are important as a life support system. Besides being an important input in agriculture (mostly as a consumptive item) water is also important for industry, sanitation (including sewerage) and drinking purposes, power generation, etc. Therefore investments in water supply are crucial for various economic activities, besides being essential for human beings. Further, water quality is important since many diseases are water-related, especially in large cities, and this can adversely affect workers' productivity, especially by worsening their health. Thus it is important to invest in good quality supplies of fresh water.

2.3 Water in the urban context

In the urban context, it is not only the problem of over use putting a strain on existing water resources but there is also the problem of water resource contamination. Thus cities have problems not only with water availability but also with water quality. Indeed a combination of limited resources and poor water management has resulted in widespread pollution, water scarcity and even land subsidence, the actual sinking of cities caused by excessive groundwater extraction. The larger cities of the developing world show the most visible signs of these problems.

Increasing population is one of the major causes of water contamination. The water on which cities rely is often polluted by enormous amounts of human waste that is sometimes channelled untreated into open bodies of water. Other cities depend on water sources that cannot provide enough water for their mushrooming populations, forcing people to find alternative, usually unregulated sources of water.

Urban centres also use large amounts of water for industrial purposes. Once used, these waters suffer significant quality degradation. The polluted waters are often dumped into rivers, lakes, and coastal waters, adversely affecting the environment with the double blow of reduced quantity and degraded quality. Polluted water also finds its way into the groundwater, where it is usually unnoticed and almost impossible to clean up.

Pollution control legislation in most developing countries is either non-existent or vague, and it is usually possible to circumvent it. A major problem facing the developing world is how to meet its increasing financial obligations. This usually results in urban centres concentrating on the production of cheap export goods, mostly by multinational companies. An example of the resulting damage to the environment is the coffee production waste ruining the freshwater environment in the Megdalena and Cauca basins in Colombia. Some heavily industrialised large urban centres like São Paulo, Calcutta, Mexico City and Cairo are known for their poor record of environmental protection of water resources. Thus urban centres, by their expanding populations and industrial development, are damaging or even destroying their life-giving water resources and are now beginning to realise that they cannot continue these ways.

For the urban poor, water is important for improving their productivity and keeping them in good health. Almost 60 per cent of the deaths amongst the slum settlements in various countries are known to be water-related, and care should be taken to ensure freshwater supplies for drinking and sanitation purposes for the urban poor.

A major feature of the urban scene is the large population of slum dwellers and squatters who live in very unhygienic conditions with hardly any civic amenities, such as potable drinking water. Their major health problems are the result of inaccessible adequate supplies of water for sanitation and drinking purposes. There is clearly an urgent need to provide them with safe drinking water and for the community to participate in this process.

Indeed, water is such an obviously felt need, as opposed to other longer-term needs such as education, that it can provide a useful entry point for developing a range of community development and community participation programmes. It may be difficult to motivate the members of a community to work together to build a new primary school for themselves or a new road to link them with the outside world. But it should be much easier to arouse enthusiasm for community involvement in digging a new well or installing tubewells. The water that the community stands to gain from such action is easily perceived as fitting a deep need, whether it is for irrigation or domestic use. Once such a water resource development and management programme has been developed with popular participation, the interest and confidence in joining in other not so obviously useful self-help projects should be greatly increased.

3 Water Availability

Water is one of the most pervasive substances on earth — almost 70 per cent of its surface is covered by water. Out of a total water volume of some 1.4 billion cubic kilometres, more than 97 per cent is the salt water of the oceans and as such unsuitable for human use. The remaining two to three per cent is freshwater, of which 85 per cent is not readily available: it is either locked in glacial ice, stored in groundwater, or is in the soil, the atmosphere or in living things. Apart from lakes, only about 2000 km^3 of freshwater, mostly in rivers, is available to satisfy human needs. These freshwater sources are unequally distributed among the continents (see Table 1).

Table 1 Freshwater volume in rivers, by continent (km^3)

Continent	Freshwater in Rivers
Europe	76
Asia	533
Africa	184
North America	236
South America	946
Australia	24
Total	1,999

Source : Adapted from *Mirovoi vodnyi balans i vodnye resursy Zemli* (The world water balance and the water resources of the Earth) (Leningrad, Gidrometeoizdat, 1974)

In many areas of the world, limited precipitation, high population density or both make available fresh water inadequate or barely adequate and so substantially limits human use. Large fluctuations in precipitation are already causing large scale region-wide problems resulting in the emigration of 'environmental refugees', such as occurred during the 1987 drought in Ethiopia.

In terms of per capita water availability there are wide variations between continents and between countries. For example, South America provides about 10 times more water per person than Asia or Europe. In Africa, the per capita availability of water for the Congo river is about 40 times higher than along the Nile river. The picture for the year 2000 shows that much less water will be available per capita in Asia and Africa, but availability will be reasonably stable in Europe and North America. Table 2 gives some idea of water availability by broad categories.

Table 2 Water availability per capita

Category	Per capita availability	Countries (%)
Very low	1000 m^3a^{-1} or less	14
Low	1000-5000 m^3a^{-1}	37
Medium	5000-10,000 m^3a^{-1}	14
High	10,000 m^3a^{-1} and more	35

Source: World Resources Institute (1986)

Clearly, water availability alone is just a first indicator as to whether abundance or scarcity is more likely. Not all water made available by nature can be used and the actual withdrawals depend upon upstream–downstream relations as well as upon water needs emerging from socio-economic developments. Only a detailed analysis of various water users and their quantity and quality requirements will permit an assessment of the adequacy and/or deficiency of the available water.

Table 3 Average annual availability of freshwater (surface and groundwater) in selected countries

	Total (km^3)	Per capita ($m^3 \times 10^3$ per person)
Water-rich countries:		
Iceland	170	685.48
New Zealand	397	117.53
Canada	2901	111.74
Norway	405	97.40
Nicaragua	175	49.97
Brazil	5190	36.69
Ecuador	314	31.64
Australia	343	21.30
Cameroon	208	19.93
USSR	4384	15.44
Indonesia	2530	14.67
USA	2478	10.23
Water-poor countries:		
Egypt	1.00	0.02
Saudi Arabia	2.20	0.18
Barbados	0.05	0.21
Singapore	0.60	0.23
Kenya	14.80	0.66
Netherlands	10.00	0.68
Poland	49.40	1.31
South Africa	50.00	1.47
Haiti	11.00	1.59
Peru	40.00	1.93
India	1850.00	2.35
China	2800.00	2.58

Source: International Institute of Environment and Development and World Resources Institute, *World Resources 1987* (New York, Basic Books, 1987), Table 81.1, 268-9, and Table 23.1, 314-5.

Table 3 classifies 24 countries as water-rich or water-poor, based on the annual per capita availability of fresh water run-off resulting from precipitation falling within a country's borders. As populations and economic activities grow, countries approach conditions of water stress, where estimated water demand matches the maximum renewable freshwater resources. Under such conditions, countries will experience difficulties in ensuring self sufficiency in meeting agricultural and industrial water needs. There is also a barrier, given contemporary technical knowledge, beyond which it is not possible to easily use further quantities of freshwater resources. This barrier occurs around a point where per capita availability is below 500 m^3 Countries which have traversed this barrier, such as Saudi Arabia, often resort to high technology, high cost processes, such as desalination, for their water supply, or else they attempt to reduce the gap between demand and availability through recycling waste waters, as is the case in Israel, which recycles 40 per cent of its waste water in a bid to bridge the water gap. Deficits in water availability are particularly concentrated in the rapidly growing cities of the developing countries, where supplies are at best unreliable and intermittent. Satisfying urban water deficits implies large-scale trans-basin transfers of water resources, with inherent environmental problems.

4 Demand Trends and Water Allocations for Industry, Agriculture, Energy and Domestic Use

4.1 Water demand

The structure of the water economy differs among countries, depending upon natural climatic conditions, the availability, accessibility, and quality of water resources, and the economic and social development of a country. The principal uses of water are agricultural, domestic and industrial.

Globally, 73 per cent of water demand is for crop irrigation, 21 per cent for industry and 6 per cent for domestic consumption and recreational purposes. Table 4 gives the trends in global water consumption by major category, reflecting the following predictions for the year 2000:

(1) Industrial water needs will grow at a lower pace than domestic water consumption, mainly due to internal recycling and water conserving technology.

(2) Many irrigation practices have associated water losses, estimated at between 50 and 80 per cent. Reducing these losses offers a considerable potential for technological improvement and substantial water savings.

(3) There is considerable potential for water reuse within industry which could reduce the share of water resources demanded by industry (especially chemical, pulp and paper, petroleum and coal, primary metals, and food processing industries).

(4) The potential for the reuse of municipal waste water in arid and semi-arid zones in order to meet some of the irrigation water demands is gradually being reduced, although this would not be clearly reflected in the global balance.

Looking at the global picture with regard to per capita water availability, we find wide variations ranging from 120,000 m^3 per year in Canada to less than 100 m^3 per year in Malta (WRI, 1987). It is expected that large cities and industrial centres in water-scarce areas would be the first to require costly water transfer and storage schemes to sustain their economic growth.

According to Shiklomanov (1986), the global water use during 1970-2000 is likely to double with the North American proportion dropping to around 15 per cent. Asia's needs are likely to increase to 60 per cent. Table 5 gives the trends of water consumption by continent.

Table 6, cited in UNCHS (Habitat) *People, Settlement, Environment and Development* gives a clearer picture of the distribution of water demand by uses for selected developing and developed countries.

It will be seen from Table 6 that, in general, as countries industrialise, the industrial sector represents a greater proportion of the demand. In contrast to Eastern Europe, where industry uses nearly 80 per cent of the region's fresh water, industry in Ghana accounts for only 3 per cent of the country's total use of fresh water. Also, in developing countries which rely increasingly for their economic growth on industrialisation, water demands in urban areas will increase exponentially. Failure to meet this demand will increase the cost of producing goods, and thereby damage their already threatened national economies. Also, increased water use can lead to increased water pollution unless effective treatment and other control measures are implemented. Similar increases in, for instance, industrial

***Table 4** Trends in global water consumption by major category ($km^3\ a^{-1}$)*

Water usage	1900	1940	1950	1960	1970	1980	1990	2000	Percentage (for 2000)
Irrigated lands (10^6 ha)	47 3	75.8	101	142	173	217	272	347	
Agriculture	525	893	1130	1550	1850	2290	2680	3250	62.6
Industry	37 2	124	178	330	540	710	973	1280	24 7
Municipal needs	16.1	36.3	52 0	82 0	130	200	300	441	8.5
Reservoirs	0 3	3.7	6.5	23.0	66.0	120	170	220	4.2
Total	579	1060	1360	1990	2590	3320	4130	5190	100 (rounded up)

Source: Global Water Quality Assessment cited in Shiklomanov, 1986

Table 5 Trends in water consumption ($km^3 a^{-1}$)

Continent	1900	1940	1950	1960	1970	1980	1990	2000	Percentage
Africa	41.8	49.2	56.2	86.2	116	168	232	217	6.1
North America	69.4	221	286	411	556	663	724	796	15.3
South America	15.1	27.7	59.4	63.5	85.2	111	150	216	4.2
Asia	414	682	859	1220	1520	1910	2440	3140	60.5
Europe	37.5	70.9	93.8	185	294	435	554	673	13.0
Oceania	1.6	6.8	10.4	17.4	23.3	29.4	37.6	46.8	0.9
Total	579	1060	1360	1990	2590	3320	4130	5190	100 (rounded up)

Source: adapted from Shiklomanov, 1986; cited in Meybeck *et al.*, 1989.

and municipal water use may lead to quite different water quality impacts depending on the level of pollution control applied.

Table 6 Sectoral withdrawal of fresh water by country (%)

Country	Domestic/ commercial	Industrial	Agricultural
Developing countries:			
Algeria	23	5	72
Botswana	8	17	75
China	6	7	87
Cape Verde	8	0	92
Egypt	7	5	88
Ghana	44	3	54
India	4	3	93
Mauritania	2	0	98
Turkey	24	19	58
Uganda	43	0	57
Developed countries:			
Albania	30	60	1
Austria	20	77	3
Bulgaria	14	15	71
Belgium	11	88	2
Czechoslovakia	24	72	5
Finland	12	86	1
France	17	71	12
Ireland	11	83	6
Netherlands	5	64	32
Poland	17	62	21
Switzerland	37	57	6
United Kingdom	21	79	1
Yugoslavia	17	75	8

Source: The World Resources Institute and Institute for Environment and Development, World Resources 1988-89 (New York, Basic Books, Inc., 1988), Table 21.1, pp.318-319.

Water demand has four dimensions: quantity taken, quantity returned, quality taken and quality returned. Each user takes a quantity of water of some quality and may return a different quantity of changed quality. The ratio of quantity taken to quantity returned can sometimes be considered as fixed. This may not always apply and there may be significant variations in all four dimensions. Let us now review in greater detail water demand by its principal uses: agricultural, industrial and domestic & municipal.

4.2 Agricultural use

Irrigation is extremely water intensive and irrigation withdrawals are known to have very destructive environmental effects (see the official Report of Government Committee on Arab Sea Regions, Meteorology and Hydrology, 1988, volume 9).

Water withdrawals for irrigation are declining compared with other uses, and should be around 55 per cent by the year 2000, down from a current level of 63 per cent (A.V. Belyaev, USSR Academy of Sciences, Institute of Geography, Moscow, in consultation with other international sources). This change in water withdrawal patterns is likely to occur mainly in Asia, Africa and Latin America because of increased industrial withdrawal. Until recently, irrigation contributed little to the pollution of water basins. But the wide application of fertil-izers and pesticides has heavily polluted irrigation return flows, presenting a significant threat to the aquatic environment. The use of irrigation is likely to continue to grow but not anywhere near the rates experienced over the past century nor as fast as predicted. The total irrigated area is projected to increase by 19 per cent or about 44 million hectares.

4.3 Domestic and municipal use

Domestic water use includes water for drinking, food preparation, sanitation, washing, cleaning, watering gardens and

and the service industry (e.g. laundries, pools, heating systems, restaurants, medical services etc.). While domestic and municipal water needs have always been modest, around 6 to 7 per cent of total water withdrawal, the quality must be high. Domestic water use tends to rise with a rise in living standards. The existing variations in domestic water use are substantial, ranging from as low as 20 litres per day to well over 500 litres per person per day. Only about 4 per cent of the population uses as much as 300-400 litres per day per person. Two thirds of the population, concentrated in Africa and Asia, uses less than 50 litres per day. By the year 2000, a projected 17 per cent of the population will be using more than 300 litres per day, but 30 per cent will still be using fewer than 50 litres per day. The USA, Canada and Switzerland have high domestic water use.

A serious problem that is facing developing countries is one of providing potable water for rapidly growing urban populations — a situation demanding vast amounts of capital. Another problem associated with increased domestic water use is the increasing amount of waste water, which is about 70 to 80 per cent of water withdrawals. With the expected high growth in population and economic activity in most developing countries, the per capita water use is expected to increase substantially. This will necessitate large investments in treatment of increased volume of waste water. An area requiring urgent attention is to find ways to accord high priority to waste water treatment techniques.

As far as water demand for domestic use is concerned, it is generally agreed that it is a function of price charged. A number of studies have shown that the typical values of price elasticity are in the range of -0.15 to -0.70. Many planning studies tend to ignore the fact that water is price responsive, and use pricing that reflects engineering costs of supply rather than social values. Where marginal costs exceed average cost, the average cost pricing can indeed result in misallocation of resources. Other factors influencing household demand for water are household income and family size. The elasticities for these characteristics are generally in the range of +0.3 to +0.5 and 0.4 respectively.

There are several ways in which domestic demand can be restricted. Use of water meters, restrictions on outside use of water and intermittent water supply are some of the measures which reduce water demand for domestic use. Recent work with marginal cost pricing has also shown large savings in water consumption. The relevant cost data for East Africa suggests a downward-sloping demand curve for water, implying an elastic response to price. For a middle-income worker in Nairobi, it is found that he may spend about 8 per cent of his income on water — more than such a worker spends on, say, fuel, transportation or household equipment. Unfortunately, using water pricing as a conservation mechanism for domestic supply, especially in developing countries, can thus be regressive in the socio-economic context.

4.4 Industrial use

Industry uses large volumes of water for cooling, processing, cleaning and removing industrial wastes. With industrial use, most of the water is returned to the water cycle, but it is often heavily polluted with chemicals and heavy metals.

Worldwide, the water withdrawn for industry and energy production now totals 760 km^3, which is, as mentioned earlier, second to irrigation. Only in Europe, where irrigation is relatively less prevalent, does industrial water use equal other uses taken together. Use in energy production and other industries, comprising 21 per cent of total water withdrawal, is estimated to increase to 24-28 per cent by the year 2000 (A.V. Belyaev, USSR Academy of Sciences, Institute of Geography, Moscow). North America has the highest industrial water use; this has increased 20-fold during the present century. The USSR and United States together account for almost half of the world's total industrial water use.

Different industries require different amounts of water to manufacture their products. For instance one metric tonne of linen requires about 250 m^3 of water (not counting the water required to grow the flax), and producing one tonne of synthetic fibre requires as much of 2500-5000 m^3. Similarly, the chemical and metal industries require substantial water inputs. Producing one tonne of ammonia requires almost 1000 m^3; 2000 m^3 is used per tonne of synthetic rubber; 4000 m^3 for smelting one tonne of nickel. The precise amount of water needed will however depend on the technology employed and on the climatic conditions. In warm climates water use is generally higher. Table 7 provides further information about water requirements for selected industries.

Waste water from industrial use is generally high. On average waste water from industrial use is about 87 per cent (or 660 km^3) of total water withdrawals by industry. It is estimated that water withdrawals for industry in Asia, Africa and Latin America will increase three to five times, and in the developed world by 10-25 per cent. Clearly the waste water, which will increase proportionally, will require regulation and control

The large amounts of water used by industry for heating and cooling are at the heart of the problem of estimating industrial demand. The many technical substitution processes available for water conservation in industry all have different costs and performance characteristics. An industry's demand for water for a particular use is a function of the price. Industry uses water as an economic input in such a way that a decrease in the use of water may cause it to need to use other, more costly inputs. The value of water is then given by the added cost of these other inputs. By examining an industry's production technologies, it is possible to compute the derived demand function for water in such a way that they will choose the optimum mix of inputs at each price level for water; thus the quantity of water needed can be calculated.

It is generally seen that at low water prices there is a temptation to resort to processes such as 'once through' cooling. However, at high prices there may be a switch over to optimum technology with effectively zero water use — for instance the use of dry cooling towers in electricity generation. There is indeed a lot of potential for introducing appropriate technologies in situations where water is severely underpriced.

Finally, a word about the products of industry. While it is true that water costs, as a percentage of the total value of output may be as small as 1 per cent or even lower, the lack of water in sufficient quantity and of required quality may act as a serious bottleneck to industrial development. There are indeed many instances of wrong industrial locational policies arising out of inadequate or non-availability of water of the right quality and in sufficient quantities.

An issue which needs clarification is the price of water for industrial use. While industrial demands for water have been scantily studied, the fact that water cost constitutes a very small component of total costs of industrial production implies that there is very little possibility of industrial demand for water falling — unless specific supplementary measures are also used along with price to economise on water use by industry.

5 Water Supply Investments

The rapid pace of urbanisation usually results in increasing water scarcity and deteriorating water quality in urban areas, with its consequent adverse effects on health and economic activity. Large investments in water supply projects have been made by many countries to alleviate these effects, generally benefiting large sections of the poor. Indeed during the course of the last decade or so, sufficient capital was raised to increase the number of people served by more than 1 billion. The investment level was estimated to be sufficient to invest slightly over 100 US dollars for each person reported to have received new water and/or sanitation services (World Bank, 1990).

This level of investment, however, is believed to be only a fifth of the amount that will be required to achieve complete coverage by the year 2000. In fact the limited organisational capabilities of many water supply institutions may not be able to provide reliable and sustainable services even at the current levels. Therefore increases in the levels of investment are needed in the sector and also a more efficient use of the resources that are currently available. Information on the investment in water and sanitation may be found in the Water Supply and Sanitation Sector Review for FY90 (World Bank, 1990). The total public investment, as a share of GDP, has declined during the late 1980s. Also the investment in water supply and sanitation has remained constant (or increased slightly) both as a share of public investment and share of GDP (averaging about 5.8 per cent and 0.5 per cent, respectively). If the sample is taken as representative of the developing world, total investment would work out to be around 9 to 10 billion US dollars (1985 value) per annum during the second half of the 1980s.

Table 7 Water Requirements for Selected Industries

Product (Country; unit)	Water required per unit (litres)
Bread (USA; tonne)	2,100-4,200
Canned foods (USA; t)	24,000
(1965 average of fruits, vegetables & juices)	
Meat packaging (USA; t)	23,000
Canned fish (Canada; t)	58,000
Chicken (USA; per bird)	25
Milk (USA; 1000 l)	3,000
Sugar (USA; m^3)	6,000
Beer (USA; m^3)	15,000
Pulp & paper (USA average; t)	236,000
Gasoline (USA, m^3)	7,000-10,000
Synthetic gasoline (USA; m^3)	377,000
Oil refinery (Sweden; t)	10,000
(per tonne of crude petroleum)	
Synthetic fuel (USA; m^3):	
From coal	265,000
From shale	20,800
Sulphuric acid (USA, t)	2,700-20,300
(100 % H_2SO_4 by the contact process)	
Textiles	
Steeping & dressing flax; t	30,000-40,000
Bleaching, t	180,000
Dying & finishing; t	60,000-100,000
Textile mills (synthetic fibres; t)	2,000,000
Iron and steel mills (USA; t)	86,000

(Note. These values are dependent on technology and are indicative based on figures given by Leeden, 1975.) Cited in Chaturvedi M.C. (1987)

The investment in water supply and sanitation as a proportion of GDP and of public investment is relatively stable. Nevertheless, the magnitude of investment is clearly inadequate to provide the services to all those currently not served as well as any growth in population. Also, while the expected increases of GDP during the 1990s may tend to push up investment in this sector, the current level of investment of 20 US dollars per person may be quite inadequate to meet new and existing demands. Given the constraints on resources in most countries, the only way to deal with the situation effectively is to base allocation choices (and choices of levels of service and technology) on realistic estimates of demand, and to enhance investable resources through user charges. The relationships between the incremental costs of providing additional services and the prices which are charged for these services has important economic and financial implications, and some of these are discussed in the following sections.

6 Allocation of Water Among Competing Uses

Economic efficiency is the most widely used method for allocating water to competing users or classes of users. If water is allocated to low value uses (such as irrigating low value or surplus crops) while higher value uses (new industrial activities for example) are foregone, the total benefits obtained from a limited supply of water may fall far short of optimum. In other cases, government policy or social objectives may suggest some minimum allocation of water to certain activities, regardless of the value added by water use. Demand management, utilising pricing and various conservation or restrictive measures, can influence the allocation of water, promoting use in sectors where increased allocation is desired, while discouraging use elsewhere.

When viewed from a national perspective, most countries seem to have ample water resources for agricultural, industrial (including energy development) and other uses. However this simplistic view overlooks the spatial and temporal distribution of the resource. With progressively increasing population pressures in urban areas, the requirements of water for different purposes will continue to rise. Indeed certain regions of the world have already started experiencing water shortages, so much so that water is becoming one of the major constraints for further socio-economic development.

For instance in the case of water requirements for energy development in relation to those of agriculture, we find that agriculture will have difficulty in paying the real cost of irrigation water, considering its low value in crop production. The fact is that the value of water for industrial use, including industrial development, is commonly higher than the value of the same water for agriculture. However agriculture in developing countries is a deeply entrenched way of life with strong political support for a preferential position with respect to water resources utilisation. Nevertheless, more efficient use of water requires that low-value uses of water be shifted to higher value uses. This suggests the need for an integrated approach to development of various sectors of the economy and water resources which at the same time conforms to the objectives of national economic and social development plans.

In areas with limited water supplies and no scope for additional development of them, as economic activity and population expand, a considerable amount of water required for industrial and municipal use may have to be diverted away from irrigation. The literature on water resource management emphasises the market system that governs water allocations on the basis of how much consumers are willing to pay for water. Thus water prices are used as signals to consumers to increase or decrease the consumption of water. Prices are either raised to discourage consumption or lowered to encourage it. Prices set equal to marginal costs are neither positive nor permissive, they simply reflect the scarcity of water resources. Punitive prices exceed marginal costs and lead to excessive conservation. Permissive prices are those below marginal costs and lead to waste.

Optimal allocation of water is a function of the pricing scheme where optimality conditions show that the price of the products of competing sectors are functions of water costs and water pollution abatement costs. Therefore, the market system encourages water to be allocated with greater preference to its most valued uses. The drawback to this is that if one industry can generate only a comparatively lower net revenue out of using one unit of water than another, it will not be able to obtain water if the latter needs all of the water supply. This should not be allowed to happen. Agricultural uses, for instance, have a lower marginal value product of water when compared to say energy uses. However, food is a basic necessity of life, and there is no reliable way of estimating the benefits of self-sufficiency of food. Therefore agriculture should be assured the minimum amount required for food production. The same reasoning applies to assuring a minimum required quantity of water for domestic use and maintaining acceptable environmental conditions.

It is now widely recognised that economic efficiency criteria alone are not adequate for project evaluation. The optimum allocation of water amongst various uses can be achieved by applying the theory of multi-objective planning, an extension of benefit-cost analysis. This provides a better assessment of non-monetary as well as monetary aspects in the overall evaluation of projects. This technique enables planners to indirectly quantify social preferences in terms of economic values. Net economic benefits can be maximised depending on the reduction in social quality that can be accepted or tolerated by the people affected. An important aspect of this analysis is the slope of the transformation function at the optimal point. The extent of this slope (usually termed elasticities) represents the weight placed by society on an additional increment of net benefits. This weight is interpreted as the net income to the economic account that the society is willing to sacrifice in order to obtain the marginal account of water for other uses, that is, the trade-off between economic efficiency and social quality at the optimal level of design. In theory the explicit definition of the value of the trade-off would determine automatically the optimal plan for the system. In practice such weights or trade-offs usually cannot be specified *apriori*. The information must be inferred by decision makers from expressions of choice made by the public.

Not many economists have really chosen to explore this topic. Many consider this as merely an attempt to justify unsound public investments under the guise of broader criteria. Others doubt the ability of government 'decision-makers' to provide quantitative trade-offs among social objectives. Those economists holding this latter view tend to focus efforts on predicting the allocative and distributive consequences of water policy proposals, and recommend that the political system should resolve the conflicts.

7 Impact of Water Reallocation

A major area of concern in the context of meeting the increased water demand arising out of the rapid rise in urban population concerns a choice between developing a new source of water and expanding the existing water supply sources.

A regional water economy can be characterised as being either in an 'expansionary' or a 'mature' phase. In the expansionary phase, the cost of new water supplies remains relatively constant over time, and water development project sites are available to meet growing demands. The mature phase is characterised by rapidly rising incremental costs of water and increased interdependencies among water uses and users.

The rising cost of water supply in a maturing water economy brings about a search for sources of water among existing uses whose incremental value productivity is less than either the cost of new supplies or the benefits of new uses. Since crop irrigation accounts for 80-90 per cent of water consumption in arid regions, reallocation of water from agriculture to sectors with rapidly growing demands is receiving increasing attention.

As pointed out earlier, the willingness to pay by agriculture tends to be much less than that by households and industries as the latter group has higher use value. Hence where municipal and industrial demands are rapidly growing in water scarce regions, foregone benefits from reducing agricultural use may be less than the costs of a new supply. Substantial economic savings can be achieved from reallocation to higher uses as compared to developing new water supplies. However, this hypothesis has been disputed. Arid region governments have shown special concern for both the farm water users and the forward and backward linked economic sectors supplying inputs, processing and marketing services. The conventional wisdom is that the indirect effects of reallocation on employment and income would be large, such that full costs of removing water from crop production could be unacceptable. The empirical evidence seems to suggest otherwise, and that the economic impacts would be relatively limited. Water removed from irrigation would be the least valuable, drawn largely from food and food grain and forage sectors. Since foreseeable urban growth would account for only a small percentage reduction in irrigation water supplies, the sacrifices in net productivity would be minor relative to the gains in the growing sectors. These sectors also account for relatively small indirect incomes per unit of water consumed as compared with those from the emerging urban sectors. Also, inexpensive water may be obtained by reducing seepage in irrigation canals.

Since water and property laws generally protect the interests of farmers whose water is demanded by urban sectors (indeed they often reap large capital gains in the transfer), the rate of loss of irrigation water, even in highly urbanised areas will be slow, on the order of one or two per cent per year. In such cases, the indirectly affected workers and businesses have time to anticipate and adjust.

8 Water Scarcity and Degradation: Costs of Developing New Sources

Apart from reallocation of water among competing uses, an issue worth some detailed discussion concerns the costs of developing new sources of water supply in the situation where an urban area has problems both with the availability and quality of water.

8.1 Water scarcity

Basically, water scarcity is the result of two phenomena: (a) limits imposed by the availability of new freshwater resources, and (b) limits generated by the development of land and water resources.

Water scarcity is increasing rapidly with a growing world population and urbanisation, and the process of economic growth. However, the availability of freshwater resources per capita varies widely from place to place and from region to region. Asia and Africa are the two continents facing the greatest water scarcity. Several countries, such as Bahrain, Kuwait, Democratic Yemen and Syria, are now, or are expected to be by the year 2000, at a point at which total demand for water will either equal or exceed the available supplies.

By the year 2025, about 15-25 north African and sub-Saharan African countries may face serious problems with water shortages. These African countries need higher than average inputs of water for food self-sufficiency, and water demand for domestic and industrial uses would make this goal difficult to achieve. The occurrence or even the possibility of occurrence of significant water shortage imposes costs on a community which can easily exceed the value of water uses at risk. In a situation where people and institutions are accustomed to receiving water from a public system, the failure of that system to produce water causes inconvenience, disruption in economic activities, and even potential sanitation problems. When shortages are anticipated, people are motivated to avoid activities and lifestyles which depend on a constant availability of water. From the viewpoint of expected benefits from a public water supply system, chronic unreliability, even in a situation of a small shortfall in water supply, can prove counter-productive. Proper demand management can contribute to achieving greater reliability through reducing demand, as well as minimising costs generally associated with the expected shortages.

8.2 Water quality

Water quality can be of even greater concern than water quantity. Water bodies throughout the world are becoming increasingly subject to a variety of pollution loads, with sometimes irreversible consequences. The degradation of water resources is attributable to such factors as expansion of irrigation, over-use or misuse of fertilizers, insecticides and pesticides, discharge of industrial wastes and untreated sewage into surface water bodies, domestic waste and toxic chemical dumps, and air pollutants.

A serious problem connected with water quality is the increasing infusion of nitrates into drinking water, leading to possible serious threats to human health. The fouling of water courses and lakes and untreated discharge of industrial wastes and sewage has proceeded apace in the past few decades. Most industrial countries have however set up waste-water treatment facilities at considerable cost. Consequently, river water in some cases has shown quality improvement, although long stretches of numerous rivers still remain heavily polluted. Despite increased municipal treatment in the industrial regions, lakes and rivers have been undergoing eutrophication. Lake Balaton in Hungary and Lake Leman in Switzerland may be cited as two prominent examples of eutrophication. The problem of eutrophication is particularly serious in certain sources of community water supply, such as artificial lakes and reservoirs, especially in several countries in Latin America.

Pollution of inland water bodies is not restricted to industrial countries but is a growing problem throughout the developing world where pollution control is either non-existent or unable to keep pace with the increasing environmental impact of production and consumption. Growing urbanisation and industrialisation have caused much damage. Most urban centres in developing countries lack adequate facilities for collection and disposal of domestic and industrial wastes. This results in urban run-off highly polluted with pathogens and organic materials, with consequent adverse impacts on the quality of nearby surface waters and shallow groundwaters. In many cities of the developing world, open sewers and surface run-off after rain create 'rivers of sewage' which contaminate the local supplies.

Urban centres in developing countries have also undergone a concentration of industrial plants and attendant water pollution over the last decades. In Latin America, for instance, there has been rapid development of urban industrial complexes producing petroleum, petro-chemicals and steel. Oil and gas processing urban centres have mushroomed in the Middle East, and energy, chemical and metallurgical industries and steel processing and petrochemical plants in urban India. The major industries in the traditional sector of the developing countries responsible for causing widespread pollution are those processing primary products such as sugar, oilseeds, minerals, coffee, hides and oil palm. The classic example is India where 70 per cent of total surface water is believed to be polluted.

Water quality can also be degraded by air pollutants. For example, sulphur dioxide from the combustion of fossil fuels, and pesticides from agriculture, can be transported by the atmosphere. These contaminants can be washed out by rain and impact the soil and water. For instance, numerous lakes in Sweden, Norway, the North-Eastern USA and Canada have turned acid, with particularly harmful effects on fish populations.

Contamination of water supplies is not only posing serious health risks but is also drastically increasing the costs of water treatment facilities. Polluted inland water bodies and seas are also causing fish-kills or declines in fish stock productivity, as well as health risks from the consumption of the fish caught in those waters. Water pollution in general is degrading the recreational and aesthetic aspects of water, sometimes causing odour nuisances or prohibiting access to water areas.

8.3 Cost of developing new sources

Purely in terms of cost implications, water scarcity and water quality degradation present serious problems. Developing new sources of water supply is expensive, regardless of the location and region. There are several reasons for high increasing costs of developing new sources of water supply. First, there is the possibility that the least expensive sources have already already developed. Also new water sources are progressively more remote and need additional expenditures for laying pipelines. Similarly additional groundwater sources will usually be at greater depth with more expensive boreholes and higher pumping costs. Rising opportunity costs of inputs and increasing costs of capital owing to increasing population pressures and economic activity would keep pressure on costs of developing new sources of water supply. Also the costs of treating degraded water will progressively rise over time.

It is useful to compare the average costs of a present water supply with the projected costs of a replacement water supply. The calculation has been carried out for the cities of Shenyang, Yingkuo, Dhaka, Bangalore, Hyderabad, Algiers, Lima, Great Amman, and Mexico City. For these nine cities the average replacement cost of a water supply is approximately two to three times the current cost. With such expensive replacement costs it is imperative to ensure that existing water supply sources are used as efficiently as possible. Efficiencies could include reducing water use in a controlled way and reducing water losses. Indeed it would be economic to conserve water until such time that the marginal cost of conserved water remains below the marginal cost of new water supply. In order to establish a trade-off between conserving water and developing a new water source, more work is needed to calculate the costs of water conservation and water reuse and compare them with the costs of developing new water sources. This is especially important when a new water supply project is being planned.

Stricter pollution control will also prevent water degradation and help keep down water treatment costs. Pollution control generally goes hand in hand with conservation in industry, agriculture and municipal water management. However, additional measures are needed, particularly to avoid eutrophication of surface and ground water through careless use of fertilizers and other chemicals in agriculture, and pollution of water through the long-range transport of pollutants. Also, polluted water can be cleaned up and put to other uses that require lower water quality, such as for cleaning and sanitation purposes. Once again, before undertaking investments in developing new water sources, the relative costs of clean-up operations and new water sources must be calculated. This of course will have important implications for the costs of industrial products.

9 Water Resources & Poverty Alleviation: Public Health and Sanitation

The poor constitute the largest single economic grouping of urban residents in the Third World. Although a larger number of poor households currently live in rural areas, by the turn of the century this trend will be reversed because of rapid urbanisation, and more poor households will be located in cities than in rural areas. In most cities in developing countries, the proportion of poor people ranges from 25 per cent to over 50 per cent of the city population. Thus cities will progressively become the principal focus of trade-offs between environment and poverty alleviation.

Water and sanitation are crucial for a productive life. For large areas of developing countries the water is often remote and unsafe, while sanitation is at best primitive. The poor suffer most, having neither the knowledge nor the means to improve their condition. Dehydration from diarrhoea alone kills over a million children every year in developing countries. The debilitating effect of endemic diseases together with malnutrition causes untold misery and suffering. Poverty has an adverse effect on productivity. Lower productivity contributes to poverty, completing a vicious circle linking poverty and productivity.

The provision of adequate water supply is basic to human needs and essential to the health and well-being of a community. Traditional sources of water in urban areas are often inadequate and highly polluted. Often the only water of reasonable quality may be that purchased at an inflated price from vendors, from the houses of private individuals, or sometimes obtained from local standpipes. Most of the urban slum dwellers are in the lowest income category. But, because of the beneficial effects of improved water supply on public health (and therefore on productivity and quality of life), there must be provision of a primary level of service. Of course this should not rule out the opportunity to pay for a higher level of service if that is wanted.

9.1 Water and sanitation

Water-borne diseases, traceable to poor environmental health conditions, account for countless deaths per year among the poor in the Third World: a growing proportion of those at risk will be urban dwellers. Household sanitation, which affects many millions of poor people, has not generally been the target of education and action campaigns on the environment in the Third World. Water supply and sewerage have accounted for about 6 per cent of World Bank annual lending for both rural and urban projects. If costs and benefits of investment in environmental improvement are weighed in the light of their significance to the poor, urban sanitation improvement is among the most effective of any short-term measures. Since there is insufficient capital both for the elimination of risks of child death and illness due to waterborne disease and for the creation of environmentally viable alternatives to slash-and-burn techniques in the rainforest, policymakers (in donor agencies, borrowing countries and non-governmental organisations alike) face a trade-off.

A full-scale attack on urban sanitation problems in developing countries would require huge increases in investment. For example, at least a three-fold increase in historical levels of annual investment would be needed to reach WHO (World Health Organisation) goals for water and sanitation services in urban Latin America by the year 2000. To give an idea of the order of magnitude of this task, it is estimated that the expenditure of nearly 50 billion US dollars would be required to catch up by the year 2000. Even these could be gross underestimates if rapid household formation is taken into account. As a further example, the youth bulge in Brazil's population pyramid is moving into the age range of marriage, and will need 80,000 connections to water and sanitation per year — just to keep up with the present levels of service.

The stakes in this competition for capital are dramatic. Although no hard correlations have been drawn that isolate the health benefits from investments in water and sanitation, it is apparent that mortality and morbidity decline roughly in proportion to the volume of water, good or bad, flowing through a household. For example, again in Brazil, child mortality among the poor in the Northeast is 50 per cent higher than among the poor with water in the larger cities of the Centre and Centre-South. Similarly, the children of poor families in São Paulo face many times greater risks from waterborne diseases than do middle-income children living only several city blocks away. In a country like Brazil, child mortality indices translate into tens of thousands of deaths annually. The prevention of child mortality is a function of many variables: wealth, education, health care and the level of knowledge and awareness of young mothers. But water, drainage and sanitation are key factors in preventing the environmental pathogens from finding human hosts.

Despite the high cost of sanitation, the problem is not insoluble, nor do solutions necessarily involve major technological breakthroughs. The basic strategy for improving local environmental conditions was evolved by grass-roots groups concerned with housing in the 1950s and 1960s, the period of most rapid urbanisation in the Third World, especially in Latin America. It involves the social organisation of low income groups and their exertion of political pressure on local and national officials, coupled with 'sweat equity' and capital channelled into the construction of household and community facilities.

Both the social and the technological factors have been tested in Asia and Latin America. The central technologies range from improved ventilated pit-latrines, which cut costs per served household by two-thirds, to improved micro-drainage at the neighbourhood level, to simple modification of standard sewerage designs that reduce diameters, excavation, inspection chambers, and other standard specifications —all of which can result in reductions of between 25 per cent and 50 per cent in the costs of conventional sewerage systems. A very large number of households in Brazil, Asia and Africa have benefited from on-site or simplified waste disposal systems. In dozens of cities in these and other countries, local alliances are carrying out community projects that were almost unthinkable a decade or so ago.

9.2 Water resources and health

The Primary Health Care (PHC) strategy formulated in Alma Ata in 1978 emphasised disease prevention, universal service coverage, appropriate technology, community participation and inter-sectoral cooperation for health, and it included 'safe water supply and basic sanitation' as one of its elements. Environmental health is generally neglected and has remained a weak component of the health care system so far.

The International Drinking Water Supply and Sanitation Decade 1981-90, which urged governments to extend environmental hygiene services to their populations, has attracted attention to poorly assisted water supply and sanitation programmes. In actual practice, the programme does not seem to have made any significant impression either in urban or in rural areas. While the situation in rural areas remains depressing, in urban areas the current service coverage is estimated at 77 per cent for water supply and 63 per cent for sanitation, implying minor percentage increases during the decade. These figures reveal, however, that because of rapid population growth the number of persons without sanitation has increased to 300 million.

9.3 Improved water supply and its impact on diseases

While interventions such as water supply improvements, safer disposal of excreta and other waste, etc. can help reduce transmission of various infectious and parasitic diseases, it is difficult to determine their precise effects. Improved water supply facilities for instance are likely to reduce diarrhoea incidence, diarrhoea severity, eye and skin infections and intestinal parasites, and probably malnutrition as well. Improved water quality, i.e. a reduced degree of viral, bacteriological and parasitological contamination, has been shown to reduce diarrhoea morbidity by 16 per cent on the average. But drinking water, it must be admitted, is only one of several transmission routes, and in a heavily contaminated environment the impact of improved quality alone is likely to be small, at least in the short and medium term.

The preceding discussion shows that there is a direct relationship between access to potable water and improvements in health and productivity. It is therefore not surprising that over the past several decades, international assistance organisations and national governments in developing countries have invested vast sums to extend potable water to both rural and urban communities. However, the rising costs of extending services and maintaining existing systems, and tight financial controls imposed by debt-management and structural adjustment policies have severely restricted the ability of the central governments in most developing countries to meet the growing needs for water.

10 Concluding Remarks

Water has a key role to play in the urban economy. However, there are likely to be problems of water availability and quality arising out of rapid urbanisation. There is a need for an evolving urban water management policy where pollution abatement and water conservation are key components.

The role of water pricing is stressed, since a large proportion of excess use is generally related to the low price of water. Research is needed to clearly define the relative costs of conserving water and developing new sources of water supply.

In the future it will become particularly important that water users be made to pay for treating the water they pollute, or purify the used water themselves. Water bodies can no longer be expected to provide a source of high quality water and at the same time to be used as a sink for dumping wastes. Dilution is not the solution to pollution. Developing countries cannot possibly afford to subsidise pollution clean-up and at the same time step up investments to maintain and develop water services. Consideration should be given to the costs and benefits of alternative technical solutions to water development, water conservation, and pollution prevention.

Water is crucial to the alleviation of poverty, especially for urban squatters and slum dwellers. Indeed the labour productivity of the urban poor is largely determined by their access to an adequate and safe water supply. Community participation in water management can be used as an example for community participation in other projects to improve the quality of life.

Given the priority needs of other sectors and the constraints on resources it will be necessary to constrain the costs of water development. This can be achieved through the judicious choice of economically efficient low-cost technologies that rely on locally available materials, and by favouring smaller projects over grandiose schemes. It is also important to ensure the continued maintenance of existing water services, and water supply capacity, as this may prove to be the least expensive alternative.

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6

Environmental and health issues: impacts of water and waste management

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EXECUTIVE SUMMARY

Water has played an important role historically in the creation and development of cities and even civilisations. The Rivers Tigris and Euphrates helped in the creation of Mesopotamia, and the Nile has been a key to the development of Egypt. Urbanisation is occurring at a very rapid rate throughout the world, stressing water supplies and creating waste management problems.

Urban and industrial development is leading to serious degradation of rivers, lakes and even groundwater. Toxic chemicals from industry, pesticides, nitrates and phosphates from agriculture are all contributing to the contamination of the freshwater resource. Over-pumping of groundwater aquifers is leading to saltwater intrusion and falling levels. The construction of large reservoirs can also have a serious impact on the ecosystem, leading to the disappearance of flora and fauna. Contamination of reservoirs by excessive quantities of nutrients results in eutrophication and poor water quality.

There are 1.2 billion people suffering from disease caused by drinking polluted water or transmitted by inadequate sewage treatment. Some 15 million children under five years old die annually in developing countries, largely because of poor water. Poor health caused by water-related diseases and unsanitary practices is a considerable cost to the economy in terms of workdays lost and reduced productivity.

The increased use of water in cities results in increasing discharges of wastewater. Rivers have a limited but natural ability to decompose and purify wastewaters. In many cities this limit has been reached and wastewater must be managed and treated. Technology is usually available to treat wastewater but care must be taken in transferring technology between countries: it must be appropriate to the environment and to existing technological expertise. Recycling of wastewater is an alternative that should be considered. Wastewater has been successfully used for irrigating crops.

Untreated wastewater contains bacteriological pollutants and pathogens that can cause sickness and death. Other pollutants which are dangerous to human health include nitrates from fertilisers, pesticides from agriculture and a host of toxic chemicals from industrial processes. Treatment and removal of these is difficult and costly.

Recommendations

1 Before water resources are developed it is important to carry out comprehensive water resource assessments including the nature, extent and vulnerability of these resources.

2 Cleaning up contaminated water resources is a costly and sometimes impossible task. A preventive strategy is always preferable to remedial action.

3 Environmental considerations must be part of cost-benefit analyses of water projects.

4 Public involvement is necessary in the evaluation of water resource projects.

CONTENTS

1 Trends in the Availability of Water Resources, including Drinking Water

Water is one of the most precious elements of mankind's heritage: natural water supplies, such as springs and rivers have played a key role in the establishment of cities. History is rich with examples of the ingenuity of successive civilisations in managing water resources: Egypt is a gift of the Nile; the Tigris and Euphrates created the great civilisation of Mesopotamia, and the Romans constructed the longest aqueduct to supply water to Carthage.

When cities were smaller, they did not need complex infrastructures for their drinking water supplies, and human activities at that time did little damage to the water quality. Water mostly came directly from natural sources, from groundwater, springs or rivers. For three decades, and particularly during the last decade, cities have undergone an incredible transformation into urban areas. The great metropolises at the beginning of the century did not exceed 250 km^2 whereas their current areas quite often exceed 6,000 km^2. In the developing countries, migration to the cities and population growth have created metropolises which are surrounded by belts where health conditions are very poor.

The consumption of water per inhabitant is very variable. It constitutes a useful indicator of the quality of life. In the United States, for instance, the requirement is 1,500 m^3 per capita per annum, whereas in Europe it is 500 m^3 per capita per annum and in the rest of the world it is approximately 100 m^3 per capital per annum. The combination of a fast growing population and an increasing per capita demand for water will result in excessive demands for drinking water throughout the world. Already, despite efforts over the last decade, the number of those living in and around cities who do not have clean drinking water has reached 225 million.

Water plays an essential role in ensuring peoples' life, health and activities, and if it is to continue to do so in future there is a need for rational water management. Water resource management will need to consider all aspects of the water cycle, from water collection to waste water discharge. Each aspect will also have to be analysed for its potential impact on the environment. Only in this way can the costs and benefits of water supply and wastewater treatment be properly balanced.

The mobilisation of water resources to meet urban demands requires a variety of technologies which are continually changing and improving to ensure a sufficient supply in terms of both quantity and quality. The system for collecting and treating both drinking water and waste water is becoming increasingly costly and complex to manage.

2 Impacts on the Environment and Health of the Increased Use of Water in Cities

Water resources are continuously subjected to development pressure in almost all countries, particularly in arid countries. As a result, the quantities of available water are declining and the quality of water is rapidly deteriorating.

Declining supplies are obliging cities to seek water further away from their centres. Water is now being transferred over long distances which is very costly and can lead to inter-regional or even international conflicts. The areas which are used as a source of water are being deprived of a large part of their natural resources, and their impoverished populations are obliged to migrate to urban peripheries where living conditions are precarious.

Urban water supplies are also experiencing a decline in quality. Rivers and streams which supply cities also receive urban waste water and industrial effluents, which means that they cannot be used directly as a water supply. Toxic chemicals from industry, pesticides, nitrates and phosphates from agriculture are all contributing to the contamination of the freshwater resource.

Groundwater is usually the best source of water because of the filtering capacity of the soil, and it is usually the first used. As such it is therefore under increasing pressure. The quantity of water available is declining as a result of over-pumping, leading to a drop in the water table. In coastal areas this can lead to salt water intrusion and subsequent salt contamination of the aquifer. Also when the water table has dropped the soil may subside, damaging infrastructures. Groundwater quality is also deteriorating because of human pollution from wastewater and industrial discharges. Groundwater bodies sometimes undergo irreversible deterioration when polluted by bacteriological and toxic pollution from waste water in urban areas with no sewage system. For these reasons, many groundwater bodies cannot be used directly for human consumption and require costly treatment.

The construction of large reservoirs for water storage can have a serious and complex impact on the environment that is often difficult to quantify and identify. When large dams are built, the river regime changes and influences the behaviour of the whole hydraulic system from the headwaters to the outflow. Flora and fauna living along the river suffer the effects of this change, whilst the population living in the area to be flooded must move elsewhere permanently. Some adverse effects can sometimes appear years after the start of reservoir operations. Reservoirs are also vulnerable to the inflow of nitrates and phosphates and toxic chemicals. Fertilisers, such as phosphates, are creating eutrophic systems in reservoirs and the degraded water quality makes for inferior water supplies.

Some countries resort to desalination of saltwater and seawater to meet water requirements. But the desalination plants themselves have an impact on the environment because of their use of power derived from fossil fuels. The effluent, made up of brine and the chemicals used in pre-processing, also has an impact on the receiving environment. Moreover, some water collection works reduce the natural flows of water. This can cause natural lakes to dry up or undergo a drop in level. This in turn has an impact on the fauna and flora in the area which is sometimes irreversible.

Droughts, especially when they occur in successive years, can accentuate the damage to urban water supplies. Human uses usually take priority and groundwater bodies are further depleted, reservoirs become empty and the flora and fauna downstream of the reservoir suffer.

The pressure caused by urban drinking water demands is also detrimental to the environment because of the excessive disturbance of the natural water cycle and the negative impact of the return of the waste water to the natural water cycle. Impact studies on withdrawals from, and return to, the natural water cycle can help to find means to minimise these negative impacts.

3 Impact of the Urban Use of Water Resources on the Environment and Health

Water is usually considered a staple commodity like bread, or an essential raw material forming part of industrial production. Therefore in cities water must be distributed to users as a collective or public service. Access to this commodity implies organisation, policy, costing and distribution of charges. Consumers thus have both rights and responsibilities.

Deterioration in the quality of this vital resource has very serious implications for health and the quality of life. Access to it becomes a right requiring equitable distribution to all society. Attempts have been made in most countries to ensure that even the poorest sections of the population have access to good quality drinking water, but much effort is still needed to attain this objective. At present, 225 million inhabitants of cities and their peripheries do not yet have clean drinking water. Several million still have access to water only with great difficulty, not counting those who are subjected to rationing and chaotic distribution.

Although in many places water of sufficient quality is available, it is nevertheless subject to pollution. The dangers of contaminated drinking water and inadequate sewage systems are well known. There are at present 1.2 billion people suffering from diseases caused by drinking polluted water or transmitted by inadequate sewage equipment. Some 15 million children under five years old die annually in developing countries, mainly following an illness caused by water. These diseases also play a significant role in adult mortality and sickness. Poor health caused by water-related disease and unsanitary practices is very costly to the economy in terms of work days lost and reduced productivity. The pollution of water supplies may be aggravated if drinking water supply programmes are not accompanied by appropriate sewage systems.

Many countries do not have the operational means to assess their water quality. Without this information, they may be unaware of problems and perhaps endangering their population's health. Water quality can have a direct and immediate impact on health. However, some pollutants bioaccumulate and the health effects may not be detected for some time. Therefore, the monitoring and quality control of water is of prime importance for human health. Moreover, when deprived of drinking water close to their homes, millions of women and children are obliged to spend many hours each day covering long distances in difficult conditions to fetch water for their families. Home management, well-being and the education of children suffer as a result.

Much more effort is now being directed towards preventing pollution and treating polluted water, particularly now that more sophisticated methods of water treatment are available. Industrial effluents, urban sewage, as well as chemical fertilisers used in agriculture and urban or municipal waste, contribute to the pollution of the water used directly by human beings. In several countries, some groundwater bodies and streams have become unfit for consumption or other use. Monitoring and control must be carried out systematically, especially in areas where is a lot of industrial activity.

The increased use of water in cities is inevitably increasing discharges of waste water (the average percentage discharged into the sewage system amounts to 80 per cent). The volume of waste water will thus continue to increase, with a resultant proportional rise in expenditure on collection networks and wastewater treatment plants. The self-cleansing capacity of the receiving waters is also rapidly diminishing. In many countries, the water supply has run ahead of the waste water management system. A great effort must now be made to close this gap and preserve the environment through waste water treatment.

4 Remedial Action

The rational management of city water supplies is essential to preserve human health and the environment. Mismanagement of the collection and use of water has had negative effects in many countries. The management of water resources for the various users must be equitable in order to maintain community solidarity. The system must also generate sufficient financial resources for it to maintain its quality and quantity over the duration of operation.

Before starting a water supply construction project, it is essential to have as much information as possible about all aspects of the project. A water resource assessment must be made to determine the nature and extent of the water regime and its degree of vulnerability. Information is also needed on the choice of appropriate techniques to collect, protect, treat, distribute, recycle and remove water. This information has to be analysed within the framework of a long-term plan for the subsequent action to be harmonious and the system functional. Community participation is also an important aspect of the decision-making process.

The improvement in living standards, whereby individuals' essential needs are met in terms of food, housing, clothing and participation in society, enables people to concern themselves with the quality of life. Indeed, a correlation exists between increased income and ecological concerns, which can be seen both in nations and in individuals.

Standard indicators of water quality can be used for the periodic monitoring of water supplies to prevent degradation and determine preventive action. It is preferable to have the water monitored by a different agency from the one managing the water supply. Water quality indicators can also be used to assess the impact of discharges on the receiving water. If the indicator standards are too stringent efficiency is lost; if they are too lax the environment is damaged.

The health and environmental risks associated with water pollution are fairly high. Remedial actions are always costly and may not be reliable. A preventive strategy is preferable, where measures are taken to preserve the quality of the water resource. The dissemination of an objective risk assessment helps decision makers and the public to avoid action which may have a negative impact on the environment.

5 Techniques to Attenuate Impacts on Environment and Health

The planning of water resources for use as city drinking water must consider short- and long-term requirements. The plans must provide preventive measures to minimise damage to the environment and health and to avoid unnecessary financial expenditure.

In most cases there is not a great deal of choice in selecting a water supply. Population growth and economic development create tremendous demands for drinking water. In the past, no environmental impact studies were carried out on water projects, since the tools for carrying them out were non-existent. Such studies can now be carried out and provide the basis for a variety of options which can minimise the negative adverse effects on the environment.

The consideration of environmental protection criteria in the evaluation of projects can suggest options and alternatives that are both economical and protective of the environment. This is closer to reality and therefore preferable to former methods which tended to conceal environmental parameters.

Taking account of environmental degradation and the deterioration of the quality of life in project evaluation helps considerably to reduce negative impacts and makes the solutions adopted less aggressive and more durable. Recycling of waste water has a potentially important application in the irrigation of crops, provided that certain precautions are taken. In several countries treated waste water is recycled for irrigating fodder crops. However, it must be strictly monitored to avoid damaging effects on health.

6 Sustainable Development and Environmental Conservation

The involvement of water professionals in conserving water resources is of great importance in finding solutions to environmental conservation problems. This involvement leads to their better appreciation of the benefits of environmental conservation. With this appreciation they are better able to design and plan water projects that conserve the environment.

It is necessary to train project designers, decision makers and operators and provide them with the methodologies, reference criteria and analytical systems to implement water projects that result in sustainable development.

Current methodological and research means are still poorly able to deal with present water resource problems in the context of sustainable development. Research is needed to understand the mechanisms involved, and to identify the elements required to make water resource management decisions. The transfer of water technology and the adaptation of technologies to developing countries are imperative as environmental conservation and sustainable development are of universal concern.

7

Integrated urban water resources management

Peter Rogers (USA)

EXECUTIVE SUMMARY

This paper focuses on the organisation and institutional issues of water resources management strategies. It considers integration both as a cross-sectoral issue and in terms of the communication and coordination of activities among all levels of sector agencies. Themes common with other papers at the conference are: community water supply; water supply to industries and services; and water for use by power supply and recreation activities.

The paper concentrates heavily on the economic aspects of planning for urban and other water use. The reason is that, despite a large literature on economics of water and the environment, the actual application of these principles and concepts to practical water planning problems has not been widespread. Hence, four sections of the paper are devoted to economic concepts and measures for efficiency, economic benefits, demand and supply for water goods and services, and practical pricing problems. The following section contains recommendations for improving water planning. The remainder of the paper is the contextual material on the nature and magnitude of urban water problems.

'Stylised facts' about water that need widespread dissemination are (1) that water is a unitary resource; surface and groundwater, and fresh and polluted water are all part of the same resource base, and (2) that scarcity of water has no meaning outside of the consideration of alternative uses. If policy makers could be brought to understand these facts and incorporate them into their thinking about water, then the rationale for many of the needed policy changes would be in place.

Over the past few decades tremendous progress has been made in providing basic water supply and sanitation to the people of the world. Nevertheless, much remains to be accomplished. For example, the current level of capital expenditure in this area is only roughly 20 per cent of the amounts required to carry on the progress of the recent decades and reach 100 per cent coverage of the world's urban population. The only way out of this problem appears to be to make the current utilities more economically effective.

The single most important policy improvement would be to make sure that each utility covers its operating costs *as well as* its capital costs by economic pricing of water use. An effective, forward-looking revenue generation scheme will position the utilities to provide an expanding service to everyone in the service area.

CONTENTS

1 Introduction

The world is entering a period of intense competition over limited supplies of water among alternative uses in agriculture, urban and industrial supply, recreation, wildlife, human health, and environmental quality. Manifestations of this competition and our current inability to deal with it can be observed in many parts of the world. For example, a large irrigation project in India does not operate because water has been diverted to the rapidly growing city of Pune. In China industries are reducing their production due to water shortages even though they are surrounded by irrigated paddy fields. In California selenium salts leached by irrigation are killing wildlife. Irrigation projects in Algeria are now competing with urban water supply projects for the same water, and many proposed irrigation projects and most hydro project proposals are on hold because of environmental concerns.

Until recently the approaches taken to water planning and management by water planners in the countries concerned and by the analysts at the funding agencies were, by and large, appropriate and adequate to the task at hand. The increased competition for water has, however, made most of the project-by-project planning methods inadequate. New approaches are needed that will integrate water resource use across different users and across different economic sectors.

1.1 Issues in urban water resources management

The main driving force behind urban water demand has been the rapid increase in urban population over the past 30 years. The next 30 years will experience similar increases in demand for urban water resources, largely due to the increasing affluence of the already large urban populations. From 1960 to 1990 the world's urban population increased from 1 billion to more than 3.5 billion. The most rapid rates of growth have been in Africa and South America, but the largest contribution came from Asia's 1.3 billion increase. Since only 30 per cent of the Asian population was urban by 1990, it is expected that the rate of urbanisation in Asia will accelerate because the rural sector is losing its capacity to absorb still more people. Urban water resources will continue to be stressed and will require ever-increasing amounts of capital investment just to keep up with demand.

Figure 1 shows annual water withdrawal by region and as a per cent of locally available water resources. From a resource availability point of view, the figure is reassuring; no more than 15 per cent of the total available water is withdrawn in the worst case of Asia. This, however, masks the fact that in many and countries of the world the withdrawal is much closer to the available supply. The figure also indicates the effect of affluence on water demand; in North

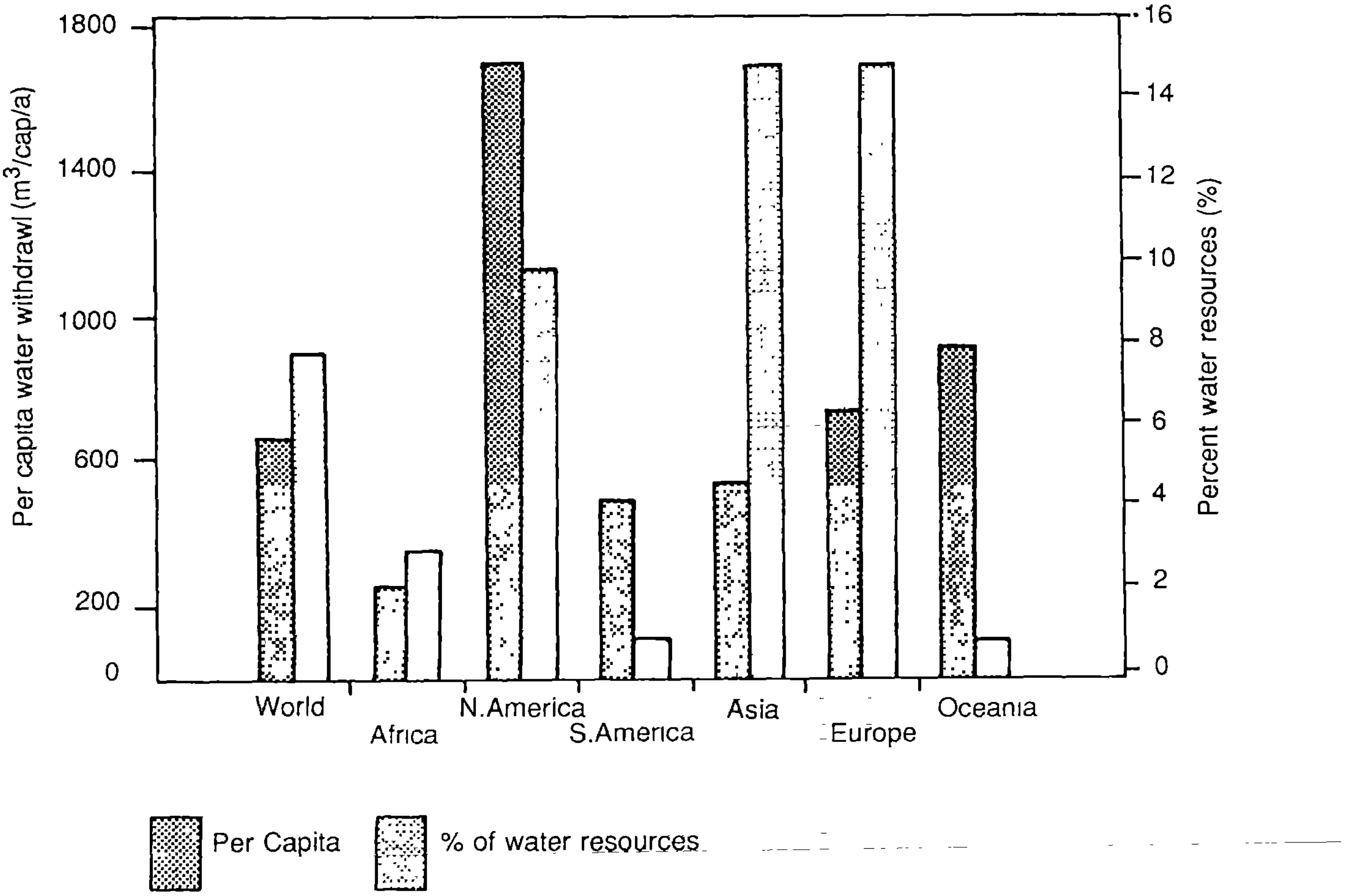

Figure 1 Annual water withdrawal, per capita and as percentage of total water withdrawal

America the amount withdrawn per capita is almost three times the global average and almost eight times the amount used per capita in Africa. With increasing affluence we would expect the levels of per capita water use to increase rapidly and begin to approach the North American average, with potentially devastating impact upon the total resource base. Figure 2 demonstrates the sectoral use of water from a global point of view. By far the largest user of water in all regions except Europe is agriculture. As will be seen later, it is this pivotal use of water that allows water planners to view the expected rapid increase in water demands with some equanimity: irrigated agriculture is the safety valve of the system.

Figure 2 also shows the large amounts of water that are withdrawn in the developed regions for domestic and industrial uses. Of course, when water is provided for urban and industrial uses most of it is not consumed but is returned contaminated to the water source. Roughly 33 per cent of the water withdrawn on an annual basis is used outside of agriculture. Of this amount, 153,000 million m^3 will show up as urban wastewater streams. As little as one third of this amount receives any level of treatment. In addition to domestic and industrial uses, there are several other important uses for water in urban areas that are often overlooked. For example, the provision of electricity often requires large amounts of cooling water, and water-based recreation is one of the major forms of urban water use and often makes the difference between liveable and unpleasant environments in tropical cities. Finally, the control of urban flooding is a major problem in many metropolises around the world. The nature of the technical approaches to solving the flood problem condition the other technical options for urban water resource development.

The above gives an indication of the magnitude of global urban water resources problems. Drawing specific generalisations from them is difficult because individual countries may face more or less severe problems depending upon the current levels of infrastructure, availability of water and wastewater disposal options. Nevertheless, with continuing rapid population growth, the number of cities of over one million people is expected to increase rapidly. It is in these burgeoning metropolises of the Third World that the most pressing needs for water supply and wastewater disposal investments will be felt. Nevertheless in all cities of the world the costs of providing new water supplies and wastewater facilities are rapidly increasing.

1.2 Water and health

The public health aspects of water supply and wastewater disposal have always been used to motivate public investment in such facilities. A relationship between water and health has been accepted since at least the time of Frontinus, the Water Commissioner of Rome in A.D. 97, but the exact relationship is not well understood even now. A World Bank

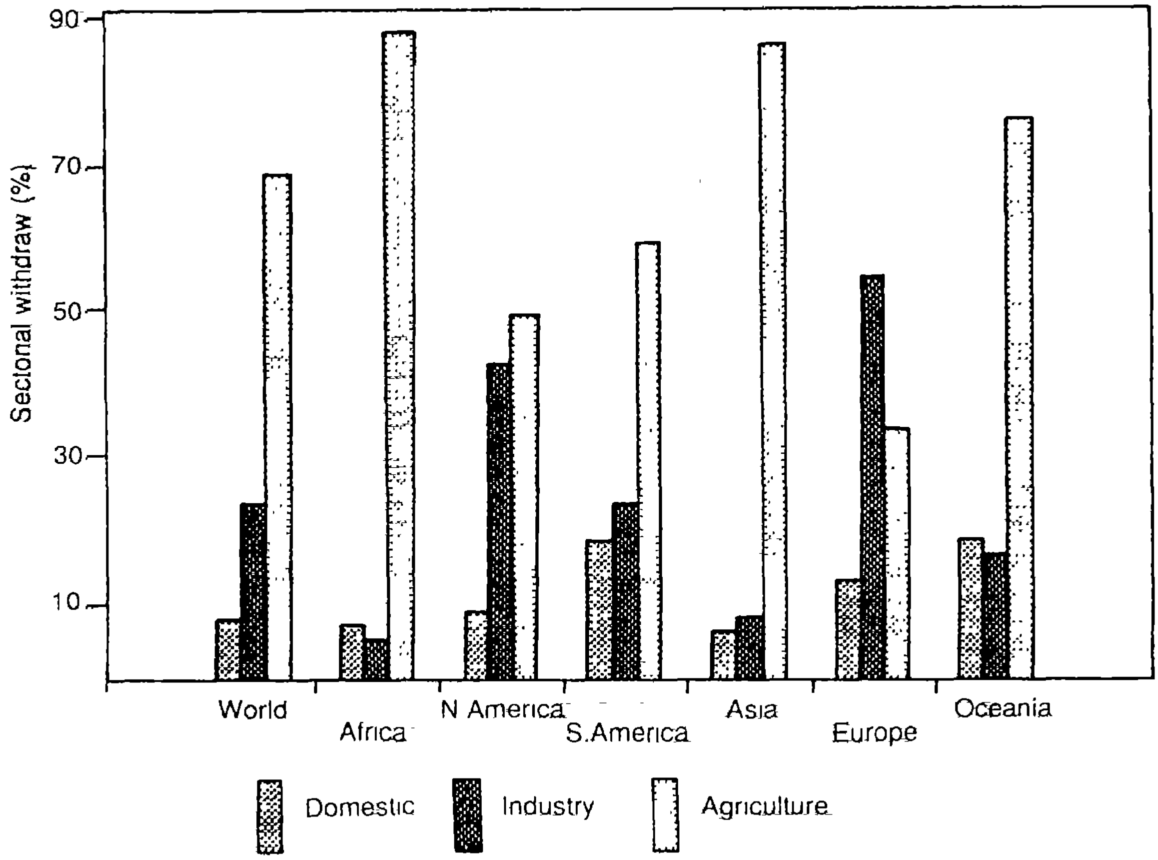

Figure 2 Sectoral use of water resources: domestic, industry and agriculture as a percentage of total withdrawal

position paper on domestic water supply (World Bank, 1976) cautiously limited itself to saying that "other things being equal, a safe and adequate water supply is generally associated with a healthier population." Many of the benefits observed during the 'sanitary revolution' in the industrialised world were achieved when protected water supplies were provided to societies with rising income levels, which induced other positive behaviours with respect to personal hygiene and nutrition. At low levels of per capita income, investments in improved domestic water supplies are often necessary but generally not sufficient to realise the potential health benefits. For middle-level developing countries, where the population is generally better educated, the health benefits of investments in water supply and sanitation are generally substantial. At higher levels of development one typically observes small additional health benefits from further investment in such facilities.

Apart from drinking water and sanitation, serious human health problems can be introduced into an area through the development of water resources. The classic case is the spread of schistosomiasis in Africa and Asia after the introduction of irrigation. Debilitating rather than fatal in most cases, schistosomiasis now infects more than 200 million people. Malaria, filariasis, yellow fever, onchocerciasis (river blindness), dracunculiasis (Guinea worm disease), and sleeping sickness can be brought by irrigation projects. Many water-soluble chemicals used in agriculture, particularly chlorinated hydrocarbons, accumulate in animal and plant tissues and thus enter or become concentrated in the food chain. High concentrations of nitrogen fertiliser in water supplies cause blood diseases in infants. In many countries unregulated and indiscriminate production and disposal of chemicals and their wastes have led to serious contamination of surface and ground waters by toxic and carcinogenic substances. Some of the worst cases are observed in developing countries which have few resources to deal with them.

We should not, however, allow the traditional 'water-health' equation to go unchallenged. One of the reasons for emphasising the intersectoral aspects of investments in water is to raise the question of whether or not investing in water and sanitation is the best way of spending for improved health? Maybe similar amounts invested in nutrition, maternal health care, and immunisation programmes could bring equal or better health impacts. This question can only be addressed in an intersectoral study where water and sanitation are just two of many potential health improvement technologies.

1.3 Urban water supply and wastewater disposal

The UN and its specialised agencies have played a major role in the International Drinking Water Supply and Sanitation Decade (1981-1990) with the goal of providing clean water and adequate sanitation to all by the year 1990. It would be particularly appropriate to include a critical review of the Decade in this paper; unfortunately, the detailed *ex post* review has not yet been completed. Christmas and de Rooy (1991) provide a summary of the accomplishments of the Decade. Starting from 1980 when two billion people lacked adequate water and sanitation, and only 40 per cent had access to safe water supply and only 25 per cent access to sanitation, by 1990 over 60 per cent had access to water and 40 per cent to sanitation. This represents a major achievement. Surprisingly, Table 1 shows that more success was achieved in the rural than the urban areas in terms of the increased numbers of people served with both water and with sanitation. According to Christmas and de Rooy, by 1990 82 per cent of the urban populations are served with potable water and 72 per cent with some form of sanitation. Again, these global figures cover a wide range of country experiences. Figure 3 shows the variability between regions and Figure 4 shows the wide variability between and among selected countries. Figure 4 also shows the changes from 1960 to 1985 for these selected countries, some of which exhibit a declining coverage of the population. This may be due to extended periods of unrest, as in Nicaragua, or that the programme was unable to keep up with the rate of growth of urban populations, as in India and Malaysia.

The New Delhi Statement (Water International, 1991) compares the current $10 billion annual capital expenditures with the estimated $50 billion annual expenditures needed to achieve 100 per cent coverage for both water and sanitation by the year 2000. Munasinghe (1990) points out that the historical bilateral and multilateral lending in this area has traditionally been less than $1 billion. He concluded that, since much higher levels of finance are unlikely to be forthcoming, the shortfall will have to be met by greatly improved cost recovery from existing and new projects.

There is a need to look harder for innovative ways of dealing with urban water and sewer costs. Technical and managerial performance needs scrutiny to ensure that excessively costly systems are not built merely to copy the industrialised countries. This is particularly true now in Eastern Europe, where the tendency is to proceed immediately with the same approaches as those used in Western Europe. As is well known, the general rule is that removing the first 50 per cent of pollution is quite cheap, with the incremental improvements being increasingly costly. This consideration often supports developing a system in stages, moving to the expensive higher levels of performance as general economic growth generates increased ability to pay for them.

The costs of alternative approaches to urban water supply and waste disposal should also be carefully examined. Gunnerson (1991) points out that the cost of wastewater disposal in Third World cities is routinely five to six times as much as the cost of supplying the water, and that for North American cities it often exceeds the cost by as much as fifteen times. Local agencies should be made aware of these

***Table 1** Water supply and sanitation coverage 1980-1990*

Region/sector	1980 Population	1980 Per cent coverage	1980 Number served	1980 Number unserved	1990 Population	1990 Per cent coverage	1990 Number served	1990 Number unserved
Africa								
Urban water	119.77	83	99.41	20.36	202.54	87	176.21	26.33
Rural water	332.83	33	109.83	223.00	409.64	42	172.06	237.59
Urban sanitation	119.77	65	77.85	41.92	202.54	78	160.01	42.53
Rural sanitation	332.83	18	59.91	272.92	409.64	26	106.51	303.13
Latin America & the Caribbean								
Urban water	236.72	82	194.11	42.61	324.08	87	281.95	42.13
Rural water	124.91	47	58.71	66.20	123.87	62	78.80	47.07
Urban sanitation	236.72	78	184.64	52.08	324.08	79	256.02	68.06
Rural sanitation	124.91	22	27.48	97.43	123.87	37	45.83	78.04
Asia & the Pacific								
Urban water	549.44	73	401.09	148.35	761.18	77	586.11	175.07
Rural water	1823.30	28	510.52	1312.78	2099.40	67	1406.60	692.80
Urban sanitation	549.44	65	357.14	192.30	761.18	65	494.77	266.41
Rural sanitation	1823.30	42	765.79	1057.51	2099.40	54	1133.68	965.72
Western Asia (Middle East)								
Urban water	27.54	95	26.16	1.38	44.42	100	44.25	0.17
Rural water	21.95	51	11.19	10.76	25.60	56	14.34	11.26
Urban sanitation	27.54	79	21.76	5.78	44.42	100	44.42	0.00
Rural sanitation	21.95	34	7.46	14.49	25.60	34	8.70	16.90
Global totals								
Urban water	933.47	77	720.77	212.70	1332.22	82	1088.52	243.70
Rural water	2302.99	30	690.25	1612.74	2658.51	63	1669.79	988.72
Urban sanitation	933.47	69	641.39	292.08	1332.23	72	955.22	377.00
Rural sanitation	2302.99	37	860.64	1442.35	2658.51	49	1294.72	1363.79

Source: WHO

costs and encouraged to set their tariffs to reflect real costs and projected trends of costs. Christmas and de Rooy (1991) show urban water supply investment costs ranging from $200 per capita for high technology systems, to $100 per capita for intermediate technology systems, and to as little as $30 per capita for low technology systems. The corresponding costs for urban sanitation are $350, $25, and $20. In order to cover these costs effective cost recovery is critical. Studies should also be initiated to elucidate the economic benefits of the provision of these urban services. Such studies should be based upon assessments of the willingness-to-pay for these services by different socio-economic groups. Such studies are conceptually difficult as well as time-consuming, but they should be carried out in a sufficiently large number of cases that the basic magnitude of the expected benefits can be demonstrated. This is particularly important in this sector since most of the literature focuses upon the cost of the services and on complaints that they are becoming too expensive. 'Too expensive' compared to what? The only meaningful comparison is with the benefits received from consuming these goods and services.

For urban wastewater disposal, consideration of the role of industry in the management of the ambient quality of the water resources is vital. Industry uses only five to ten per cent of all water supplied but still represents an important segment of demand. This results in part from the fact that industrial

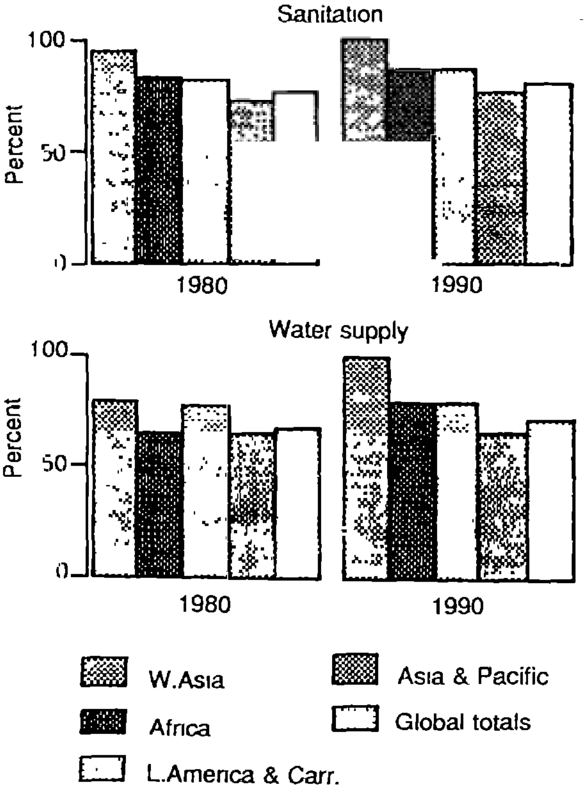

Figure 3 International Drinking Water Supply and Sanitation Decade: decade performance 1980-1990

processes pollute a disproportionate amount of water. For example, in São Paulo and Seoul, industrial pollution has turned many streams and rivers into open sewers. Developing countries should learn from the experience of industrialised nations: it is much more expensive to clean up polluted water than it is to avoid polluting in the first place. Economic incentives against industrial pollution need to be established. Currently the 'polluter pays' principle is becoming widely accepted around the world. Under this principle policy instruments, such as effluent fees, are established so that companies will have an incentive to control their effluents at the source. In addition to the usual regulatory methods, innovative approaches such as tradeable permits and privatisation of facilities should also be explored. The failure of some of these approaches in the industrialised world does not mean that they may not be appropriate in Third World settings.

1.4 Irrigation

As mentioned above, worldwide consumption of irrigation water accounts for about two thirds of the total water withdrawn and it also accounts for more than 80 per cent of the water consumed. Hence, policies influencing irrigation are extremely important in the planning of urban water resources. 'Water and food' carries many assumptions about development policy which need to be carefully laid out and separately examined. Food security is a major concern of

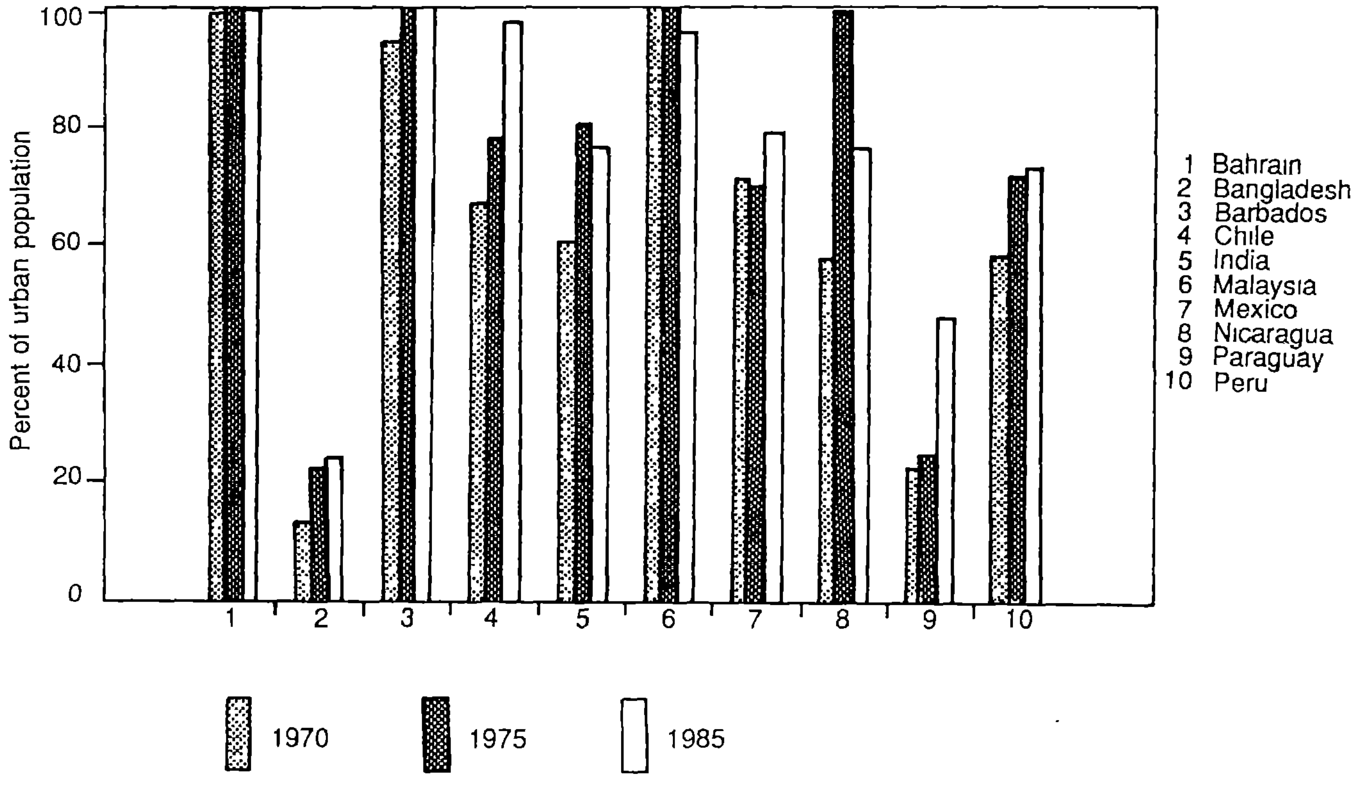

Figure 4 Access to safe water in selected countries

every government throughout the world but how to achieve a satisfactory level of security is not obvious. National self-sufficiency in food grains is not the imperative that it is often assumed to be. In the modern world oil is essential for survival, but nowhere do we find the belief that every country should be self-sufficient in oil. There is no reason why every country should grow grain, which requires, per ton, 2,000 to 3,000 tons of water. In a dry country water can have a much higher value for other uses. International trade can redistribute water — in the form of grain — to nations that decide not to grow it. Several North African countries now subscribe to this practice, emphasising valuable cash crops such as fruits, vegetables, and flowers for the European market. Countries that take this approach could maintain stockpiles of the basic grains; even though stockpiles are costly and can deteriorate, replacing spoilage is less expensive than growing grain. Such countries could grow a diversity of cash crops so that fluctuating international prices for individual commodities could not devastate their economies.

Even the definition of self-sufficiency is not clear. Does it mean that a country should be self-sufficient on the average, or for drought years, or only 75 per cent of the time? The choice of the definition has a large impact on planning for water use in agriculture. The issue of food security cannot be adequately addressed by studying the irrigation sector. It can only be dealt with at the intersectoral level which asks questions about the relative investments in different sectors to achieve national goals. It may turn out that in comparison with food import and storage investments, investments in irrigation may not be the most economically and socially desirable. It cannot be stressed too strongly that this issue can only be illuminated by economic and political analysis at the level of intersectoral investments.

Increasing 'water use efficiencies' in agriculture is another widely suggested solution to water shortages. However, in many parts of the world one farmer's inefficient use provides the water for another farmer downstream or recharges the groundwater for many other farmers. It has been argued that the irrigation efficiency in California's San Joaquin Basin approaches 100 per cent despite the fact that on any one farm the efficiency may only be 60-70 per cent. Individual cases must be closely considered before much can be made of the advisability of improving 'irrigation efficiency'. Many commentators looking only at farm level efficiencies have advocated improvement of efficiency of water application as the best way to conserve water. Although this may be true in some cases, it is not universally true and should be subjected to careful analysis.

It is more appropriate to start from the larger perspective of the overall regional efficiency of the use of water for irrigation. But even this is a difficult concept, and agricultural and irrigation professionals will be on still stronger ground if they orient themselves to the further-reaching concept of the 'economic efficiency' of all water use rather than of 'irrigation efficiency'. 'Irrigation efficiency' is a seductive notion because it simplifies the problem to water alone, and focuses it down to essentially engineering and management variables. But if pursued for its own sake, as it too often is, it can become a form of tunnel vision; it can throw the larger benefit-cost picture seriously out of balance, and lead to misplaced investment on a significant scale.

There are many other issues involving choice of technology and cropping policies that have not been featured here, which are also of major concern in this part of the water sector. Many of the sector-wide issues apply in the irrigation area. For example, a recent paper by Johnson (1990) indicates that the problems with irrigation in South and Southeast Asia are becoming particularly acute because of the funding of the operations and maintenance (O and M) of the systems. In agricultural systems, as in all systems, pricing and cost-recovery are fundamental to achieving proper operation and maintenance of the system.

1.5 Economic imperatives of water policy

To appreciate fully water policy options and how they are evaluated, it is necessary to understand how economics is used and misused in the water area. Even though politics ultimately controls water resource planning, the discussion is usually framed in economic terms, and the ability to understand and manipulate the economic analysis may significantly improve the final outcome. Hence, much of this paper is devoted to exploring the possibility of improving the economic aspects of planning. The attention devoted to economics should not be taken to mean that the institutional and technological dimensions are unimportant, but rather that the pay-offs from improving the economic dimensions are currently larger than those from other areas of concern.

The problem with economics is that everybody seems to have some instruction in the subject. The public retains few of the basic concepts but remembers many of the ideologies. Constant evangelism by disciples of the right or the left of their assumptions about reality, though they may be unrealistic to any common sense observer, results in a widespread rejection of economics as a way of dealing with practical problems. In this paper an attempt is made to strip away the assumptions and to look for economic approaches which rely upon observed behaviours. The goal is to show that rules based on the behaviours which can be expected of capitalists and communists alike do exist, and can serve as helpful guides for rational water policy.

For example, basic empirical observations show that, in both Boston and Beijing, if the price of water is increased, consumers will use less of it. In other words, there is a 'willingness-to-pay' for water that is not an abstract economic concept depending upon elaborate theories of private property but is rather a reliable behavioural trait of consumers of products like water. The same behaviour would be expected in Kansas and Katmandu — and is a good basis for assessing the economic demand for water. If human nature acts the same way in these widely differing locations on the globe we can surely expect the natural environment to respond to human modification in similar ways in different locations. So for example, the most accessible water for human use is the cheapest to develop and the next most accessible costs a little more, the next a little bit more, etc., and very soon one can observe an increasing 'marginal cost' curve that depends upon nature, not upon theory. Between these two observed phenomena of willingness-to-pay and increasing marginal cost curves a good set of practical rules can be derived for helping to decide upon how much to invest in developing a particular water supply.

To decide whether to spend money on irrigation or flood control systems, or on other investments outside the water sector, these simple behavioural rules need to be bolstered with additional assumptions and theory. Much of the economic literature is devoted to explaining how to decide which are the most plausible and least constraining assumptions and theoretical constructs.

Other approaches to allocation of water are based upon the concept of meeting 'basic needs'. This approach is often advocated under circumstances where it is believed that the economic approaches have failed or will not work well. The problem with the basic needs approach is that it works quite well in assuring everyone access to some minimal amounts of water, but it does not address the next level of questions of how to allocate water above and beyond the levels of basic needs. In most urban situations in the world the actual amounts of water available to the populations are already above the minimum basic needs levels (20 to 40 litres per capita per day) and are in the range of 'economic' allocation choices. Hence, this paper will not focus on the basic needs approach other than when it occurs under the concepts such as 'life-line' rates for public water supply tariffs.

It is also important to note that urban water resources management involves many more disciplinary inputs than economics. The role of technology, not only for supply and disposal options, but also for conservation of water and the reduction of waste streams through pollution prevention, is very important. The roles of education and public relations are also often ignored to the detriment of the successful operation of urban systems. Utilities need to be encouraged to employ non-engineering staff with backgrounds in the social sciences to deal with these issues.

2 Fundamental Concepts for Water Management

2.1 Water, a unitary resource

Rain, surface water in rivers and lakes, groundwater, and polluted water are all part of the same resource base. They are all one and the same resource, although in different manifestations, occurring in different parts of the hydrological cycle. Unused surface water can recharge the groundwater and, conversely, over-pumped groundwater can reduce the flows in surface streams. Contaminated water can be purified by constructing wastewater treatment processes or it can be recovered by the natural assimilative capacity of the surface and groundwater ecosystems. Thus, the entire hydrological balance must be considered, not just parts of it. Actions taken in one part of the system often have significant impacts upon other parts; these linkages must be taken into account when assessing the costs and benefits of specific actions.

Because water is a unitary resource there are often conflicts among users. The most common example is the conflict between surface and groundwater users in irrigated agriculture. Improvement in the efficiency of application of the surface water results in an immediate decline in the availability of groundwater. Allocation decisions are also frequently ambiguous. For instance, water is often allocated to irrigation projects at low cost to the users when nearby urban areas are suffering serious water shortages and are willing to pay high prices for water. As a result of these types of problems, water use in all countries has become embedded in complex legal and institutional settings. While it is evident that many of these institutional complexities can hinder economically efficient use of water it should be remembered that they arose in the first place because of the genuine problems that water raises for any politico-economic system. As the costs of ignoring the unitary nature of the resource rise one would expect to see the gradual easing of institutional constraints on development in the direction of more rational integrated use of the resource.

2.2 Scarcity of water

The discussion about scarcity is usually intimately bound up with the concepts of water as a renewable or non-renewable resource. If it is renewable, how can we ever run out of water? Certainly in many arid or semi-arid zones, people are currently experiencing shortages of water. Part of this problem no doubt has to do with the fact that under earlier historic conditions and population size, we were able to sustain the populations of cities and regions, even under relatively arid conditions; however, with the growth of population and income, the demands for water seem to be overwhelming our technological capability to supply it. Under these conditions water scarcity and conflicts over water use begin to appear. It is also noted that the cost of supplying additional water to water-short areas is increasing. As a result it becomes increasingly difficult to supply the same amounts of water to users at the old low prices. The Malthus-Ricardo theory of resource scarcity seems to be working exactly as predicted: scarcity of resources limits economic growth, and ultimately brings it to a halt. It is no surprise that this theory earned economics the sobriquet of 'the dismal science'.

Modern economists define water scarcity slightly differently, which allows for a way out of this dilemma: the need for water has to be expressed as a quantity and a price.

This is called the 'economic demand' for water and both quantity and price must be specified. In the current economic models resources do not 'run out,' because as the quantity demanded increases new sources will be tapped, at the same or higher costs, and/or the price will rise, restraining what each user will desire to purchase. This is essentially a self-limiting process. Clearly, if a resource base is fixed and the consuming population increases, something has to give. This will be either the price or the quantity of the resource used. However, even this system would ultimately be forced to a halt by population or economic growth. The magical ingredient that enables the economic system to continue to grow is the existence, at some reasonable cost, of substitutes for the scarce resource. A paradox arises here because there is *no* substitute for water in sustaining human and animal life. But there is an almost infinite supply of sea water, which can be converted at a cost of energy into fresh water; so now energy, or the capital available to access the energy, becomes the limiting resource. Similarly, political boundaries, management skills, or human labour could be the factors which limit the availability of water.

Part of the problem of dealing rationally with water scarcity is the different perceptions that various groups have about how close we are to reaching the resource limits. For example, in a study for the World Bank, Falkenburg *et al.* (1990) claimed that some countries (Israel, Jordan, Saudi Arabia, Syria and Yemen) were very close to being unable to supply their populations with the minimum needed amount of water (500 cubic metres per capita per year). However, others looking at the same data see many possible adjustment mechanisms, which include recycling, cut-back in agricultural use, changes in population policy, and the reclaiming of additional brackish water. Has water been a significant limit on economic growth in any of these countries? How will each country address the future of this resource? Has water been priced out of the reach of significant portions of the populations? What accounts for the fact that in many other countries with much larger per capita quantities of available water the per capita water use is lower? On closer inspection the 'water barrier' of 500 cubic metres per capita per year does not appear to be a real barrier in the Malthus-Ricardo sense. The idea put forward by many (Postel, 1990) that we are running out of water cannot be true globally, and even in specific water-short countries there is little doubt that water will always be available at some reasonable price, provided those countries follow sensible water policies. *The definition of scarcity in non-economic terms is a distraction that can lead to major misallocations of the water resource.* The rapid disappearance of the 'oil crisis' once limited market responses were allowed to take place should be borne in mind by water planners.

The response to the Californian drought is another good example of how market responses were allowed to mitigate the effect of the drought. In the fourth year of the drought when the reservoirs were at exceptionally low levels, the State government set up a water bank to buy water from farmers. Within a few weeks of announcing that the bank would buy water rights for the year at $125 per acre foot the required amounts were made available by farmers eager to sell their water at this high rate for agricultural water but which is less than half of what municipal water suppliers are willing to pay. Over 700,000 acre feet of additional water were then available to the municipalities.

2.3 Valuation of water

Allocation of water among the myriad conflicting potential uses presents a major task to governments, all of which take responsibility in some degree for regulating access to water. It is difficult to assign unambiguous economic values to many uses, and hence these may be implicitly overvalued, undervalued, or completely ignored in the decision making process. Rogers (1986) gives several examples of the problems that arise from undervaluing water. Many of the problems of valuing water stem from the market failures mentioned above. In particular, the existence of externalities and the lack of mobility of resources make finding the market price quite difficult. In a perfectly functioning economy envisaged by the classical economic model 'price equals value,' and the cost of providing a good, after allowing for payments to all of its factors of production, will precisely equal its market price. As a result of this elegant solution one only has to establish 'cost' to establish 'value.'

Unfortunately, many water resources planners forget that simply equating cost with value only holds true in a perfectly functioning market economy. In all other cases (that is almost all cases) care must be taken not to confuse 'cost' with 'value.' What then is the 'value' of water? The answer appears to depend upon 'to whom' and for 'which use'. Drinking water is obviously valuable and becomes increasingly so as the amount available decreases. A glass of water could be infinitely valuable to a person dying of thirst in the desert but not very valuable to a person living alone on the banks of a pristine river. In the second case the person would only be willing to pay the cost of somebody going to the river and fetching the water for her. She would be unwilling to pay more because she could go and take it herself. So the value in this case is the cost of obtaining the water. Now, if there was a farmer irrigating land alongside the river, how much would the water be worth to him? If there is enough water in the river so that the woman can have as much as she can drink just at the cost of obtaining the water from the river, then obviously the farmer can take as much as he wants at the cost of obtaining the water. Clearly, the farmer would also value the water at the cost of obtaining it. So far, so good: cost equals value.

Unfortunately, such bucolic settings no longer exist in the modern world. Typically there are many users of the resource apart from the housewife and the farmer. At some point in time the use by one user will start to interfere with the use by another. At that point the water is said to have an 'opportunity cost' since the continued withdrawal by one user reduces the amount available to another; there is a loss of the opportunity to use the water by one user. This lost 'opportunity' costs the affected user the amount he values these units of water. At this point the 'value' of the water should reflect the willingness-to-pay of the user who is losing water. If for some institutional reason the housewife has to cut her consumption of drinking water, then the opportunity cost to society of this allocation of water away from her is her willingness-to-pay for water. If the allocation of the water shortage were the other way around, the relevant opportunity cost would be the farmer's willingness-to-pay for irrigation water.

Now, if the question of how to allocate the water were left to an outside party, for instance, the United Nations, then that party might ask how society would best benefit from the allocation. One way of answering this question is to apply the logic of social choice theory embodied in modern economics, which implies (*ceteris paribus*) allocating the water to the use with the highest value (highest opportunity cost).

Establishing the willingness-to-pay for various consumers of water is a fairly well developed field in economics and can be easily adapted in many water conflict situations to establish estimates of the opportunity cost of water. Unfortunately, many economic studies of water use ignore the opportunity cost of water and only reflect the actual costs of obtaining the water itself. As mentioned above, if there were well-established markets for water then the market price would itself reflect the opportunity cost of water. However, in most countries such markets do not exist and one is left to estimate the opportunity cost in indirect ways.

The opportunity cost of water is only zero when there is no shortage of water. In evaluating water investments it is important to remember that *the value of water to a user is the cost of obtaining the water plus the opportunity cost.* Ignoring the opportunity cost part of value will undervalue water, lead to failures to invest, and cause serious mis-allocations of the resource between users. The opportunity cost concept also applies to issues of water and environmental quality.

3 Economic Concepts of Efficiency

> *...the environment consists of scarce and exhaustible resources. That is where economics enters, for economics is the science of allocating scarce resources among competing ends* (Dorfman and Dorfman, 1972, p. xiv).

Property and ownership rights are fundamental to an economic analysis of water policy. The institution of private property and the other economic institutions in the United States and other market oriented countries have evolved together in ways that tend to promote the efficient use of things that are privately owned. A corollary to this phenomenon would be that if a resource is not privately owned then the institutions do not work well in promoting its efficient use. This appears to be the lesson from the environmental situation in Eastern Europe.

Efficiency is a good place to start since the economic concept of efficiency differs radically from the engineering and scientific concept. For an engineer efficiency means designing, planning, and using technology in such a way that the amounts of materials handled and used are minimised and at the same time accomplish a given task. So for instance, to remove organic pollutants from an urban wastewater a treatment plant should remove approximately 90 per cent of the offending material at the least cost.

An ecologist would look at the same problem from the point of view of the impacts upon the ambient environment and define an efficient solution in terms of the ability of the natural systems to process the wastes with minimum damage. An economist, however, looking at the same problem would consider all of the resource inputs which should be used in concert to achieve the best economic outcome. For the economist, it is not at all obvious that the most important goal is to minimise the cost of prevention. This is because there may be many other ways of achieving the goal of improved environmental quality than building the sewage treatment plant.

By looking at all of the resources used, both on the input and the output sides, it may also be possible to achieve the desired outcome by (1) process change induced by taxes on the inputs to the process or (2) effluent taxes on the waste discharges. Efficiency then, carries with it some notion of an objective or goal that is broader than the use of one input. Many of the environmental policies promoted by governments are guided by engineering and scientific concepts of efficiency, rather than the economic concept.

3.1 Public goods and externalities

Dorfman (1972 p. xv) claims that the resources that make up the environment are unsuitable for private ownership because they lack the 'excludability property.' In other words, it is not practical to exclude people from using the resource either because it is physically impossible (breathing the air) or very expensive or cumbersome to limit access. Improved water quality in lakes and rivers, the guidance of navigation lights, public beaches, security from flood damage and many other investments which improve the quality of the environment have this property to a greater or lesser extent, and, at some time or other in the history of the United States, have indeed been considered private property. There is little incentive to provide services or own property from which other people cannot be excluded: "Everyone's property is no one's property".

Non-excludability is not the only thing, however, that makes water resources different from the classic privately-owned resources. Water resources also have the property of 'mutually interfering usage'. Individuals take the valuable commodities of clean air and water from the same environment which they then use to dump wastes interfering with the use of the no-longer-clean air and water by themselves and others. In economic parlance these are referred to as 'externalities'. It is both the nonexcludability and the externality aspects that make water an inherently difficult resource to manage.

If the demand for public goods cannot be effectively controlled, either by rationing or pricing, then the only relevant public policy question is how much of the particular public good to provide. This decision has to be a social not a private decision and is based upon the total 'willingness-to-pay' for the good by all of the potential users. If, however, there are externalities involved, then the criterion for selecting the amount of resource provided should also be limited to that point at which the benefit to an additional user just counterbalances the total cost that he or she imposes upon all the other users. Unfortunately many natural resources and environmental amenities have some of the properties of private property which leads to uses of them which conflict with their public good properties and to difficulty in applying these principles.

3.2 *Criteria for assessing economic performance*

...the question for humankind would appear to be 'not whether to pollute or not, but how much to pollute?'
(Dorfman and Dorfman, 1972, p. x)

Economists have arrived at four criteria for judging such types of policy decisions. The first two relate to 'welfare' or 'satisfaction' in utility terms and the second two relate to the productivity of the economy in monetary terms.

3.3 Broad utility criterion: pareto optimality

Pareto optimality is usually described as an equilibrium of individuals' utilities (measures of satisfaction) where a reallocation of utilities is not possible without making at least one individual worse off. Pareto optimality does not depend upon being able to measure the utility of individuals but only which outcome he or she prefers in any given choice between a pair. The trade-off between dollars and utility is left to each individual to decide. Hence, monetary transactions are perfectly appropriate as measures of utility and satisfaction. If there are no further possibilities of increasing A's utility without reducing B's utility, then the output is said to be 'Pareto optimal' or 'Pareto efficient' (named after Vilfredo Pareto the Italian railway engineer-turned-economist, who introduced the concept in 1906). This type of analysis could also be applied to groups of individuals if it were possible to assess their group preferences; or, if they were identical to each other, their preferences could simply be added together. *In any realistic setting the assessment of strict Pareto optimality is practically impossible.*

3.4 Sharp utility criterion: social welfare

If it were possible to devise a community 'welfare function' as some function of the welfare of its individual members, then it would be possible to improve upon the broad utility criterion given above. This welfare function would, of course, have to be able to deal with the relative merits of each member in defining the welfare of the whole; the equitable distribution of the utility to the various members is a prerequisite of a welfare function.

The elegance of this solution, however, is diminished by the unfortunate fact that *no completely satisfactory social-welfare function dependent on individual utilities has ever been constructed.* Despite this fact, the economic literature spends a great deal of time discussing the properties of this hypothetical construct — tending mainly to erode the credibility of economics among policy makers. But when economics comes down from this lofty pedestal it does have something profound to offer to decision makers, as demonstrated below.

3.5 Broad productivity criterion

In the practical world of goods and services the concept of Pareto optimality has an analogue, the concept of 'productivity efficiency.' An economy is said to be productively efficient if it produces as much of every good and service as is possible, given the level of the outputs of all goods and services and the level of resources used as inputs. While an economy cannot be Pareto optimal unless it is productively efficient, it can be productively efficient without being Pareto-optimal. This means that the wrong combination of commodities are being efficiently produced—not an unusual phenomenon in many centrally planned economies. Despite this drawback, the broad productivity criterion is attractive because it is computable in many circumstances where it is not possible to compute or even conceive of Pareto-optimality. This is as far as we can go without making major new assumptions about how the economy 'ought' to work.

3.6 The sharp productivity criterion

Neoclassical economic theory states that the relative desirability of private goods is reflected in their prices. Therefore the best point to choose on a production-possibility frontier is where the value of goods and services produced is greatest. This is referred to as the *GNP criterion;* that is the point where gross national product (GNP) is at a maximum. From a practical point of view this criterion is the most attractive. It is straightforward to compute and does capture the ideas of its predecessors without the drawbacks of hypotheticality. The sharp productivity criterion is the conceptual basis of all of the project evaluation methods based upon benefit-cost analysis.

3.7 Economic efficiency v. equity

Even though the economic literature emphasises efficiency and equity as the two goals of economic endeavour, it must be noted that when it comes to operational definitions of equity economists are no better prepared than others to respond. Of the four criteria discussed above, only the social-welfare criterion deals directly with the issue of equity; it was also the one that was most hypothetical and least operationally useful. This leaves the policy maker with some useful and quite powerful tools for social analysis, which are nonetheless deficient in the area most critical to public decision making in democratic societies.

Moreover, the idea of 'fairness' which seems to be missing in economists' ideas about equity, raises moral imperatives that are hard to avoid in dealing with externalities in practical cases. Coase (1960) showed that externalities by themselves do not lead to economically inefficient solutions provided that the polluters and the people being affected can freely and inexpensively negotiate with each other. Coase claimed that the responsibility for damages is a reciprocal one, with the affected party taking steps to avoid them as much as the perpetrator takes steps to avoid producing them. Economic efficiency is achieved by having the costs of avoiding external damages being borne by the party that can most cheaply repair them.

A resource reallocation decision is said to be Pareto efficient if the decision can improve one individual's well-being without decreasing the well-being of anyone else. Most allocation decisions in the public domain involving environmental resources, however, appear to make some people better off and some worse off and, therefore, cannot be evaluated using the simple Pareto concept. In response, economists have developed the 'compensation' principle to extend the relevance of Pareto optimality. The Kaldor-Hicks compensation criterion is a widely used version of this principle under which a reallocation is a 'potential' Pareto optimal if the gainers would theoretically be able to fully compensate the losers and still be better off themselves. For 'strict' Pareto optimality the compensation would actually have to be paid.

In real cases, however, there is typically no easy way to make the compensatory payments. For example, the beneficiaries of a large government-financed water project could be charged for the water supplied and the revenues generated could be used to compensate those who lost access to land and water as a result of the project. However, the beneficiaries are usually a small and clearly defined group receiving substantial amounts of benefits, whereas the losers tend to be a large number of widely scattered people each suffering small damages. How does one get them together *a priori* to agree on the levels of compensation to be paid? How does one actually pay the compensation?

The compensation test can be used as an analytical tool even though compensation will not actually be paid. Taking the value of economic goods and services gained or lost, the gains to the gainers are compared to the losses to the losers. *If the gains outweigh losses, it is considered that the overall welfare is increased.* This is the conceptual basis of benefit-cost analysis which received a boost in Section I of the Flood Control Act of 1936 when it said:

> *...the Federal Government should improve or participate in the improvement of navigable waters or their tributaries including watersheds thereof, for flood control purposes* ***if the benefits to whomsoever they may accrue are in excess of the estimated costs...*** (emphasis added; Holmes, 1972, p.19).

Even though the Pareto discussion is carried out in terms of the preferences of groups, the actual measurements used in applying the compensation principle are those based upon the GNP criterion. Benefit-cost analysis using the compensation principle also implicitly assumes that a social-welfare function exists in which everyone's welfare is counted equally, and in direct proportion to the goods and services gained or lost, measured in market prices. Since the demand for goods and services is known to depend upon income, this implies that the current distribution of income is an acceptable one and should be used as the basis for further allocation of goods and services. The compensation principle has been widely criticised as a basis for public policy decisions on this score.

4 Measurement of Benefits

4.1 Conceptual issues

It is easy to say that the 'benefits must exceed the costs,' but even using the GNP criterion of benefit-cost analysis the question still remains; 'How to measure benefits?' As mentioned above, in a perfectly functioning market, *price* is a measure of *value* Therefore, the total benefit of consumption can be simply measured by the sum of the price times the quantity of the commodity consumed. Making the usual assumptions, this is a perfectly good way of estimating benefits for environmental management decisions. But what about outputs for which there is no traditional market, such as health, air and water quality, and aesthetics, or for which there is a market but entry is constrained, or there are large economies-of-scale, such as irrigation water, navigation, and hydroelectric power, or cases where a policy or project creates a unique market such as water-based recreation in an arid area? These are hard cases which have nonetheless been satisfactorily resolved conceptually by the economics profession. And in many cases robust methods have been developed for operational measurement of the benefits.

4.2 Benefits of national level programmes

Another level of benefit estimation is also relevant to environmental decision making: the national programme level. Freeman (1982) discussed this for air and water pollution control and estimated the benefits of the Clean Air and the Clean Water Acts. Table 2 shows the categories of benefits that he included in his studies. Using the above schema Freeman culled the literature and summarised his results for water in Table 3, see below.

Table 2 Assessing benefits from environmental regulation

Effects on Living Systems
(Involving Biological Mechanisms)

1 Human health (nonmarket)
    a mortality
    b morbidity
2 Economic productivity of ecological systems (market)
    a agriculture
    b commercial fisheries
    c forestry
3 Other ecological system effects impinging directly on human activities (nonmarket)
    a sports fishing
    b hunting
    c wildlife
    d water-based recreation
    e home gardening and landscaping
    f commercial, institutional, public landscaping
4 Ecological system effects not directly impinging on humans
    a species diversity
    b ecosystem stability

Effects on Nonliving Systems

1 Producers (market)
    a damages to materials, e g , corrosion
    b soiling
    c. reduction in product quality
2 Households (nonmarket)
    a damage to materials
    b soiling
3 Changes in weather and climate, (nonmarket)

4 Other (nonmarket)
    a visibility
    b tranquillity

Source: A. Myrick Freeman, III Air and Water pollution Control A Benefit-Cost Assessment. John Wiley, 1982, p 9

These tables point to a major paradox which underlies the motivation for most environmental programs in the United States, public health is the major concern. For water pollution control only 10 per cent of the benefits accrue because of improved public health and more than 50 per cent are due to improved recreation possibilities. Politically it is easier to motivate strong regulation based upon threats to the public health. It may be difficult to get the body politic too exercised about providing more recreation facilities! It remains to be seen in Third World settings just what the relevant distribution of benefits would be. Clearly, public health benefits would be substantially larger but unless one also experiences a 'hygiene revolution' along with improved water quality the actual benefits derived may not be significant.

4.3 User and intrinsic values

Recent work on benefit estimation has distinguished between user and non-user (or intrinsic) values. All of the benefits listed in Table 2 above fall under the definition of 'user benefits' (possibly with the exception of category 4). Intrinsic values are associated with potential use either by oneself or someone else. A comprehensive review of the different types of benefits occasioned by environmental management is given in Desvouges and Smith (1983). In Table 4 examples from water development are given. In this table they split the benefits into two major categories of 'current user values' and 'intrinsic or option values'. The current user values themselves are split into two major categories of 'direct' use and 'indirect' use. Direct uses are in turn split into 'withdrawal

Table 3 Benefits in 1985 from removal of conventional water pollutants (in billions of 1978 dollars)

		Range	Most likely point estimate
1	Recreation	$1.8- 8.7	$ 4.6
	Nonuser Benefits		
	Aesthetics, ecology,		
	and property value	$0.5- 4.0	$ 1.2
	Commercial Fisheries	$0.4- 1.2	$ 0.8
	Diversionary Uses		
	Drinking water-health	$0.0- 2.0	$ 1.0
	Municipal treatment	$0.6- 1.2	$ 0.9
	Households	$0.1- 0.5	$ 0.3
	Industrial supplies	$0.4- 0.8	$ 0.6
	Total	$3.8-18.4	$ 9.4**

* *Source A. Myrick Freeman, op.cit., p. 15, 170*
** *Estimated costs $15-20 billion.*

uses' and 'in-stream uses'. These represent the obvious benefits of municipal, agricultural, industrial, commercial, recreation, and hydropower that feature in the conventional analyses of water projects. The indirect uses which Desvouges and Smith categorise as 'near stream' uses include recreational, relaxation, and aesthetic benefits, which are typically not included in conventional studies.

Desvouges and Smith's other major category, the intrinsic values, are almost never considered in project analysis. They are broken down into 'potential use' and 'no use'. The potential use, often called 'option value,' is broken into the categories of near term potential use and long term potential use. In other words there are some consumers of the project outputs who would be potential consumers some time in the near or more distant future. Just because they are not current consumers it does not mean that their benefits should be ignored. Finally, there are the 'no use' set of benefits based upon the existence value of the project itself or the resource base which it alters. These are based upon the values associated with vicarious consumption by others, good stewardship of the earth's resources, pure existence values associated simply with the knowledge that the project exists (or does not exist), and the idea of bequest value to future generations. The intrinsic existence benefits are least well defined and distinguished from each other, nonetheless they do reflect real willingness to pay by the population at large and are, therefore, just as important and real as the direct use benefits described above.

Desvouges and Smith make the important point that individuals are willing to pay for all of these types of benefits (or to avoid disbenefits in these areas) and, hence, they are just as real and important to evaluating a water investment or management decision as the more conventional benefits. Since most of the intrinsic, or option and existence values, tend to be preservationist or conservationist they will show up as negative benefits for most water decisions that lead to significant changes in the environment. This means that they are not popular with proponents of water development. However, if people are indeed willing to pay for them then following strict economic logic they *must* be considered in the analysis. To dismiss them because they are difficult to measure is not permissible — it behoves the analysts to attempt to measure the magnitude of these benefits and incorporate them into the final decision calculus. This is all the more important because neglect of these has generated much of the unhappiness about how current water policy has

***Table 4** Types of values associated with water resources projects*

Current User Values	Direct Use	In Stream	Navigation Recreational Commercial Hydropower
		Withdrawal	Municipal Agricultural Industrial/Commercial
	Indirect Use	Near Stream	Recreational Relaxation Aesthetic
Intrinsic Values	Potential Use	Option Value	Near-term potential use Long-term potential use
	No Use	Existence Value	Stewardship Vicarious consumption Pure existence value Bequest value

Based upon:

Desvousges, William H and V Kerry Smith. Benefit-Cost Assessment Handbook for Water Programs, Volume I Prepared for the U S. Environmental Protection Agency Research Triangle Park, North Carolina Research Triangle Institute, April 1983, p 3-2.

been implemented. This approach has not been used extensively in other areas of environmental decision-making but there appear to be no insurmountable difficulties in making use of these concepts elsewhere. Note that even though environmental values appear in this analysis they still have to be articulated by some human's willingness to pay for preserving them. This may be as close as it is possible to include environmental values in formal economic analysis.

4.4 Practical approaches

In estimating benefits for water uses, the easiest uses to deal with are those that have well established markets and firm monetary valuation for the outputs. For example, evaluating benefits from municipal, commercial, industrial, hydropower, and irrigation uses is relatively straightforward where markets are well established in comparison with estimating benefits from recreation and aesthetics. Estimating the intrinsic values is expected to be significantly more difficult. At the basic theoretical level, however, the approach to each of the benefits is more or less the same.

Mu, Whittington & Briscoe (1990) report on one of the recent World Bank case studies estimating willingness-to-pay for village and small town domestic water supplies. They found that in their sample town in Kenya the traditional economic factors (price, income, level of education, etc.) appeared to have little impact upon the quantity of water used but did have a strong impact upon the source of water chosen. This is an important finding since it indicates the major differences between small towns in developing countries (and maybe everywhere) where there are always multiple sources of water for the consumer to choose from instead of the large city case where typically the choice is greatly restricted between the piped supply or a water vendor. The results of the other case studies (Tanzania, India, Zimbabwe, Brazil, Nigeria, and Pakistan) in the World Bank's programme are not yet available, but one interim report states:

> *"The results from the case studies support the use of the standard microeconomic, utility-maximising framework for understanding household water demand and source choice decisions. The variables suggested by demand theory were generally significant determinants of a household's willingness to pay for improved water supplies in all countries.... A common rule of thumb used in the water sector is that a household will pay 3-5 per cent of its income for improved water supplies. This research found little support for this assumption. When water is scarce and alternative supplies are expensive, households are often willing to pay much more than this; when water is easily available households are often willing to pay much less."*

Details on estimating the intrinsic values of a wide variety of environmental amenities are given in Fisher and Raucher (1984), Stavins and Willey (1983), and Meta Systems (1985). What is beginning to emerge from these studies is that the intrinsic benefits are about the same order of magnitude as the current user benefits (ranging from 47 per cent to more than 139 per cent of the user benefits in Fisher and Raucher). It is clear that intrinsic benefits can no longer be dismissed out of hand by agencies promoting projects. As can be expected, most of the intrinsic values tend toward preservation and conservation and are, hence, likely to end up as 'negative' benefits in the actual benefit-cost analysis.

The improvement of 'intrinsic' benefit measurement is an area of great importance for the nation's environmental decision-making. From a purely philosophical point of view, the incorporation of these benefits makes the 'rational' economic model of resource management much more acceptable in the policy arena. The difficulty in measuring these benefits with exactness in no way makes them any less real than the ones usually added-up in the benefit-cost calculations. As Saunders (1986) shows, there can be great uncertainties and disagreements about conventional 'user' benefits for water projects, but this has never implied that they should therefore be ignored. There is no reason to treat intrinsic benefits differently; the economics profession should insist that 'all' of the benefits be considered in the analysis.

5 Evaluating Demand and Supply

The 'demand' for water is an economic term, meaning the schedule of quantities of the commodity that consumers are willing to purchase at various prices. In market economies resource allocation and distribution problems are solved simultaneously by the price mechanism. The demand for a certain resource is brought into balance with available supply at some new price level: as the demand increases the resource becomes more expensive to provide, the price rises, and rationing occurs in the sense that some consumers consume less than they would have consumed at the lower price; if the demand declines or, if new cheaper sources of the resource are found, the price drops.

In the strictest sense the concept of a demand schedule applies only to consumer purchases. Purchases of resources and material used as inputs in the production of some other commodity which is purchased directly by consumers (for example, irrigation water used for growing food), reflect 'derived demand,' since call for them derives from the final demand of the consumer product that they are used to create.

Unfortunately in most public discussions of demand for water resources and environmental amenities associated with water, the word 'need' is often mistakenly used for demand. It makes no sense to project quantities of amenity needed without specifying how much people would be willing to pay for these quantities: demand must be specified by the two numbers; quantity and price. For example, in making plans for future water development current water use rates are usually put on a per capita basis and projected forward by forecasting population increases. This leads to projections into the future of excessive quantity of water as 'needs'.

5.1 Demand curves

The concept of demand curves was first put forward by the French engineer, Arsene-Jules-Etienne-Juvenal Dupuit (1804-1866), who among other things invented the concepts of consumer surplus and the Laffer curve, all while he was the Inspector General of Roads and Bridges in France during the early nineteenth century. The concept is very simple: the amount of a commodity that would be consumed over a range of prices is estimated (ideally from empirical observations of the same consumer).

However, this simple concept immediately becomes complex when applied to environmental amenities such as water and water quality. First, there are many uses for water, not one; therefore, water behaves like several different commodities at the same time and, depending upon its quality and how it is to be used, it may also belong to one of several markets. While demand curves originally applied to only one market for one good and for one consumer, methods to build demand curves for groups of consumers with similar preferences and market behaviour was established early, and demand curves for one commodity used in several markets have been calculated for some time.

5.2 An illustrative example

Consider two industries on a river with industry A upstream of industry B. A takes water from the river, uses it in its processes, contaminates it, and returns it to the river. B now has to treat the river water before it can use the water for its own processes. A causes additional costs to B by its action of polluting the river. B has recourse to several approaches to redress this situation. The first, and most obvious, is to request A to cease polluting the river. A may agree and the problem is immediately resolved by A treating its wastes or changing its production processes in such a way that B is not damaged by A's actions. A has 'internalised the externality'. What if A refuses a polite request to stop? A might agree to negotiate with B so that both would share the cost of cleaning up the waste. B might pay A for treating the wastes or A might pay B to clean up water it needs for its processes. Depending upon the relative costs of treatment this latter case could be a lot cheaper than having A treat all of the wastes. In these cases the externality is internalised by building a 'bubble' over the two plants and considering them as one.

Using these types of examples, Coase (1960) showed, that externalities do not necessarily lead to economically inefficient solutions provided that the polluters and the people being affected could freely and inexpensively negotiate with each other. Coase claimed that the responsibility for damages is a reciprocal one with the affected party taking steps to avoid them as much as the perpetrator to avoid producing them. Economic efficiency is achieved by having the costs of avoiding external damages being borne by the party that can most cheaply end them. Coase skirts the fundamental issue of the equity and distributional issues by saying that the parties freely negotiate the agreement; this may work quite well in the hypothetical case given between two industrial plants of similar size but is unlikely to work so easily between one large industry and hundreds of thousands of private citizens. Both the asymmetry of the power to negotiate and the transactions costs of the negotiations themselves argue against achieving a satisfactory solution.

What if plant A refuses to negotiate with plant B? At this point the process has to move outside of the two participants and involve a third party. In the US this would typically be a law suit brought by B against A. At this stage the process would involve the relevant state and local laws as well federal laws. A typical solution would have A being forced to treat its wastes up to the current level of Best Available Technology (BAT) for that particular industry. As a result B may still be forced to treat its intake water because the residual wastes now legally allowed to be discharged by A have deteriorated its water supply. From this it becomes evident that the total costs may be substantially higher than the economically efficient solution. It is also apparent that the water pollution legislation and laws have created property rights for A to pollute the river up to a certain level.

The current situation in the US with regard to water quality is almost exactly the situation described in the last paragraph except it is more likely to be citizens groups suing the government to enforce the existing regulations against particular industries and, now increasingly, against municipalities. This is certainly a long way from being economically efficient, but it does have a flavour of being equitable, in as much as each industry type and each municipality is more or less forced to use the same type of treatment and, hence, face similar costs. However, because of economies-of-scale small communities may face disproportionate per capita costs.

Since it is unlikely that the negotiated solutions between the polluters and the impacted will come about spontaneously some form of government regulation is inevitable. Is what we have created in the United States the best possible under the circumstances? The hypothetical two plant example demonstrates the principles. Figure 5 shows the costs for plant A to treat its waste to various levels of purity: 100 per cent means that the water is returned to its original condition, and 0 per cent means no treatment of the wastes. The figure also shows damages caused to B by A's action. The damages are measured by the cost to B to treat the water it receives in the river from A. The sum of theses two sets of costs are also plotted and give the total 'social costs' of the pollution problem. Figure 6 shows the marginal cost and damages based upon the given data. Although most economic texts explain the functioning of the market system by the use of

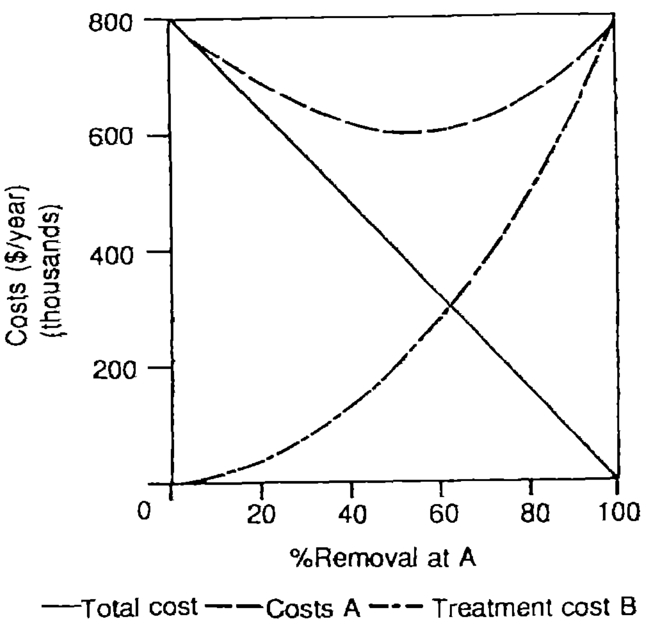

Figure 5 Treatment cost curve for industry A and the damage curve to downstream industry B as a function of the per cent removal of pollution at A. The top curve shows the sum of these two.

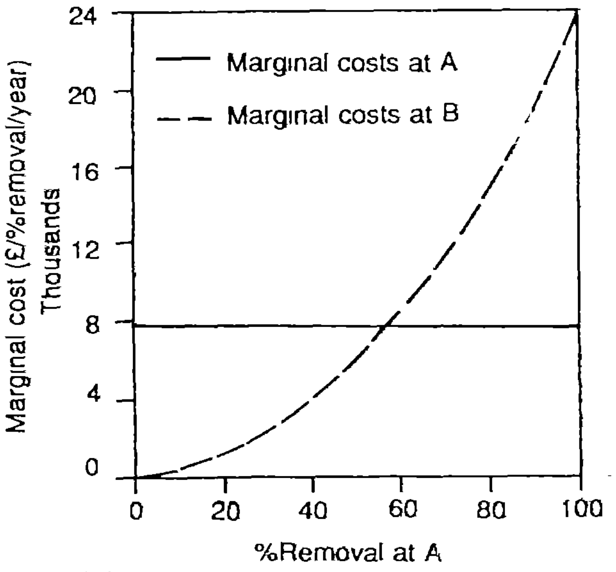

Figure 6 Marginal costs at A and marginal damages at B. Total cost is minimised where these curves intersect.

marginal analysis, the following discussion relies upon the total cost and damage functions of Figure 5 because this is how most non-economists think about costs.

If there is no negotiated settlement to the conflict between A and B and the issue is to be resolved by regulatory action of the state, what level of treatment of A's waste should be chosen or mandated? Figure 5 is informative on this point because it shows the costs to each and also the total cost (to society if these are the only two members). Interestingly, the total cost curve shows a minimum at about 58 per cent removal of A's wastes. This is the same point in Figure 6 where the marginal cost and the marginal damages curves cross; in economic parlance 'where marginal costs equal marginal damages'. This point, labelled O on the axis, should be of great interest to the governmental regulators if they are looking for efficient solutions; this point is the point of maximum economic efficiency for this problem. Another interesting point on this diagram occurs at N where the costs to A equal the damages to B. The gains and losses associated with the various solutions to this problem are as follows:

at level P, A spends $0 and B spends $800,000 per year
at level M, A spends $800,000 and B spends $0
at level N, A spends $280,000 and B spends $280,000
at level O, A spends $180,000 and B spends $320,000.

Level M is the strict liability solution with A paying for 100% clean-up of its wastes, level P is a *laissez faire* solution with B absorbing all of the damages, level N is the 'equitable' solution with both sides bearing the costs equally, and level O is the economically efficient solution.

The economic dictum of 'getting the prices right' in the case of regulated externalities now means setting a price upon the effluents of A such that the efficient solution, point O, is arrived at automatically without further government intervention.

What tax could be levied upon A that would lead to this solution? If A produces 100,000 lbs of pollutant per year, treatment at 57.5 per cent removal would leave 42.5 per cent, or 42,500 lbs in the effluent stream. At this level of pollution B suffers $340,000 of damages so if A were charged $340,000/42,500, or $8 per pound of effluent B could be fully indemnified for its damages. Also at this rate of tax A would treat exactly at this level because at 57.5 per cent removal the marginal cost of treatment is seen in Figure 6 to be $8 per pound. Below $8 per pound it would be cheaper for A to treat and above $8 per pound it would be cheaper for A to pay the tax. Hence, an optimal tax exists and the problem is solved. Or is it? If it were not practical to reimburse B, B would agitate to move at least to the 'equitable' solution at N which is no longer socially optimal but at which B suffers less damages and this resolution has the property that now the costs to each are the same. Therefore, in order to work effectively the tax would have to be used to reimburse the damaged party.

Should the problem be viewed differently if B moved in after A was already polluting the stream, or vice-versa, if A moved in after B was already established? What about the entry of a third industry after the others had reached an agreement? This problem can get harder and harder to analyse and resolve as more and more realistic issues are allowed to intrude, and the proposed economic solutions become less and less acceptable to society.

So far the discussion has only considered the two industrial polluters, but this is not the whole story. If it were, then we would be tempted to let the polluters fight it out and arrive at any settlement that they could. There are two other important interests which have been ignored so far: (1) the other actual and potential users of the river, and (2) the fauna and flora and other components of the aquatic environment. How are their interests to be accounted for and protected in this case? This is now the crux of any pollution problem. In a typical situation there are a few large polluters and many thousand individuals who are impacted. It is unrealistic to expect, either for them to negotiate with each other in a meaningful way, or to set an optimal effluent tax and then repay each person according to their respective damages. Moreover, in this hypothetical example it was possible to measure the benefits (or damages) borne by each individual: in a practical case this is very difficult. The upshot of the measurement difficulties and the problems of reimbursing the impacted parties is that effluent charges have not been used in the US for pollution control. Instead, effluent levels have been set based upon the expected performance of specific treatment technologies: the current legal requirement (approximately 80 per cent removal of BOD) would force a solution to the right of N in the water pollution example given above.

All of this still neglects the non-human components of the problem. Should the environment be protected for its own sake? If so, by how much? How are we to assess the marginal costs and benefits to the environment itself? These are still largely unresolved issues and economic theory is of little help in giving guidelines for resolving them.

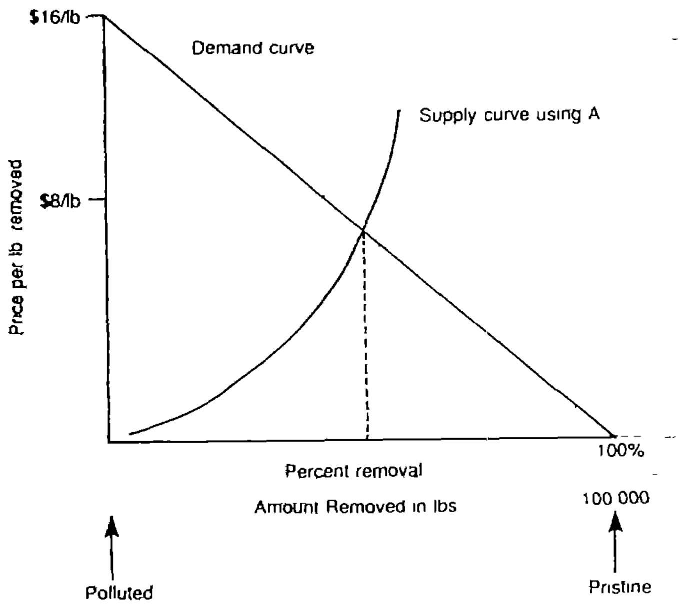

***Figure 7** Derived demand curve for water quality at B: this shows the water quality at B ranging from polluted at a removal cost of $16 per lb to pristine if the cost were zero.*

Using the example given earlier of the two industries on a river, it is possible to create the demand curve for water quality in the river by user B. The ordinate on Figure 7 is the amount user B would be willing to pay for removal per pound of pollutant upstream of her use point, and the abscissa is the amount of pounds of pollutant removed. The total 'willingness-to-pay' is the area under this demand curve which is seen to be $800,000, the amount of total damages suffered by B in Figure 5. Alternatively this can be viewed as the total benefit accruing to B if the contamination were completely stopped. The question remains, however, as to what B will be really willing to pay for reducing pollution upstream? This cannot be answered without information about the costs of supplying this reduction which is the subject of the next section.

5.3 Supply curves

Another economic concept that is important in understanding water economics is that of a 'supply curve'. This is created by arranging, in ascending order of cost, the amount of water available to the consumers in a given market area.

In Figure 6 we have already observed two functions dealing with the incremental costs of providing wastewater treatment. These are supply curves. Note that the supply curve for removing wastes at A is an increasing non-linear function whereas the supply curve for removing wastes at B is a horizontal line. The supply function at B is then said to have 'constant marginal costs' and the supply function at A has 'increasing marginal costs.' The supply curve at A is a typical shape of supply functions.

5.4 Market clearing

One of the great conceptual breakthroughs in economics is the idea that the most efficient economic solutions occur when what a consumer is willing to pay and the supply prices just match each other; the market is said to 'clear.' This concept, as originally formulated was based upon little economic theory, but later it was demonstrated that for this to be the most efficient solution, all of the assumptions made in Section 2 above must also hold. Nevertheless, even in its simplest form it does provide planners and policy makers with a set of tools that refer to engineering, ecology, and physics (supply curves) and to observed behaviour (demand curves) that give good indications of efficient economic solutions.

Using the examples given above, simply placing the supply curve over the demand curve will identify the price and the quantities at which the market would clear. This is shown in Figure 7 where both the supply curve of treatment at A and B are used. If we are forced to use the treatment processes available at B then the 'market will clear' with a 50 per cent removal of the wastes; if we can use the function from A then the market will clear with a 57.5 per cent removal of the wastes. The level of treatment declines as the supply curve becomes steeper (the marginal costs of treatment increase).

This discussion highlights the role of prices in encouraging or discouraging excessive use of the environment. If, as is often the case, the price of environmental resources such as municipal wastewater treatment is held unrealistically low, the demand grows very large. As consumption grows, the real costs of treatment increase, necessitating an increase in the public subsidy that often exists because the utilities price their treatment upon historical average costs which are much lower than the future marginal costs for expanding treatment.

Due to restrictions on the transfer of rights to the amenities, such as water, it is possible to have multiple markets for the same commodity. In such cases as separate water markets for irrigation and domestic supply in California, prices cease to give the correct rationing signals. Moreover, in markets which are heavily regulated, such as municipal water supply and wastewater utilities, the market will not clear where the supply curve intersects the demand curve because the price is set either too high or too low by the regulators. These cases are shown in Figure 8. If the price is set below the marginal cost (shown in Figure 8a) then the actual level of consumption will be at E' rather than at E. In order to maintain this consumption above the economically efficient level the consumers must be subsidised by the shaded amount in the figure: these are called 'deadweight' losses. On the contrary, if the price is set above the marginal cost then the consumers will actually consume less than they would have under the efficient solution, E in Figure 8b, and available resources are under-utilised. This less than optimal consumption means a 'welfare loss' for society equivalent to the shaded area in Figure 8b. Hence, marginal cost pricing is the economic prescription for tariff-setting.

5.5 Price and income elasticity

In the mid-nineteenth century Ernst Engel (1821-1896) was the first person to formulate the concept of elasticity as it is now used. Engel, not to be confused with Friedrich Engels of Marx and Engels, was not a professional economist but was a medical doctor interested in nutrition. He noticed that persons in higher income classes in Germany spent a smaller proportion of their income on food than people in the lower income groups. He defined the income elasticity of food as the ratio of the percentage change in quantity consumed to the percentage change in income. Engel found that for food this ratio was less than 1; in other words, the relative amount of expenditures for food declines as income increases. If elasticity is less than unity the consumption is said to be 'inelastic', meaning that a big change in income leads to a smaller increase in the quantity of food consumed; if above unity it is said to be 'elastic,' meaning a small change in income leads to a larger change in the amount consumed.

Elasticities can be measured for almost any two sets of quantities which vary simultaneously, but the important

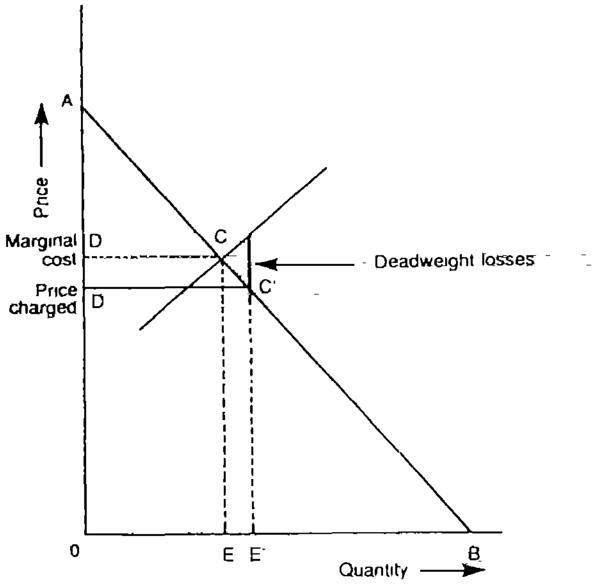

Figure 8a Role of prices in encouraging the use or abuse of environmental amenities. In this case the price is set below marginal cost leading to overuse of the resource and deadweight losses to be borne by society.

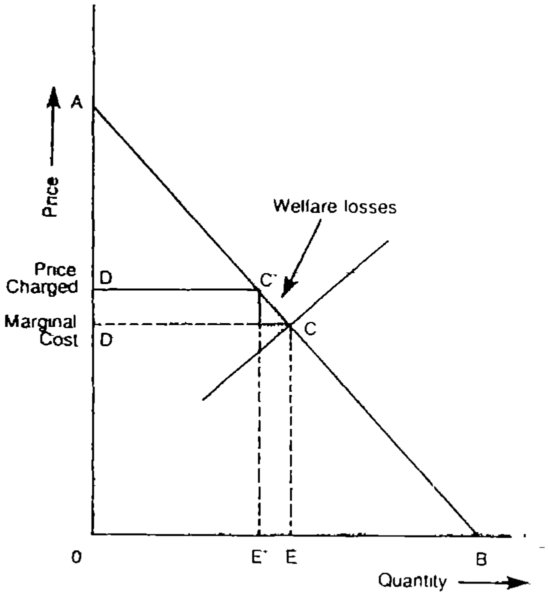

Figure 8b In this case the price is set above the marginal cost leading to welfare losses to be borne by society because of deviation from efficient prices.

ones from the point of view of water are those of price and income. A price elasticity for industrial wastewater treatment of -0.7 implies that a 10 per cent price increase will decrease the demand for treatment by 7 per cent. Even though this demand is said to be 'price inelastic' it does not mean that pricing cannot be used as a rationing tool for industrial wastewater treatment. If waste production were price 'elastic' the impact of pricing would be greater than when inelastic, but a 7 per cent decline in waste production for a 10 per cent price increase could have major implications for the future adequacy of a particular wastewater treatment system. Municipal water supply is typically 'income inelastic' (the demand increases with increases of income but less rapidly).

The joint effect of price and income effects need to be taken into account in making forecasts of future demand. For example, the US Department of Commerce (1985) forecasts that the population by the year 2000 will be 267 million, (i.e. growing at about 1 per cent per annum from 1980). How large would the demand for water be in 2000? Simply assuming water use proportional to the population growth rate, it would increase 22 per cent above the 1980 level. If the forecaster wanted to include the effects of increasing income levels estimated to be growing at 2 per cent per annum over that period he would need to know the income elasticity of water. This is typically inelastic and about 0.5. Incorporating this into the forecast would lead to a 49 per cent increase of water demands by 2000. So far this assumes that price remains constant.

What if the forecaster allowed for a price increase at about 3.5 per cent per annum and assumes a -0.5 price elasticity over this period? Then the demand would only increase 5 per cent over this 20 year period. This would have tremendous implications for easing the water quality management problems. Which forecast should be used? The answer to this depends upon whether a prescriptive or a descriptive stance is taken. According to this simple example the USA could have a 'water crisis' — the 49 per cent increase — or just a modest increase in demand — the 5 per cent increase. The choice is up to governmental policy makers. 'Needs' forecasts do not reflect the restraining effects of price. If the regulators leave water sellers free to make water prices more nearly represent the marginal cost of supply and, in those cases where the supply has to be controlled by government, realistic pricing policies are pursued, then the forecast crisis will never take place.

5.6 Empirical studies of water demand

The previous section introduced the concept of demand and showed how important it could be in estimating future investments in water. The most up-to-date review of demand studies for water in the US is by Gibbons (1986) Table 5 (taken from Gibbons) reports on municipal water demand studies from 1963 onwards showing price elasticities ranging from a low of -0.02 to a high of -1.57. The elasticities vary widely from region to region and from season to season with low values in areas in the moist Eastern parts of the country with low prices for water and which have experienced only small price changes in the recent past, and the high values being for summer water use in areas with higher prices. Short run elasticities are more inelastic than long run ones because the adjustment to conserving water often requires planning and capital investment on the part of the consumers (low flush toilets and improved lawn watering equipment) and planners should not be mislead by them into believing that the demand for water is very price-inelastic.

For example a price elasticity of -1.57 was found for residential outdoor use in 11 Eastern US systems and an indoor water use price elasticity of only -0.23 for the same systems (Howe & Linaweaver, 1967). Commercial and industrial production of wastewater is also price responsive. Elliott (1973) found that for industrial water use a 1 per cent increase in water charges reduced wastewater effluents by 0.75 per cent (a price elasticity of -0.75). He also reported that increasing the charge for wastewater effluents from industry reduced the demand for water supplied to the industry with an elasticity of -0.44. Moreover, even the introduction of a nominal water tariff often causes large scale behaviour adaptation by consumers. For example, Miglino and Harrington (1983) studying industrial water use in São Paulo, Brazil, found that the introduction of a separate wastewater tariff led to a 30 per cent drop in the water demanded and a resulting 37 per cent shortfall of revenue for the water utility.

Gomez (1987) reported on work done at the Inter American Development Bank on predicting willingness to pay for water projects in 11 Latin America countries. Table 6 shows the price, income, and family size elasticities for the demand for municipal water supply. These results are quite remarkable in their consistency. In each case the price was a statistically significant determinant of water use with an elasticity ranging from -0.02 in Haiti to -0.627 in Guatemala. The table shows that the demand is also income inelastic with an elasticity ranging from not significant in Costa Rica to 0.784 in Brazil. In order to get these data Gomez and his colleagues mixed data for consumers with several different priced sources. While this does give much more price variability it also gives much more variability in the quality of the various sources. As Mu *et al.* (1990) explained, however, the quality of the different supplies may have a large impact upon the willingness to pay for them. Nevertheless, the results given in Table 6 and plotted in Figure 9 fit in extremely well with the theory and with what few studies there have been made to date in the developed world.

6 The Political Economy of Pricing

Apart from certain aspects of religious and health significance, most people in every day use do not regard water as an end in itself. It is a commodity like 'ships and shoes and sealing

Table 5 Price elasticities for municipal water demand

Study and date	Type of analysis and location	Elasticity estimates
Gottlieb (1963	Cross-sectional, Kansas	-0.66 to -1.24
Gardner-Schick (1964	Cross-sectional, northern Utah	-0.77
Ware-North (1967	Cross-sectional, Georgia	-0.61 (log) -0.67 (linear)
Howe & Linaweaver (1967)	Cross-sectional, U.S.A.	Total -0.40 Winter -0.23 Summer: East, -1.57 West, -0.70
Turnovsky (1969)	Cross-sectional, Massachusetts	-0.05 to -0.40
Wong (1972)	Cross-sectiona, northeaster Illinois	-0.26 to -0.82
	Time-series	Chicago: -0.02 Suburbs: -0.28
Grima (1972)	Cross-section, Toronto, Ontario	Total, -0.93 Winter: -0.75 Summer -1.07
Young (1973)	Time-series, Tucson, Arizona	1946-1965: -0.62 1965-1971: -0.41
Danielson (1977)	Time-series, Raleigh, North Carolina	Total -0.27 Winter. -0.305 Summer -0.38
Gibbs (1978)	Cross-sectinal, Miami, Florida	Marginal price -0.51 Average price: -0.62
Foster and Beattie (1979)	Cross-sectional, U.S A	New England -0.43 Midwest -0.30 South. -0.38 Plains. -0.58 Southwest. -0.36 Pacific Northwest. -0.69
Billings and Agthe (1980)	Time-series, Tucson, Arizona	-0.39 (log) -0.63 (linear)

Table 6 Elasticity values derived from demand functions

Year	Country	Functional	Elasticities[1]			Average Values			
		Form	Price	Income	Family size	Income (US$)[2]	Family size	Exchange Rate (per US$)	Quantity consumed[3] (M3/month)
1980	Chile	log	-0.547	0.101	n s	349	5.0	39.00	11.0
1981	Guatemala	log	-0.626	0.541	n s	695	5.7	1.00	21.0
1983	Bolivia	linear	-060	0.208	0.586	528	6.1	162.80	21.0
1983	Brazil	log	-0.597	0.784	n s	626	6.3	420.00	13.0
1984	Costa Rica	log	-0.444	n s.	0.581	559	5.0	45.00	13.0
1985	Chile	log	-0.310	0.430	0.169	457	5.0	150.00	16.0
1985	Haiti	linear	-0.21	0.207	0.657	157	5.6	5.00	10.1
1985	Honduras	linear	-0.033	0.422	0.083	611	6.2	2.00	15.3
1985	Mexico	log	-0.377	0.323	0.325	825	5.2	180.00	10.0

n s.: Statistically non-significant

[1] *Elasticity values for Bolivia, Haiti and Honduras correspond to families of average size and income at a price of US$ 0.30*

[2] *'Per capita' per year: for Haiti it represents food expenditure*

[3] *Quantities consumed are estimated at a price of US$ 0.30 per cubic metre*

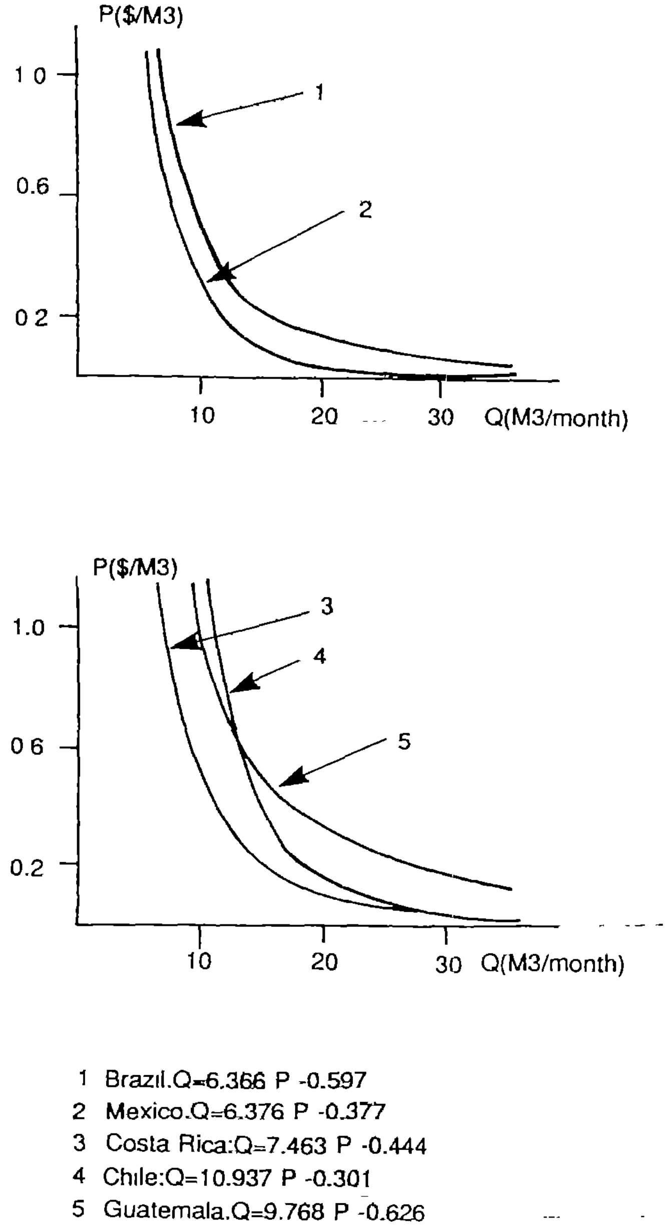

Figure 9 Municipal water demand curves

wax', consumed directly or used as an input to other processes. Empirical observation shows that in Boston as well as in Beijing, if the price of water is increased, consumers will use less of it. In other words, there is a 'willingness-to-pay' for water that is not an abstract economic concept depending on elaborate theories of private property, but rather is a reliable behavioural trait of consumers of the products. The same behaviour can be expected in Kansas and Katmandu — and is a good basis for assessing the economic demand for water. (Water has a downward sloping demand curve.) We can expect human actions to meet demand to be similar in widely different locations. The most accessible water for human use is the cheapest to develop, the next most accessible costs a little more, the next yet a little bit more, and so forth, and very soon one observes an upwardly sloping 'marginal cost' curve that depends upon nature, not upon theory. Based upon these two observed phenomena of willingness-to-pay and increasing marginal cost curves, a good set of practical rules can be derived for helping to decide upon how much to invest in developing a particular water supply.

However, although most people understand water in this way at an individual level, the same individuals treat water differently when they gather collectively to make decisions about future uses of water. This contradiction may be due to the common social misperception of water as a 'pure public good' which belongs to 'everyone' at the same time, with a right of access for all. As a result it is "customary to treat water as a free good when it is in fact anything but free. People come to expect that it is their right to take (and to waste) as much water as they want." (Baumol and Oates, 1979).

There is clearly a paradox here, since it is obvious that for many uses (for example, irrigation and municipal supply) water has all the properties of an exclusive economic good — just the opposite of a 'public good.' Adam Smith was one of the first to define a 'pure public good': once the good is provided, it is not possible to exclude anyone who wants to take advantage of a public good from using it, and the consumption of the public good by any one consumer does not impede the consumption by any other potential consumer. At the other extreme, a 'pure private good,' such as food purchased from a market, can be and usually is the exclusive property of the owning individual; his or her consumption of the food absolutely prevents anyone else from consuming it.

Water, like many other goods, falls somewhere between these two extremes. It has 'pure public good' aspects when it is left in a scenic river, but even then too many people using the scenic river will destroy some of its value for other participants. It has 'exclusive economic good' features when it is evaporated by farmers irrigating their crops for profit in a market setting.

It is the in-between cases which tend to predominate in the academic works on water and which confuse the issue. The question as to who has access to water becomes very important in determining how water is defined, and this definition in turn hinges upon the different doctrines governing water rights. In order to use water more efficiently it may be necessary to codify the water rights. Markets are based upon a system of property rights to scarce goods and the right to exclude other users of the resource. A private water market can only exist if property rights are secure and can be transferred. However, water law and water rights differ radically from country to country, and sometimes even within countries and between different water uses. It is hard to draw from the gamut of individual cases to provide a general theory, other than to say that, for many modern market-incentive systems to work, there is the need for a much clearer demarcation of property rights to water use than often exists. At any level, the definition of property rights to water is very difficult in the face of water's sacral quality in many societies, its essentiality to life, and its pervasive externalities. As a result, a large body of law has grown up around water in almost every country.

Water pricing, therefore, is not a task to be left solely to economists. The political, legal, and social dimensions are extremely important and emphasise the need for a 'political economy' of water pricing.

6.1 Pricing

Three important concepts tend to get confused in the discussion of water pricing. These are, (1) the opportunity cost of water discussed at length above, (2) marginal cost pricing, and (3) cost recovery. Marginal cost pricing is the pricing of water at the cost of supplying an additional unit of water. In a perfectly functioning market economy the most efficient solution occurs when commodities are priced at their marginal cost. The market is said to clear when the marginal cost is equal to the marginal benefit. The marginal cost *must* include the opportunity cost of the water. Cost recovery refers to pricing of water to recover the costs of providing it. Typically, cost recovery is based upon accounting procedures that are based upon historical costs. Cost recovery pricing can be close to marginal cost pricing when the costs of new projects are similar to the costs of past projects. Unfortunately, in water resources development historical costs are typically much lower than current or projected costs of projects.

Many water planners confuse cost recovery with marginal cost pricing, the economists' 'golden rule.' Most water utility officials consider marginal cost pricing as leading to unrealistically high tariffs. Unfortunately, economists often try to mandate strict marginal cost pricing, ignoring practical problems faced by utility managers. In fact, there are many different tariff structures that would allow full cost recovery without marginal cost pricing. Brown and Sibley (1986) showed for the telecommunications industry that the Ramsey prices (prices set inversely proportional to the price elasticities of the different consumer groups) necessary to cover costs and profit were only in the range of 3 per cent more efficient than tariffs based upon traditional cost recovery methods. (Remember that telecommunications industry, however, has declining costs not increasing costs like the water industry.) While tariffs have financial, economic, and political dimensions, it should be remembered that marginal cost pricing relies only on the economic dimension. The best approach probably lies somewhere between the two extremes. The tension between regulation and efficient pricing will always remain a source of contention between the planners and the political process however, as Brown and Sibley (1986) stated:

> *"...when regulation violates efficiency criteria seriously enough, not only economists become concerned. Peak load pricing in electricity, for example, was taken seriously in the US, when it became clear that excessive use of electricity was contributing to an energy crisis that alarmed many people. Hence, normative economics plays an important, though not pre-eminent, role in the regulatory process."*

Pricing is the major tool by which economists attempt to bring about efficient resource use. Pricing is more than cost recovery; it also aims at leading society to correct allocation decisions. Unfortunately, when many of the prices in an economy are artificially set, it is hard to induce rational resource allocation by 'correctly' pricing just a few of the resources. This is a major problem in all countries and regions. For example, it is estimated that in the EMENA Region of the World Bank alone the subsidy to agriculture due to incorrect water pricing is of the order of $40 billion per year.

6.2 Cost recovery

In the Indian state of Bihar, the charges for Irrigation Department water from river diversions and dams are so low, and the attempts to collect the fees so feeble, that in 1979 the cost incurred in collecting the fees for water was 117 per cent of the actual amount collected. Owing to its serious financial difficulties, the Irrigation Department has had to defer maintenance, and the water system has deteriorated. Farmers have less incentive to pay for poor service, and a vicious cycle has developed. Moreover, the low water charges have led farmers to use water inefficiently. By contrast, in both the Punjab region in India and in areas of the United States that rely on water from private wells, farmers are far more conservative in how much water they use since they pay higher prices. (Well water costs more because it is not subsidised.) Yet these farmers' crops are not doomed to economic failure: when the cost of pumping in the Punjab increased in the 1960s, farmers began growing more water-efficient crops such as high-yield wheat, and cash crops such as cotton, tobacco, and oilseeds.

Outside observers are surprised by the disparities among cost recovery rules for international loans in different sectors. In the electric energy and telecommunications sectors the Bank insists on full cost recovery for the capital as well as O&M expenses. The goal is to create viable public utilities which will be able to set tariffs that will efficiently finance the future development of the sector. In contrast, water sector projects typically require only repayment of the O&M and of some 'reasonable' part of the capital costs. Many would argue that this policy leads to sloppy performance on the part of both the suppliers and consumers of water. Since we do know that water use is directly related to the prices charged; the higher the prices, the lower the usage.

6.3 Practical pricing problems

The legitimate concern of economists analysing pollution and environmental amenities is with 'market failure.' In particular, the issue of 'how to internalise the externalities?' has received most of the attention. At the most obvious level it would seem that if the pollutants emitted could be correctly priced then industry and other polluters could be taxed by just this amount and the problem would disappear — the correct amount of pollution would be obtained, and if this were considered too large then the price could be raised until the satisfactory lower level was achieved (as was the case in the introductory example). But as H.L. Menken once remarked "for every problem economists have a solution — simple, neat, and wrong". Given the simplicity of the effluent taxing suggestion there must be something seriously wrong with it since it has never been seriously applied anywhere in the US to solving pollution problems.

Pricing has a twofold role in environmental policy. First, as discussed above, increasing prices tends to ration environmental amenities or discourage environmental deterioration by cutting uneconomical consumption. This cuts the demand by moving up the demand curve, which is the effect most decision makers are looking for when pricing policy is advocated. The second aspect of pricing, and the one most frequently overlooked, is increasing the supply of the commodity. When the price is higher, more expensive sources of supply become more economically available.

Policy makers should be careful to take the price response into account when they engage in setting prices. For example, the Tucson Water Department estimated that the water rates would have to be increased by 17.6 per cent in order to pay for the increasing cost of the city supply from the Central Arizona Project, but Billings and Day (1983) pointed out that this would be too low by a factor of three when the price elasticity was taken into account. Billings and Day estimated a rate increase of 59 per cent would be necessary to increase the total revenue by 17.6 per cent.

The cannon of price theory is marginal cost pricing. In other words, set the price at that point where the demand and the supply curves intersect. Unfortunately, for investments that exhibit returns-to-scale, as most water infrastructure projects do, there are at least four equally plausible different ways of measuring marginal cost, and each gives a different estimate of the marginal cost. An excellent summary of these approaches is given in Meier (1983). Unfortunately, Saunders and Warford (1976) showed that these four different approaches could give radically different estimates of marginal costs when applied to the analysis of the same project. This is cautionary advice to would-be 'marginal cost pricers'. It is disconcerting that the two most promising pricing schedules are not consistent with each other as the period of investment decreases. Even though there is an aspect of arbitrariness in the choice of any of the pricing schemes, it would be nice to have had some assurance that either one or the other dominates over the entire range of potential use. The way it stands now is that an agency must make an arbitrary choice and stick by it come what may.

6.4 Regulated monopoly pricing

Even if the marginal costs could be unambiguously established, the pricing problem for most environmental uses is still not resolved because of the characteristics of environmental amenities that make them a natural monopoly. The existence of large economies of scale ensure that the first entry into the market will always be able to underprice and drive out any potential newcomers. Then they could decide upon their desired profit level and set the prices accordingly. This has been recognised for a long time in the area of municipal water and wastewater treatment and the suppliers have been regulated, typically by public utility commissions. Unfortunately most of these regulatory commissions have tended to take a 'backwards' accounting stance and allow pricing based only upon average costs and the revenue needs to meet them. This stance is not appropriate in situations where the utilities are facing increasing marginal costs (all the best projects have been built and now it becomes increasingly difficult to supply the same amounts for their historical costs, or environmental mitigation costs must now be considered). Under these conditions a 'forward' looking accounting stance, such as indicated in the section on marginal cost pricing, is indicated. If this were pursued then the emphasis on revenue requirements of utilities would be replaced by establishing adequate future investment funds.

If this approach were followed, however, another problem would be encountered. Municipal water utilities exemplify this: if the utilities charged this forward-looking rate for all of the water they supply (as economic theory would indicate), they would now raise substantially more revenue than needed to cover their operating costs and retire historical debt. Serious administrative and legal problems may arise because of this. It has been suggested that prices charged to motivate rational consumption behaviour of the customers during the year, and that at the end of the year they receive a rebate from the water utility returning the surplus funds generated — but only at the end of the year after the consumption has taken place. Alternatively, the surpluses could be put directly into general revenue accounts of the municipality or placed in separate environmental enhancement funds. Whichever approach is taken it is important to remember that dealing with these funds is an integral part in any recommendations for a move toward marginal cost pricing.

6.5 Municipal water pricing

Traditional rate-setting methods, employed by state regulatory commissions as well as local government agencies appear to have produced a situation of rapidly *deteriorating water systems, both rural and urban, characterised by aging capital facilities and under-maintained water systems* (Mann, 1981, p. 101).

The American Water Works Association published a revised version of its manual on municipal water pricing in 1984. This reflects the water industry's traditional rate setting procedures of recovering the costs of providing water by use of multi-part tariffs based upon average cost pricing. Typically, the costs of providing water refer to the utility's revenue requirements which reflect historical costs and not the actual cost of providing service under expected future conditions. This approach results in over-estimating future demand leading to over-building.

The definitive academic work on municipal water pricing is the excellent study of Tucson, Arizona by Martin *et al.* (1984) which chronicles the role of water in the life of a desert city. (The Tucson city government was recalled by the electorate because of an increase in the price of water; probably the first time such an issue has led to the downfall of a city government anywhere in the world.) In only 102 pages the authors were able to analyse the political, social, economic and technical issues underlying water and its use in Tucson and to provide a definitive text on the generic issues of water planning for city managers elsewhere. Despite the highly political nature of decision making about water, and water pricing in particular, they were fairly optimistic about the usefulness of economic reasoning in influencing water policy in Tucson. They said (page 100):

> *"Economic reasoning is likely to have its greatest impact upon municipal water management through communi-cations with the staffs of municipal water agencies. The experience in Tucson indicates that water professionals have the largest stake in innovative water policy and are most likely to be initiators of changes."*

They agreed with Hanke (1973) that much of the blame for failure to influence water policy lies with economists themselves because "they have not provided sufficient concrete examples of how to apply their economic theories, nor have they spoken a language or through channels to which water managers are receptive" (Martin *et al.*, 1983, p. 100). They provided an excellent review of the AWWA manual and its application in Tucson and concluded:

> *"The current pricing schedules of the City of Tucson Water Department are neither efficient nor equitable, and they encourage rapid water development through limited attempts to encourage current conservation practices."* (Martin *et al.*, 1984, p. 57).

6.6 Effluent pricing

Regulating environmental quality by pricing the effluents that individuals, municipalities, and corporations emit is one of the standard recommendations of economic theory. This is the so-called 'polluter pays' principle. This is not based merely on the idea of being punitive, but rather is aimed at inducing efficient economic behaviour. The economic literature is full of conceptual schemes for pricing and taxing effluents that would lead to internalising the externalities of pollution. Once this is done, environmental quality can be left entirely to the usual market forces. The Washington-based research institute Resources for the Future has led the campaign for fees on effluent discharge into waterways for over 20 years with little success in the United States; it has mainly been opposed by those who think it improper to sell the right to pollute the environment.

Nevertheless a substantial amount of effluent pricing has been used in the US and in Europe. Hudson (1981) reports on the extent and mode of implementation of water pollution pricing through sewer charges. He claims that by 1970 more than 90 per cent of the municipalities with populations over 50,000 levied some form of sewer charge on residences and industry and that 40 per cent of local expenditure on sewage was derived from these charges. Industry can choose to pretreat its waste, decrease its water use, improve house-keeping, change either the production process or products, or it can choose to pay the effluent fee. The industrial charges are typically related to the quantity of water used and the 'strength' of the effluent measured in terms of the oxygen-demanding organic waste load (BOD) and total suspended solids. These charges can give an incentive to industries to change the amounts and strength of their sewage effluents. Hudson's study of five large cities (Atlanta, Chicago, Dallas, Salem (Oregon) and South San Francisco) and 101 industries found that effluent charges were overwhelmingly preferred by the industrialists to discharge limitations. There was a universal attempt by the industries in the sample to respond to the effluent fees despite their relatively small costs to the industries. Hudson concluded: "we are confident that economic incentives work well and can be effectively administered".

Downing and Sessions (1985), studying water quality in streams, examined the innovative programme of trading effluent permits on the Fox River in Wisconsin. They concluded that the method would be administratively feasible but could not judge its economic efficiency since no trades actually took place. The state officials who were originally enthusiastic about the experimental program claimed that its lack of success was due to lack of support of the programme in the Regional EPA office.

Little actual contact between these opposing positions has occurred. This is probably because both positions are unrealistic; ignoring some basic imperatives of the environment. Even if it is possible to figure out optimal prices or taxes to impose, we would still have to monitor the actual performance of the polluters to make sure that they were not cheating. Hence, we would still need large and intrusive bureaucracies to implement the market solution. Under these conditions would the 'market' be quite as efficient as it is touted? The mainline environmentalist position, on the other hand, does not recognise that under the current regulatory system, 'permits to pollute' will still be issued, unless no emissions at all are permitted. Tradeable effluent permits have been used in other areas of environmental management in the United States with limited success. For example, effluent fees are proposed for the 1990 revisions of the Clean Air Act but have run into serious opposition. Trading effluent permits for air pollution, however, has been undertaken for long periods of time in parts of the country. For example, California has well-developed markets for large point-source air pollutants. Industry can now include air pollution costs directly in their plant siting calculations.

7 Planning for Water Resources

7.1 Current planning approaches

Water resources planning has received a large amount of attention from economists and planning professionals for a long time. Based on the Flood Control Act of 1936, federal agencies in the United States, for example, were charged with devising economic criteria to ensure that only water projects for which the 'benefits exceeded the costs' would be implemented by the federal government. This policy led to major research which culminated in the 1960s in fundamental works by Eckstein (1958) and Maass *et al.* (1962) at Harvard University, Hirshleifer, Milliman and DeHaven (1960) at Chicago University, and Kneese and Bower (1968) at Resources for the Future in Washington, DC. The finishing touches with regard to dealing with environmental quality were in place by the end of the 1970s, with works by Dorfman and Dorfman (1972) and Baumol and Oates (1979). In addition to these books there are literally hundreds of other excellent texts explaining many practical aspects of the detailed analysis of benefits, costs and technology choice for each possible use of water. While this was taking place in the water resources field, the World Bank, the UNDP and many other funding agencies were working on developing reliable methods for economic appraisal of investment decisions in general. Outstanding examples of this literature are Little and Mirrlees (1974) and Squire and van der Tak (1975), sponsored by the World Bank, and Das Gupta, Marglin, and Sen (1972) and the *Guide to Practical Project Appraisal* (1978), sponsored by the United Nations Industrial Development Organisation (UNIDO). These works form the basis of the current evaluation of investments in the water sector.

The literature provides robust methods for planning water resources at a river basin level and at the level of individual projects. However, since most of the methodologies were developed in western industrialised nations, little attention has been paid to planning for water resources in a macro or intersectoral way; this was simply not relevant to the cases on which the methodology was first tested.

State-of-the-art economic project analyses are carried out routinely by the World Bank and other international funding agencies. For example, benefit-cost analysis is carried out on irrigation assessments and the project is either recommended or not, depending upon whether a suitable internal rate of return (IRR), or another index such as a benefit-cost ratio, is achieved or not. Recently the choices have also been conditioned upon not causing 'too much' social or environmental harm. For projects such as urban water supply or sewerage, where benefit calculation is very difficult, the marginal costs of providing the services are computed and compared to other ways of providing the same services. For both of these types of project analysis care is taken to shadow-price correctly the inputs and outputs.

7.2 Where does the current approach break down?

Current planning approaches have worked fairly well in the past when the competition for water was less acute than it now is. The same methods should also work under the new conditions. That they are not working is caused by a lack of attention to the correct implementation of the methods. For example, even if correct prices are computed in the appraisals, they are not used by the borrowing governments in implementing the projects once funded. This fact leads to overconsumption of water by some users and artificial shortages for others. There are two major areas where the current approach seems to be in trouble: (1) establishing and using the concept of opportunity cost of water in different sectors of water use; and (2) incorporating social and environmental concerns directly into planning.

(1) Since the methods for evaluation are applied mainly to project-by-project appraisal, consideration of the intersectoral nature of water use is neglected. Therefore, perfectly well analysed World Bank irrigation projects in Algeria, for example, find themselves in direct conflict for the same water with other, equally well prepared, Bank projects for urban water supply. In such cases the relative marginal benefits of additional investments in water must be carefully compared with those of other sectoral investments. Other resource sectors, such as energy, have well developed methodologies to relate sectoral and macro plans. Most of these were developed in response to the oil crisis of the early 1970s. It is now possible for energy planners to show the macroeconomic consequences of regulation of, and investments in, various energy sources and, in the other direction, to estimate the consequences of shifts in macro policy on demands and supplies for energy by various sectors. This has not been done in the water sector.

The role of water investments as infrastructure services which serve as both intermediate goods and final goods is also often overlooked in water planning. So for instance, Ingram (1989) worries that water infrastructure may suffer under-investment as a result of the current concern of multilateral and bilateral funding agencies with structural adjustment programmes for various countries.

A fundamental piece of information that is missing in most water plans is the opportunity cost of water. Adding the opportunity cost of water to its marginal cost of supply and comparing this with its current price indicates how efficient current water use is and how efficient it could be. In order to estimate these numbers it is necessary to have some form of intersectoral comparison of value or willingness-to-pay, hence the need to establish methods to evaluate water investments in an intersectoral context.

(2) Social and environmental impacts of water projects are increasingly becoming a source of contention between the international agencies and environmental interest groups in developed countries. It would be possible for the agencies to undertake economic analyses of the environmental impacts of water projects more diligently than has been done in the past. There is no doubt that this is a difficult task; nevertheless, there is now a large literature dealing with the economic impacts in terms of the economic impacts as lower bounds on the total impacts of a project.

"A society that allows waste dischargers to neglect off-site costs of waste disposal will not only devote too few resources to the treatment of wastes but will also produce too much waste in view of the damages it causes," wrote Kneese and Bower (1968).

As use increases, the public goods nature of water and the pervasiveness of externalities in water use lead inevitably to an increase of pollution, and in the late 1960s and 1970s the public perception in the developed countries was that the environment was being 'over-polluted.' The externalities implied in water pollution were first extensively discussed by the Resources for the Future group in the early 1960s. The above-cited book by Kneese and Bower (1968) is still a leading text on the economics of water quality.

The concern of economists analysing water pollution is with 'market failure.' In particular, the issue of how to internalise the externalities has received most of the attention. At the most obvious level it would seem that if the effluent could be correctly priced, then industry and other polluters could be taxed by just this amount and problem would disappear — the correct amount of pollution would be obtained, and if this were considered too large then the effluent price could be raised until a satisfactory lower level of pollution was achieved. Dixon and Hufschmidt (1986) have extended environmental economics to the issues faced in developing countries, particularly with respect to water projects. Papers by Desvouges and Smith (1983) and Fisher and Raucher (1984) show how contingent valuation methods can be used to evaluate the benefits (and damages) associated with a wide range of environmental impacts that hitherto had been thought to be non-measurable.

7.3 How the problems can be resolved

There are two possible, and not mutually exclusive, explanations of why problems arise in the way water resources are planned, appraised, and implemented:

(1) The accepted economic principles are adequate but the application is inadequate. The appraisal approaches used by funding agencies are based upon the generally accepted principles outlined in the voluminous literature referred to above. The application of the principles is flawed because, when faced with economic scarcity, the water itself must be priced at its opportunity cost. This is typically not done and leads to serious misallocation of resources between different uses of water. For example, in the World Bank's EMENA region the opportunity cost of water in the municipal sector is at least two to three times as high as the marginal value of irrigated agricultural production per cubic metre of water for all crops except some vegetables (tomatoes and cucumbers). However, when the irrigation projects are evaluated by themselves, without consideration of the opportunity cost of water in other sectors, they appear to have acceptable internal rates of return (IRR).

Similarly, the externalities due to environmental damages are not integrated into the appraisal of projects. The economic principles are clear, but little attention has been devoted in the past to evaluating the damages and therefore they tend to be overlooked in the analysis.

(2) The theory needs refining. No theory is perfect, and so it is with the theoretical approaches to water resources management. The relevant question is how the imperfections in the theoretical underpinnings lead to unacceptable outcomes from the point of view of the funding agencies and governments. As mentioned above, there are several assumptions about the theory that cause difficulty in water planning, but there are also approaches to softening or eliminating these market failures from the conceptual model. Three areas stand out as causing more trouble than others and, hence, may need more refinement of the theory. These are (a) the difficulties associated with making allocations in a macro economic sense between investments in water resources and other economic sectors, (b) dealing with externalities directly in the analysis (internalising the externalities), and (c) the political economy of tariff setting in the water sector.

(a) The pervasiveness of water use throughout the economy may be a partial explanation of the first problem but other sectors, including energy, radiate similar pervasive connections throughout the economy and society. Another partial explanation is the fact that water planning has been an integral part of governmental planning for a much longer time than other resource sectors. Hence, large and powerful interest groups are fully cognisant of their stakes in how the planning is done. So in most countries it is not of particular concern that the water planning and investments be balanced with other sectoral activities; indeed, the idea of such balancing is threatening to groups with a vested interest in water investments and management. The development of reliable planning methodology to relate water sector plans to the overall macro-development of a country is a generic problem that should be of major significance to guiding investments in water activities.

(b) Dealing with externalities directly in the appraisal methodology is another important requirement. The theory and methods for doing this have been developed and many environmental consequences can be adequately treated within the existing benefit-cost methodology. These methods have only received sporadic application in actual project evaluation. Fisher and Raucher (1984) report on several such studies but more work is needed to develop this methodology for urban water projects supported by the World Bank.

(c) The third area, the political economy of tariff setting, is extremely important and has to a large extent been neglected by water experts. This is particularly true in the cases often encountered when there are large economies of scale associated with the investments. The canon of price theory is marginal cost pricing. Unfortunately, establishing the marginal price for many water uses is difficult because of the characteristics of water that make its supply a natural monopoly. The existence of large economies of scale ensures that those who first entered the market will always be able to underprice and drive out any potential newcomers. They can decide on their desired profit level and set the prices accordingly. This fact has been recognised for a long time in the area of municipal water and wastewater treatment and the suppliers have been regulated, typically by public utility commissions.

Unfortunately most regulatory commissions have tended to take a 'backwards' accounting stance allowing pricing based only upon average costs and the revenue needs to meet them:

> "*Traditional rate-setting methods, employed by state regulatory commissions as well as local government agencies, appear to have produced a situation of rapidly deteriorating water systems, both rural and urban, characterised by aging capital facilities and under-maintained water systems.*" (Mann, 1981).

This stance is not appropriate in situations where the utilities are facing increasing marginal costs (all the best projects have been built and now it becomes increasingly difficult to supply the same amounts of water at the historical costs). Under these conditions a 'forward' looking accounting stance is indicated. If this policy were pursued, the emphasis on revenue requirements of utilities would be replaced by establishing adequate future investment funds.

Economic theory provides 'second best' pricing algorithms for such circumstances. However, according to Hanke and Davis (1973), even these lead to problems for utility managers and therefore they suggested the need to develop 'third best' pricing methods, which would be more responsive to the political dimensions of water resource pricing.

In a study of water conservation in Perth, Australia, Hanke (1982) outlines in great detail how to estimate economically efficient choices taking into consideration the resource cost to the utility, the resource cost to the consumers and the useful consumption foregone as a result of a particular conservation policy. Interestingly, when he compared two pricing policies (marginal cost pricing, and seasonal marginal cost pricing) with three non-price policies (leakage control, metering and mandated water restrictions) he found that the most economically efficient was leakage control, followed by metering and annual marginal cost pricing. All of the other policies had negative benefits. This is an eloquent reminder that rationing by pricing is not always the most efficient approach. In order to find out, however, it is imperative to carry out analysis at the level of economic sophistication applied by Hanke.

8 Broad Sector Wide Issues

8.1 International conflicts over water

Worldwide there are hundreds of rivers shared by different nations (54 just between India and Bangladesh). In many cases serious bilateral or multilateral conflicts over water have arisen. The current dispute between Turkey, Syria, and Iraq over the Euphrates is a good example of such situations. International law on trans-national rivers is weak: essentially, it is left to the goodwill of the upstream riparian interests to settle problems amicably. In an earlier period, the World Bank was a major player in one of the most successful conflict resolutions: the Indus Basin settlement between India and Pakistan.

The multilateral agencies should maintain their rule of not making loans for a project that is not acceptable to a country's neighbours, but they should also consider establishing a negotiating unit to help countries deal with these issues. In many cases the provision of a neutral corner and unbiased international expertise could make it politically easier for countries to explore their water conflicts with neighbours in a non-threatening situation, relatively free of inhibiting political limelight and implicit threats to national sovereignty. For example, although regrettably not fruitful to date, the World Bank's work over many years on hydro-electricity conflicts between Nepal and India is an example of such an approach, and a credit to the Bank. Easing some of these disputes would open up many new investment possibilities for constructive multi-purpose use of internationally shared river basins.

8.2 Linking the water sector to the national economy

It is a paradox that although water resources have probably received more analytical attention than any other kind of public investment, there has been little attention paid to relating the water sector to intersectoral or macro-allocation decisions. This lack of analysis should be of great concern in countries such as Brazil where 30 per cent of public investment is in the water sector.

Other resource sectors such as energy have well developed methodologies to relate sectoral and macro plans. Most of these approaches were developed in response to the oil crisis of the early 1970s. It is now possible for energy planners to show the macro-economic consequences of regulation of and investments in various energy sources and, in the other direction, to estimate the consequences of shifts in macro policy on demands and supplies for energy by various sectors.

The development of reliable planning methodology to relate water sector plans to the overall macro development of a country is a generic problem that is of major significance to guiding investments and other Bank water activities. In a paper with Hurst (Hurst &Rogers, 1985) the author found in the literature only a few attempts to do this. Hurst and Rogers built an economy-wide model for Bangladesh which incorporated a detailed water sector and its macro-economic linkages. While this particular model was never used in making a plan, it does indicate that quite different policy implications arise when the macro linkages are explicitly considered. Additional research in this area would help improve the quality of water investments in all sectors.

8.3 Water sector planning methodology and data requirements

At the next level down, within the water sector there are a plethora of water planning tools. One of these has come to be called 'multi-objective planning.' Although conceptually satisfying, planning theoreticians have made the approach unnecessarily complicated with its own nomenclature and dedicated computer software. In reality multi-objective planning is based upon the concept of constrained optimisation. One merely optimises one objective, for example national economic growth, while setting other objectives, such as environmental quality, as constraints upon the system. There is no doubt that this approach should be taken in any planning study, but no fetish is required: whether specialised software or more general purpose models such as linear and non-linear programming or simulation models are used, the different versions of this tool yield essentially equivalent results, and like all analytic approaches should be employed with a great deal of caution.

The literature on water resources is also heavily influenced by the ideas of comprehensive multi-purpose river basin planning. This has historically been the approach taken in Western Europe and the United States. Although intellectually satisfying, it is not clear whether it is the best approach to practical problems. It is helpful for the physical aspects of rainfall and run-off but much less helpful from the point of view of political jurisdictions and economic markets. In the United States it has since been abandoned by all major agencies involved in national water planning. Today agencies allow the specific problem to dictate the unit of analysis. With increasing concern for broader problems such as environmental quality, the idea of analysing 'problemsheds' rather than river basins is gaining ground. A recent book by Major and Schwarz (1990) shows how river basins can be building blocks in larger problemsheds.

At the practical level, however, little planning of any kind seems to have been applied consistently across water uses in the economy. For example, in many places the uses of water are still examined separately on a project by project basis. Thus, in Algeria it is possible to find examples of carefully planned irrigation projects alongside carefully planned urban water supply projects, with no way of reconciling the conflicting demands that both have for the same water supply. In Brazil (Miglino & Harrington, 1984) there was surprise when the introduction of a tariff on *wastewater discharges* led to large decreases in revenue to the *water supply utility,* almost leading to its bankruptcy. In these cases the unit of analysis was not large enough to capture the external effects of policies dealing with individual components.

There is a need to ensure that appropriate models of the water sector be included in any project appraisal. The unit of analysis must be large enough to ensure that most of the relevant externalities are captured in the analysis. In irrigation projects, ground and surface water as well as drainage must be analysed as one unit; urban water supply cannot be divorced from wastewater disposal and its downstream impacts; and water diversions from rivers must consider alternative instream uses of the same water for navigation, fisheries, downstream users, and the maintenance of stream ecosystems. Well-established methods using mathematical programming and simulation models should be required as a prerequisite for project appraisal in such cases.

In any policy study the quality of the data used determines to a large extent what conclusions can be reliably reached. However, there is a mindset that always looks for more and more data and more and more complete coverage of a region or basin. Geographical information systems (GIS) are currently very popular. Some of the practical problems encountered in the use of such systems should be examined. For instance, many of the current systems have been devised with little or no idea about how the information is to be used; this results in over-collection of some types of data and under-collection of others. The experience of GIS users to date has not been uniformly happy. Most systems concentrate solely upon physical, scientific data, with little or no coverage of important economic facts. Although many of the economic data do not need to be collected according to detailed geographic distributions, the economic realities may be as important as the physical data that do, and may be critical to understanding the meaning of the physical data. More attention should also be paid to the statistical variability of the data. Currently available methods to establish statistical reliability should be insisted upon in all data analyses and be carried over into the analyses of particular investment decisions.

One issue which ties the methodology and the data together is the issue of 'uncertainty.' Not only is it important to develop and use reliable data but it is also imperative that the planning methods used elucidate the uncertainty regarding the planning decisions. All too often in the water resources area the bulk of the analysis is aimed at the consequences of hydrological uncertainty when, as demonstrated by James, Bower and Matalas (1969), the largest part of the uncertainty in the implied decisions stems from the economic parameters which typically receive little stochastic evaluation.

8.4 Environmental impacts of water development

There are increasing pressures on international institutions to take the lead in responding to concerns about environmental deterioration. Institutions should develop policies that ensure taking the initiative in dealing with these problems, instead of being seen as merely reacting to specific challenges as they arise. As the industrialised nations have discovered, assuring water quality goes far beyond the regulation of industrial and municipal wastewater discharges. Nonpoint sources such as agricultural runoff are now recognised as major contributors to environmental problems that cannot be ignored. More importantly, at the level of questions of sustainability of ecosystems as a whole, water use and water contamination play major roles. They cannot be easily separated into water quality and water quantity issues; both are equally important.

From the environmental point of view much unhappiness with water projects stems from the casual way in which environmental consequences are handled as a last minute consideration, rather than being integrated into project design from the beginning. Big offenders include irrigation projects in which drainage issues are neglected in the initial planning, navigation projects in which the disposal of dredged materials is haphazard, and flood control projects which ignore flood-plain fisheries. In all of these cases adequate pre-planning guidelines could substantially reduce the environmental impacts. There are other projects, for example large dams, which have major environmental impacts that cannot be mitigated, such as loss of habitat, loss of fertile bottom lands, destruction of forests, and sediment trapping, in addition to the social impacts of moving large numbers of people from their homes and farms. These consequences can only be addressed on a political level by providing the right kinds of institutions that will allow for dialogue, negotiation, and compensation to the affected groups. However, guidelines that force a thorough search for alternatives could, in the case of large dams, suggest attractive alternative solutions such as modifications of the scale of the project or other storage options such as underground storage or a larger number of small storages closer to the users. For example, the World Bank Operational Memorandum 4.00, Annexes A and B, could provide a good starting point for the development of appropriate guidelines.

8.5 Social impacts of water development

In a perfect world water development would have only positive impacts on societies. However, because of the externalities inherent in many water investment projects there are almost always some winners and some losers. Local people lose their lands so that urban populations can have electric power and lowland farmers can have irrigation. Upstream users pollute rivers with wastes or choke them with sediment, causing severe damages to downstream users. Attention must be paid in planning projects to minimise disruption outside of the project area and to provide compensation to the affected parties.

As in the case of environmental consequences, many negative social impacts could be avoided by careful pre-planning. Some of the worst egregious social impacts follow from involuntary movement of populations out of areas that are flooded by dams and embankments. The move itself may be unavoidable, but social disintegration and destitution are not, and the needs of the affected populations should be integrated early into the planning process, with adequate resources and functioning transmission channels provided to meet those needs. Other cases, such as equity in water access in irrigation projects, are less obvious and are therefore often ignored by project developers and funding agencies. Particular impacts on women and children are also often overlooked until it is too late to mitigate their damage. Human health issues are often neglected in evaluating water sector investments. For example, the introduction of schistosomiasis into a region by irrigation projects is a serious matter and can be avoided or controlled to a significant extent by changes in system design and operation. Access to water for bathing, for religious purposes, for watering animals, and for recreation are all important social uses of water often inadvertently left out of project plans.

There is also the option of actively using water investments to achieve poverty reduction or other equity goals. The irrigation literature is replete with discussions of how to define equity, how to measure it and its effects on productivity and other values, and how to plan for it. Some options are more equitable than others and should be sought out in the design and implementation of water resources works. Nevertheless, if one were looking for investments in the economy to achieve equitable distributions of benefits, water projects are not the most likely candidates. Even within irrigation projects themselves it is important, for example, that the economic costs of skewing water allocations in favour of equity that are imposed upon society be defined in terms of the number of farmers, rather than farm sizes, and that they be carefully estimated and politically assessed as to whether they exceed the social benefits accruing. In some situations it may be the case that farm sizes are too small to be economically efficient and that the water might be better used on slightly larger farms.

8.6 Need for institutional reform

In most countries there is a great need to upgrade the institutions dealing with the various aspects of water. Most importantly, in every country there should be one institution with the responsibility to coordinate water policy across uses and across government agencies. Even advanced industrial countries such as the United States, suffer from lack of coherence in water policy across uses. There is often a tremendous inertial asymmetry between the staffing of agencies with traditional concerns and those with more modern ones. For instance, in Thailand the Irrigation Department is the single largest government agency. Slipshod organisation is also common in many countries. In India, the use of surface water is administered by the Central Water Commission, whereas the Central Groundwater Board oversees groundwater use. There is little practical integration of these agencies' plans, despite a formal agreement to cooperate. Each of India's 22 states also has its own department of irrigation, which usually deals only with surface-water supplies, while other departments focus on groundwater. In cities around the world, municipal water is a local responsibility, but many individuals also sell water in small quantities to households. Rural households are almost always in charge of obtaining their own supplies. The result of such compartmentalisation is that agriculture, industry, and municipalities use water inefficiently.

While institutions are likely to be highly regional and culturally specific, the need to strengthen them is one of the major generic problems facing development activities around the world. The need is not for large new institutions but, rather, for small policy councils composed of cabinet rank officials who will be able to coordinate the work of the existing water institutions. Water policy should emphasise structure, organisation, management, and the role of adequate cost recovery, to enable individual countries' institutions to carry out necessary maintenance tasks and build for future demands.

9 Specific Urban Water Issues

9.1 Conservation and recycling of water

One of the most obvious ways of extending the water resources base is by conserving water or by recycling it after use. Unfortunately, by themselves these measures are not the panaceas that they are often thought to be. In most cases people and industries 'waste' water only because it is the cheapest thing to do. Unless water prices are raised significantly there is no incentive to do otherwise. The experience in the industrialised countries is that people can be motivated to conserve water on the basis of altruism only in times of stress. Typically, after the stress is removed consumption rises to the previous levels. Vickers (1991), however, reports on considerable recent success in the United States in the area of conservation. She reports on recent results from California. For example, the city of Santa Monica started in 1989 an incentive fee programme for replacement of toilets and shower heads with low-flush low-flow equipment. By 1991 over 5,000 replacements out of a goal of 12,000 units had been completed. This has led to large and permanent savings in water by the city (as much as 350,000 gallons per day).

There is much discussion of the recycling of sewage for use in agriculture. Many cities have been doing this more or less successfully for some time. The practice is widespread in Asia with, however, some problems in protecting the public from pathogens. With care such use can be made of sewage, and should be made wherever appropriate. However, much of the discussion implies that large amounts of irrigation can be accomplished with such recycled water. One needs to be reminded of the tremendous asymmetry in volume between agricultural and domestic water uses: one large irrigated farm in the US consumes as much water as a town of 15,000 people produces wastewater. It takes the wastewater of 50 people to irrigate the land required for growing the food for one person. Although water recycling for industrial and domestic uses appears attractive and a worthwhile investment for vegetable gardening, it is not likely to make a major contribution to irrigating field crops.

Direct recycling of municipal wastewater has also been practised without the use of irrigation as an intermediary. For example, Windhoek, Namibia, has been successfully recycling large quantities of municipal water for more that 20 years without apparent problems. In some parts of the world such recycling is practised in an unobtrusive way. For example, in Holland polluted water from the Rhine is filtered through the river banks before being abstracted for urban water supplies.

9.2 Reducing unaccounted-for losses

Much has also been written about conserving water by improving the efficiency of use in irrigation and reducing the losses in urban water systems. As discussed earlier increasing water use efficiencies in agriculture is a slippery concept and the practice may not really provide great savings of water in many cases, particularly where conjunctive use of groundwater is practised. Nor is it necessarily wise to reduce losses in urban water systems, since the cost of reducing the losses may exceed the benefits as perceived by the water utility. This is clearly an area where the appropriate pricing and valuation of the water itself is the major issue. Conservation for its own sake is not a realistic or advisable goal; it only makes sense within a correct pricing policy for water. Despite these reservations Garn and Saravanapavan (1987) report that a review of 54 water supply expansion projects by the World bank showed unaccounted-for water averaging 34 per cent of water production. Often unaccounted-for water amounts to as much as 60 per cent of the total supplied. This was the case in Manila in the Philippines, while Lagos, Nigeria, was reported to be at 50 per cent, and the two largest cities in Indonesia, Jakarta and Surabaya, were reported with levels of 50 and 60 per cent respectively.

The wide scale prevalence of such high levels of unaccounted-for water is an indication of very poor management and maintenance. The World Bank concluded that no new technology is required to tackle this problem but, rather, the tightening up of existing leak management programs, meter maintenance and replacement, detailed examination of the water use practices of the largest users, and a careful review of unauthorised usage of the resource. All of these programmes together may be able to make significant changes in the system over a short period of time. An example of this occurred in Boston, Massachusetts, where the unaccounted-for water dropped from over 40 per cent in the late 1970s to about 20 per cent five years later. But Garn and Saravanapavan caution that it is often hard to achieve such rapid improvements and comment that Tokyo, Japan, took 20 years to achieve an improvement similar to Boston.

9.3 Planning for operation and maintenance

There is a huge literature on the management and operation of urban water resources infrastructure. Most of it laments the lack of success by the utilities and local city governments in managing their infrastructure in a cost effective and environmentally sound way. The laments of Cook and Lorentzen (1987) about the situation in the developing countries mirrors the complaints one hears in the developed world. In both settings the major problem is lack of revenue. If the recommendations made earlier in this paper regarding changing pricing policies were to be followed then the utilities would have both the necessary money to pay and train their own staff properly but also to consider high tech. approaches to managing and operating their system. For example, there are many remote metering systems that would speed up the response time of the managers to leaks in the system and more mundane tasks such as sending out timely and accurate water bills on a monthly or quarterly basis. Other software techniques such as the computer-based graphical method to improve maintenance discussed by Luxhoj and Tao (1990) or the expert systems developed by Collins *et al.* (1990) for water utility management, or the US EPA's CCP method for improving sewage treatment plant operation described by Esler and Miller (1987) could be used to improve performance.

9.4 Manpower planning

One of the keys to successful operation and maintenance for urban water infrastructure is the availability of skilled and motivated employees. In many countries around the world there is a need to develop training institutions to provide the training needed in the water sector. Data on actual manpower needs and supply are hard to come by, nevertheless, Otterstetter (1987) was able to pull together some data from PAHO. He shows data from 1981 that indicate that 250,000 employees provided water supply for a population of 240 million people. Is this figure of one employee per 1000 customers high or low? In the US there are more than 50,000 water utilities (the majority of them being very small) servicing about 250 million people. The Latin American figure looks excessively high when compared to the number of utilities in the US and an estimate of 96,000 employed in municipal owned water supply utilities which account for 71 per cent of the total supply. Another interesting comparison which arises from Otterstetter's paper is that there are approximately 200 schools of civil engineering teaching sanitary engineering to their 4th and 5th year students in Latin America and the Caribbean, whereas in the US only 112 universities offer sanitary and environmental engineering in their graduate programmes. It appears that the quality of the training may be more important than the numbers of trainees.

9.5 Quality and drinking water standards

The World Health Organisation has been heavily involved in promulgating guidelines for drinking water quality. The most recent ones (1984) are guidelines *not* standards and the WHO recommends that each country develop their own standards based upon the guidelines as well as economic costs and other local factors. A major part of the WHO guidelines addresses the issues of surveillance and enforcement. The recommendations range all the way from the need to establish laws and regulations regarding water quality, through the design and staffing of enforcement institutions, to the establishment of laboratories, to plumbing codes, and sampling and monitoring.

9.6 Privatisation

Privatisation, like many of the other issues discussed in this paper, depends upon the value of water and people's willingness to pay for it. With sufficiently high tariffs many of the water infrastructure problems would disappear. Under these circumstances it would then be a natural sector to consider for private ownership, or at least private management. Many international agencies are considering the use of the private market to provide many of the services which have often been provided by the governments in the host countries. Examples of these are transportation systems (private buses), some medical systems (private production or importation of drugs), selling off parts of government irrigation projects (particularly tubewells), and provision of housing. Urban water infrastructure has so far not been included in this drive toward privatisation. This is mainly because no one seems to believe that they are potentially lucrative economic properties.

In the developed world the situation appears similar with a few exceptions. For example, although 29 per cent of the drinking water in the US is supplied by investor-owned utilities there does not seem to be a movement towards expanding that fraction of the market. Indeed, in some recent cases cities have taken over previously privately owned water companies because of lack of adequate performance. In the US almost all of the major systems are government owned and managed. However, there is a fresh new interest in privatisation of wastewater management facilities. This seems to be taking two different forms: for small cities the authorities are leasing out the publicly owned facilities to be managed by private companies, and for the larger cities only certain functions are being leased to private companies. The leasing in both cases tends to be limited to the treatment plants themselves and not to the sewer system and outfalls (Jankel, 1991).

In Britain, however, just the opposite is occurring with all of the major water suppliers currently being auctioned off by the government. Kinnersley (1988) compared and contrasted the approaches taken in Britain and France. The British approach is to sell all of the infrastructure to private companies along with a 25-year licence to operate them. The French approach is for the municipalities to lease all of the infrastructure to private companies for a fixed term of about five years. Kinnersley points out that achieving efficiency in this sector needs some competition and how does one provide it in such a natural monopoly as the water sector. He sees more of a semblance of competition in the short term leases in France coupled with the actual record of the French municipalities willingness to switch lessees periodically. Kinnersley (1991) reviewed the privatisation process in the United Kingdom and concluded that it was too early to pronounce the privatisation a success but that the preliminary indications were that no major obstacles were likely over the short-run, but that some of the new private entities were seeking large amounts of capital to finance the rehabilitation of the systems.

9.7 *Public awareness and community involvement*

Public awareness and community involvement with urban water issues is of paramount importance. For example, it has been known for a long time that water savings of up to 30 per cent can be achieved almost overnight in drought situations. Unfortunately when the drought is past then the demand returns to its earlier level. Nevertheless a well motivated citizenry can be very helpful in effective management of the resource. Conservation programmes that rely upon installations of devices within the home are virtually impossible without extensive outreach by the utility to the citizens.

Recently there have been attempts to integrate the citizenry into assessing the risks of various contaminants in the water supply and in the environment. 'Risk feedback' (Benjamin and Belluck, 1990) and 'risk communication' (Shovlin and Tanaka, 1990) are the ways this approach has been designated. Shovlin and Tanaka describe the problems encountered by the Los Angeles Department of Water and Power when it decided to construct an air-stripping tower to remove TCE from contaminated groundwater. Because the Department used its usual 'decide, then inform' approach, the residents in the immediate vicinity attempted to halt the facility. The project was only allowed to proceed after a long delay and the addition of vapour phase GAC scrubbers which increased the project cost by 50 per cent. The water department is now modifying its approach to project implementation to include a discussion of the hazards with the residents before any decision is made. Public affairs professionals are now included in the planning phase of projects, more effort is being made to determine customer views regarding water quality, and a professional mediator has been retained.

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8

Coping with multi-cause environmental challenges — a water perspective on development

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EXECUTIVE SUMMARY

The paper addresses major management issues related to environment and development in poverty stricken developing countries. *The challenge is to meet the threats to livelihood security that have developed as a result of past misuse, on the one hand, and rapid population growth and water scarcity on the other.* It stresses the historic concept of the environment and development as counteracting interests in Third World development. Once the step is taken from protection of the environment as such (preservation) to protection of the productivity of the environment (conservation), environmental protection becomes an issue of common sense. What is needed in the present situation with widespread highly degraded lands, is to incorporate the new awareness of a finite and fragile water resource into a sort of *extended water management*, including immediate steps to conserve soil and water *in situ* for the productive use of the resource base. The paper analyses the water management requirements and the related environmental issues. In view of the key role of water in the environment it is important to take a water perspective to environmental problems.

A conceptual model is crucial to strengthen the communication with different decision makers, particularly on policy issues that require an understanding of the genesis of environmental problems threatening the future in many Third World regions. The concept environment is reserved for *exposition-oriented* issues on the local level (exposition of individuals to health hazards). On the mesoscale (catchment) it is replaced by a *manipulation-oriented* concept, focusing on the landscape and the different ways man has to manipulate it in order to harvest its life support systems (water, biomass, energy etc). On the macroscale (river basin, countries, continents) it is replaced by the *continuity-oriented* "Total Earth" concept with focus on how the effects of manipulations are propagated by the water cycle, causing effects on ecosystems much later in time or elsewhere in space.

The results of past environmental misuse are analysed in terms of their origins (hydroclimate, waste production, land use), the way of misuse (overexploitation, poor waste handling, unprotected land surfaces) and the subsequent environmental challenges (scarcity, pollution, fertility degradation); the consequences (depletion, water quality degradation, desiccation of the soil) and their implications (unsustainable water supply, reduced usability, shortened vegetation period).

To meet the dual threats of past misuse and population growth under water scarcity calls for an expanded view on water. Vegetation plays a crucial role in the rain partitioning between the return flow to the atmosphere (including the water needed for biomass production), on the one hand, and the surplus left to recharge aquifers and rivers on the other. This gives a *strong rationale for extending from the conventional attention to water in only the horizontal branch of the water cycle (aquifers, rivers) to include the vertical branch also (water consumption in rain fed biomass production).* The positive experience of land restoration — where non-productive evaporation losses have been partly transformed into productive evapotranspiration — highlights the need to develop criteria for a balance between "vertical" and "horizontal" water uses.

The urban-rural dichotomy is discussed at some length. An unprecedented urban growth introduces serious complications for several reasons: the dramatic influx of people from rural areas (up to half of the growth is potentially avoidable as it is due to rural emigration), the escalating costs to manage the situation (including the provision of safe water from more and more remote sources, and a safe waste handling); and the massive risks of increased rates of morbidity and mortality if the managers cannot cope with the growth rate. As urban centres are, however, important for economic development and employment, there is a clear tendency at present that urban needs are now developing into a new 'privileged solution', replacing irrigation, the privileged development solution of the recent past.

Two types of management are needed: (1) to augment the accessible water by reducing the non-productive losses by landscape management (maximise *efficiency of rains); (2)* socio-economic allocation of the accessible water to the most productive set of uses including rain fed biomass production (maximise *productivity of accessible water).* The new policies needed to address these issues have to be carefully analysed in a stepwise manner to find out what to do, how to do it, how to make it possible, and how to get it done. In doing this it is essential to *get rid of a whole set of confusing biases from the past:* the climatic North-South bias, the intercontinental bias, the preservation/conservation bias, and the urban/rural bias so that the issues can be holistically addressed and be the basis for realistic policies.

The paper concludes that an extended water management is needed to integrate environmental conservation with development-related efforts. All water uses have to be considered including the "vertical" use represented by the water consumption in rain-fed biomass production and the conventional "horizontal" uses. A holistic approach has to be taken to coordinate and integrate urban/rural planning and management, since the avoidable part of urban growth is equivalent to poverty-driven emigration of the rural poor. It is essential to get rid of all the different biases which have contributed to the precarious situation of today when most of the poverty-stricken countries are lying in the dry climate tropics and subtropics. The knowledge base is principally good enough to get started in order to make the 1990s into a real 'Turn Around Decade'.

CONTENTS

1. Background

1.1 Partial view impedes progress

Past discussions on environment and development have been conditioned by the basic concept that they represent two opposite interests counteracting each other. The tacit understanding has been that environmental protection tends to delay development, rather than supporting it.

Basically, such conceptions emerge from extrapolating the *situation prevailing in the industrialised countries.* In these countries which are mainly located in the temperate zone, protection of the environment has been taken as equivalent to measures against pollution and especially water pollution. Environmental protection is, in other words, equivalent to waste water treatment in expensive treatment facilities. In the Third World such treatment costs carry a wasteful and additive dimension. With the lack of acceptable economic methods to bring the costs of degrading water on to financial balance sheets, the attitude to environmental issues is ambiguous in large parts of the world. But more important, in a situation where millions of people are deprived of a decent livelihood and with more than one billion people living in absolute poverty, the authorities and the people in Third World countries do not see how protection measures are immediately necessary or how such measures will improve livelihood security.

However, the *Third World* countries are lying in a zone with much more extreme climate than characterises most of the industrialised countries. As a consequence, their environmental problems are much larger and partly different. In a zone where part of the year is arid, recurrent droughts are part of the climate, and the high potential evaporative demand of the atmosphere gives the rainfall a much lower efficiency than in the temperate north (Falkenmark, 1991a). Therefore there is considerable environmental vulnerability in these countries. The preoccupation with man-induced environmental problems rather than the basic challenges of development under conditions of water scarcity in a vulnerable environment leads to a one-sided view of development which has not been very constructive.

In the dry climate tropics and subtropics especially, the *environmental preconditions* for resource utilisation need careful attention. They constitute a serious challenge if depletion of resources and degradation of the environment are to be avoided or minimised. It is fair to assume that there are significant links between widespread poverty — especially with regard to the situation in rural areas — and harsh environmental conditions, not well appreciated in the North. The conventional analysis of the causality chain behind poverty may therefore be misleading. It is usually ascribed to environmental degradation driven by marginal rain fed agriculture, and cash crop production and timber export for the generation of foreign income (see, for instance, McNamara, 1991; El Ashry, 1986).

1.2 Crucial dimensions of water management

A dry hydroclimate implies a high degree of *environmental vulnerability,* seriously complicating human activities in the landscape (Falkenmark *et al.*, 1990). For example, the soil surface is highly sensitive to degradation of permeability. The result of such land degradation is the desiccation of both root zones and aquifers. Instead, heavy rains rapidly leave the area as highly erosive overland flow producing silt-laden flash floods in water courses.

A truly illuminating example of this development-cum-environment trauma is presented from the region around Cherapunji in northern India. This area, "the wettest desert on earth" (Clarke, 1991) with about 10 metres of annual precipitation, is severely affected by the changes in land use that have taken place. "Even in Meghalaya today, in Cherapunji where the rainfall is highest in the world, there is a drinking water crisis. This is because of denuded forests and a total neglect of natural resources" (Poojary, 1988). In areas where the rainwater vanishes quickly through flash floods and direct evaporation, food production is risky, and, as a result of a minimal base flow, even the household water supply is at stake. Reduction of these unproductive and rapid water losses is evidently a precondition for improving living conditions in rural areas, particularly for the billion or so people living in semiarid and arid regions.

The situation in Cherapunji is extreme, but in principle the same threat is developing in large parts of the world. Two stages in this threat may be distinguished. Through large-scale changes in land-use, including eradication of permanent vegetation and denudation of the soil surface, immediate consequences for hydrological parameters are noticeable, as illustrated by the Cherapunji example. Gradually through erosion, a secondary (and for all practical purposes irreversible) damage to the life support system will occur. In a FAO report from Ethiopia, it is claimed that some 38,000 km^2 of the highlands will be eroded down to bare rocks and another 60,000 km^2 will have a soil depth of 10 cm or less by the year 2010 if current rates of erosion were to continue (FAO, 1986). With such a scenario, it is of paramount importance to take immediate steps to conserve soil and water *in situ* for a productive use of the resource base.

An additional problem in water management that will force itself onto the policy making agenda, is the *allocation of water between various potential and competing uses.* One choice is between various uses on a watershed level: that is, between allocating water to different crops, between perennial and seasonal water requirements, etc. Another choice, referring to a larger geographical scale, is the allocation between the urban-industrial and rural-agricultural sectors, or between States and Nations. With increasing scarcity of water and investment resources, and the increasing proportion of the population living in urban areas, the demand for a coordinated and integrated management of water resources at regional or national level will increase.

Clearly a partial view of environmental issues, which does not adequately address the development preconditions and the environmental and socioeconomic implications of the allocation of scarce water resources, is a burden in any serious discussions about sustainability and policy design. For instance, fundamental needs for rural development may be jeopardised by the pronounced urban bias which is noticeable in current policy documents (see, for example, World Bank, 1991; UNCHS, 1991).

What urgently need to be addressed in extreme tropical climates — besides ordinary water pollution problems from municipal and industrial waste water — are the severe rural problems posed by rapid land degradation, which now threatens the food and biomass production needed to support rapidly growing populations. In the tropical reality, conventional environmental perceptions do not fit — they are indeed becoming outdated. *We need an extended water management which pays due attention to water resources availability and quality realities and the implications of human manipulations of the landscape.* Furthermore, criteria for the allocation of scarce water resources between various uses have to be developed that fit Third World socio-economic realities.

1.3 Conservation versus preservation approaches in environmental policies

Third World scientists have already tried during the 1970s to redefine the objective of environmental protection. Rather than focusing on the protection of a poorly defined 'environment' as such, the concern should be devoted to the protection of the productivity of the environment (Pantulu, 1985; Vohra, 1985). This interpretation highlights the significant difference between the *preservation* and the *conservation* approach.

With the latter interpretation of the concept, the objective of environmental protection pays attention to the imminent need to secure and maintain a decent livelihood for people. It carries an evident flavour of common sense in regions where threats of famine are a recurrent phenomenon and the population is growing at high speed. Evidently, under such conditions, biomass production has to intensify in order to prevent food shortages and to keep a rapidly growing population supplied with food, fibre, fodder, fuel wood and timber. McNamara (1991) estimates that Africa must set itself targets for long-term agricultural growth no lower than four per cent per annum — twice the rate achieved in the 1980s.

In summarising the past predicament, the natural resources experts have had difficulties in reaching planners with their warnings, both in the water-stressed industrialised countries (Pearce, 1991) and Third World countries (Vohra, 1982). Development policies have largely followed the ideas from the well-endowed temperate zone. To put it more bluntly: in the past the blind have been guiding the deaf.

1.4 Focus of the paper

This paper deals with water management requirements and related environmental issues. The main focus is on problems and opportunities as they appear in a landscape or a watershed context. A watershed refers to a comparatively small, local area where the interdependency of land, water and biotic resources is of significant importance. Apart from the management requirement on water and other resources at the watershed level, there are significant issues to be dealt with at a regional level. One of the most pressing requirements is to cope with the increasing competition on water from various sectors and interests at that level, that is, between urban and rural sectors. Management should also consider more general features of the hydrological cycle and its associated interactions and consequences.

This paper will address the conservation approach to land and water resources within a watershed context and to what degree human manipulations of soil and vegetation, necessary to provide the life support needed, do involve a long-term threat to the productivity of land and water bodies. We will also discuss principles of water allocation. The discussions will refer to the questions raised at the end of the paper.

The issue of multi-cause environmental challenges in development will be addressed *from a water-interactive perspective*. There are three reasons for taking that particular perspective:

- water, because of its erosive and dissolving capability, is very active in environmental degradation
- land management, and in particular vegetation changes, can disturb partitioning of rainfall, producing secondary environmental effects on groundwater and river runoff
- water scarcity itself involves both environmental and development problems.

A water-interactive perspective is of supreme importance in clarifying some fundamental links between the resource base and its relation to life-support systems and the environmental consequences of human interventions in these systems.

2 A Conceptual Model for Landscape Resources Management

2.1 Linking environment and development

Environmental and development issues are comparatively easy to handle separately. Combining them requires a conceptual framework which facilitates an interdisciplinary and intersectoral integration (Falkenmark, 1991b). The concepts have to be understood by policy makers at various levels to be translated into concrete actions. For instance, the dichotomy used in the temperate zone between water and land as two distinct realities is less meaningful in a landscape where the vegetation is water limited – rather than energy-limited – by a dry climate. Studies based on this dichotomy, such as FAO's analysis of the population supporting capacity of the Third World continents (FAO/UNEP/IIASA, 1983), can indeed be criticised, because no attention is paid to the increased return flow of water to the atmosphere that would accompany the yield increases discussed. It has, for instance, been questioned whether enough water is available in many of the African countries to allow the yield increases suggested to follow from just 'dry' agrotechnological measures like tractors, fertilisers and pesticides (Falkenmark, 1990). A yield increase from 1 t ha^{-1} to 4 t ha^{-1} might very well result in an increase of the return flow of water to the atmosphere from 1000 m^{3}ha^{-1} (100 mm) to 4000 m^{3}ha^{-1} (400 mm) for a given crop. The question raised is whether the required amount of water is indeed available in the landscape.

2.2 Defining the scale of interactions

In discussing Man's relation to the biophysical environment on which he depends for his life support and which he is forced to manipulate (skilfully) in order to get access to the resources, we need a *three-scale set of conceptualisation* that makes it possible to address the whole set of different environmental challenges on different scales. The concepts proposed here form a set of 'Russian dolls' where the lower set is enclosed in the next-order scale (Figure 1).

The special connotation of the term *environment* is associated with the *local scale*, where it semantically makes best sense. This is the interface and contact zone between humans and their surroundings and the context generally referred to in conventional discussions where the impacts on humans and other targets from exposure to hazardous substances in the surroundings are in focus. When the same concept is used for Third World problems, the focus is primarily on disease vectors to which the individual is being exposed ("environmental health").

At the next scale level, guidance can be taken from a recent World Bank study of some 70 borrowing countries (see Falkenmark, 1991), which indicates that most of the major environmental problems in Third World countries in fact emerge from human activities in the landscape. We therefore need a *mesoscale manipulation-oriented* concept for man's interactions with the surrounding *landscape*. In a water resources perspective, the landscape could be synonymous with a watershed area. It may also refer to a catchment or a small river basin. Here a watershed refers to a comparatively small geographical unit, while catchments and river basins denote larger and more complex geographical units, for instance the Ganga Basin or the Nile Basin. In this article the management of water resources at a watershed level is associated with rural development issues while catchment and basin management aspects include rural-urban interactions and development choices at that level.

When, finally, a number of landscapes, a whole river basin, or even the whole continent is in focus, attention has to be paid to the macroscale system of which all the mesoscale landscapes are components. A *conceptualisation of the Earth system as a whole* will make it possible to address the multi-cause syndrome of global change as the result of a whole set of parallel and superimposed causes. This concept should bring in the integrity of the water cycle and the fact that pollutants and other disturbances are carried or propagated by the cycling water from the atmosphere to the landscape, to groundwater, water bodies and to the sea.

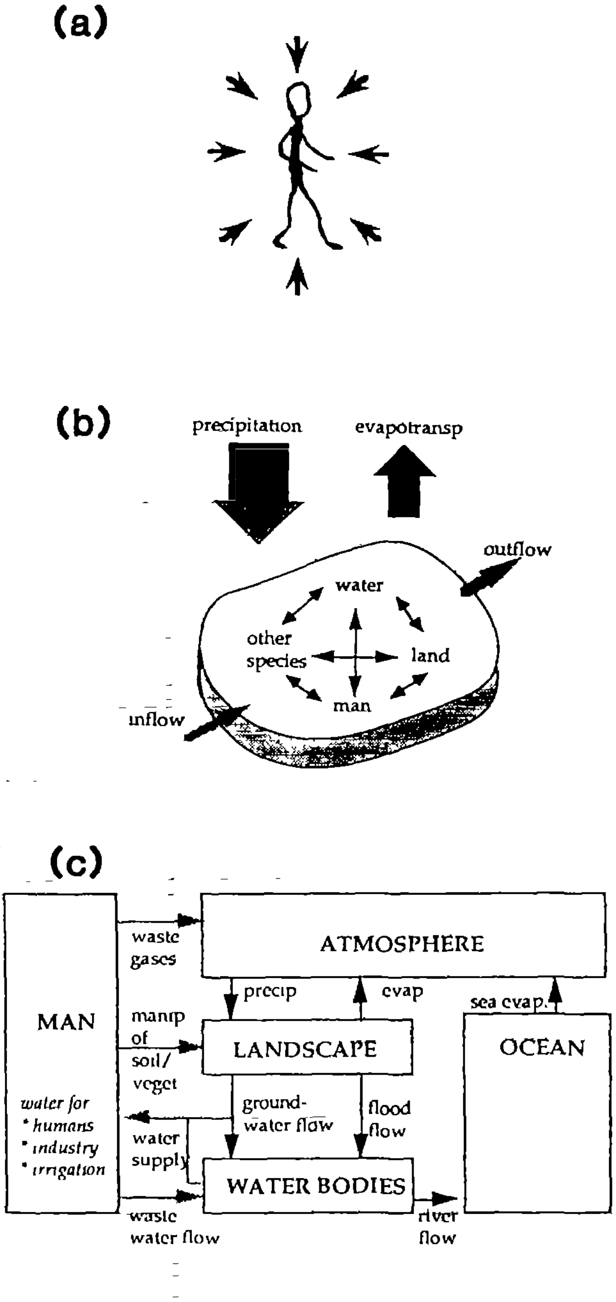

Figure 1 Conceptual structure of the former "environment" concept, as seen from different perspectives on different scales:

(a) local scale –exposition-oriented perspective,

(b) mesoscale – manipulation-oriented perspective,

(c) macroscale – continuity-oriented perspective

2.3 Manipulation-oriented mesoscale: the landscape

The mesoscale *landscape* approach is particularly helpful in intersectoral, interdisciplinary, interprofessional discussions. The landscape gets its life from water from the atmosphere. Biomass production sends water back to the atmosphere together with water evaporated from wet surfaces. The rest goes to recharge groundwater aquifers and rivers with endogenous water. In the landscape there is an intricate interaction between water, soil, vegetation, man and other species.

Man depends for his life on resources provided by the natural environment of the landscape: water, crops, fuel wood, timber, energy. In order to get access to these resources, man digs wells, clears the land, drains water-logged areas, builds canals, fertilizes, cuts trees, etc. To access or harvest these resources, soil, vegetation and water systems in that landscape are manipulated. Because of the intricate interdependencies and interactions in the ecosystem, such manipulations tend to produce environmental feedback (Figure 2), in addition to the benefits intended (water, food, energy).

The manipulations are indeed necessary ingredients of life. The fact that they produce environmental feedback implies that *a balance has to be struck between the necessary manipulations and their negative side-effects.* An essential criterion when seeking that balance is the living space needed by other species, taking into consideration factors such as biological diversity and species composition.

2.4 Continuity-oriented macroscale: the Total Earth system

The system in Figure 3 shows what has been called the Total Earth system, seen from a water perspective. The water cycle links the different spheres together: the sea, the atmosphere and the landscapes and water bodies on the continents. The conceptual framework is useful on the scale of the river basin, the country or the continent, and contributes in closing the conceptual void of the past between the atmosphere and the terrestrial, aquatic and marine ecosystems. It is also helpful in visualising how manipulations with the atmosphere, the landscape, or the water bodies are propagated onwards, producing ecological effects elsewhere in the system.

The human society manipulates the system in several ways: (a) the *chemical outputs to the atmosphere* (driving climate change); (b) the *manipulations of land/vegetation* and the outputs of dry waste to the land (producing environmental impacts on water partitioning, impacts on vegetation from soil-water pollution, and pollution of groundwater and river flow); (c) the abstraction of *water supply from aquifers and water bodies;* (d) the output of *chemical and biological waste water* to the water bodies (polluting them and producing impacts on aquatic and coastal ecosystems).

In the following sections, we discuss the mesoscale water interactions and the requirement of management.

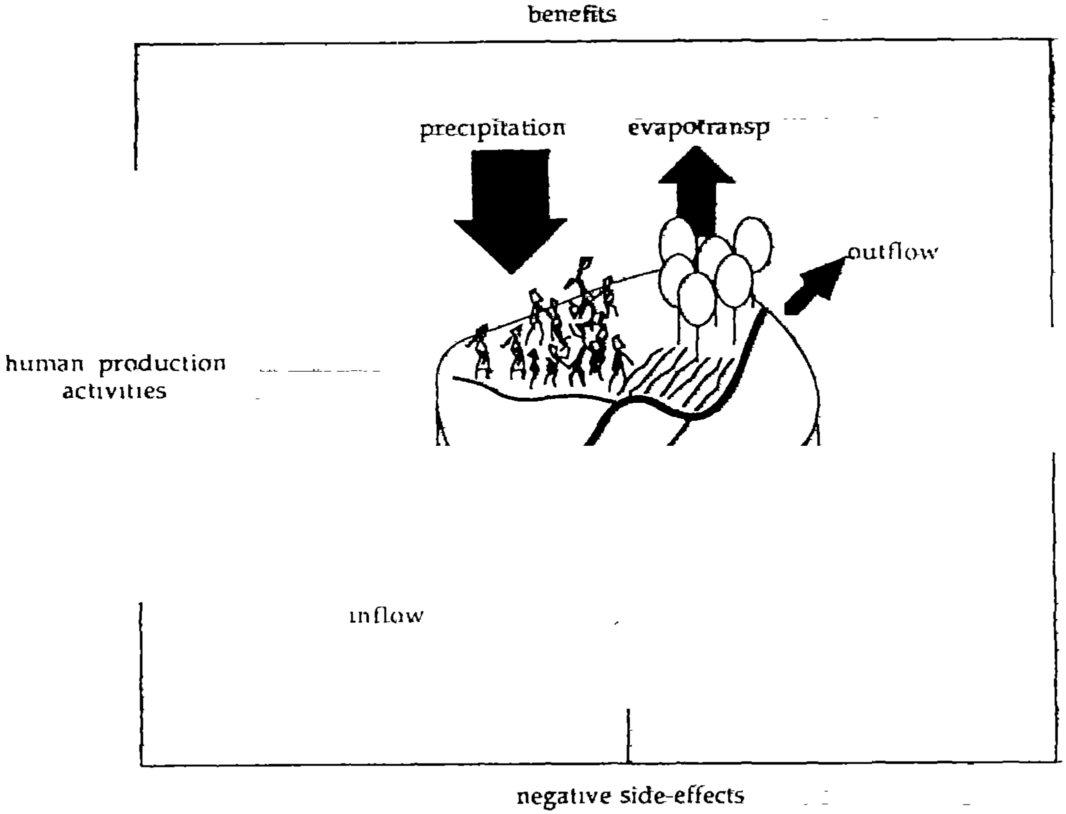

Figure 2 Human livelihood involves production activities which call for manipulation of the landscape, producing not only the intended benefits, but also negative side-effects ('environmental impacts').

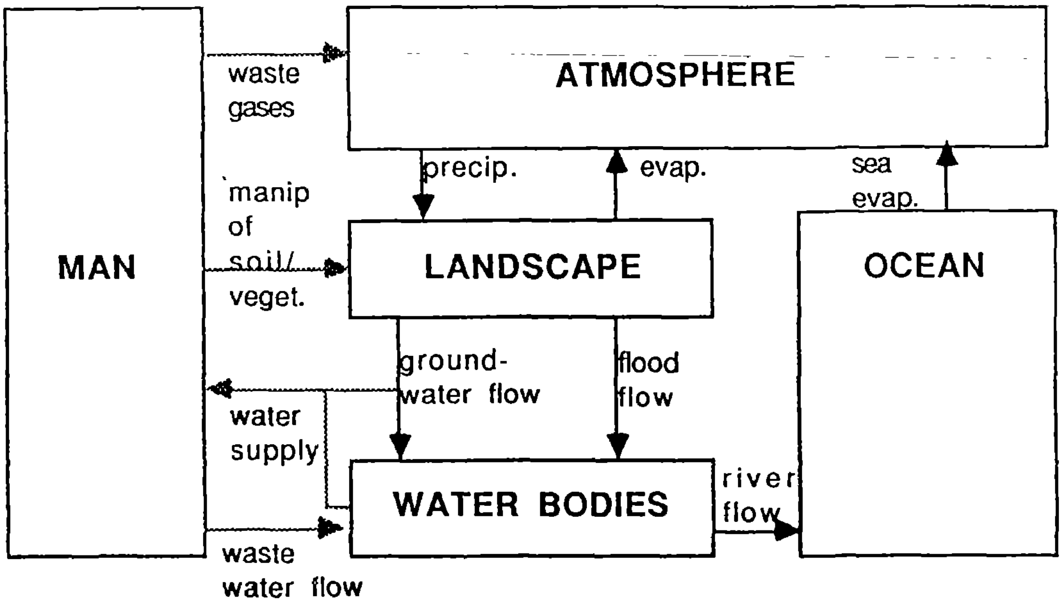

Figure 3 Man's interventions in the Total Earth system

3 Results of Past Misuse: Multi-cause Syndrome of Environmental Change

The present predicament of humanity is the result of multi-cause environmental changes (Clark, 1990). The landscape changes relate both to water quality in aquifers and water bodies (with effects on water supply, fish and biota), and to land degradation, and therefore to the productivity in terms of biomass production capacity.

Since most of the poverty-stricken countries also suffer from an additional problem related to the 'environment' — water scarcity — it may be adequate to talk about a set of multi-cause environmental challenges in describing the present predicament. These have three main components: multi-cause water scarcity, multi-cause water pollution; and multi-cause land fertility degradation (Falkenmark, 1991a).

From the perspective of the local population in large parts of the world, development involves improvements in the supply of and entitlement to basic amenities of life: food, dependable water supplies, shelter, health care, etc. For these to be obtained and remain sustainable, all three components of these environmental challenges have to be mastered. Precautionary measures are required to protect the water bodies from pollution which may propagate into the biosphere; on the one hand this makes fish, food and drinking water dangerous for human consumption and on the other hand it reduces biodiversity by disturbing the ecosystems. For a continuous development, however, the productivity of the life support systems must be protected, and even improved, so that rural self-reliance in food and fuel wood can be secured.

3.1 Three sets of multi-cause environmental challenges

The set of environmental challenges can be summarised as follows:

- *multi-cause water scarcity*, growing out of three different sets of causes: urban growth resulting in ever increasing demands for water; population growth *per se* producing an ever increasing population pressure on a finite water availability; and desiccation of the landscape leading to drought-like conditions even in high rainfall areas;
- *multi-cause water pollution*, growing out of four different sets of causes: airborne emissions, pollution related to land-based activities, and human waste — which all get caught and carried by the water cycle; and waste water outlets which pollute water bodies. Pollution from all four sources ends up in land systems, water bodies and biological material, and will have detrimental impact on ecosystems and on health;
- *multi-cause land fertility degradation*, growing out from four different sets of causes: salinisation/water logging due to poor irrigation management, effects of acid rain originating from air emissions, reduced water holding capacity due to reduced use of organic fertilisers and removal of organic matter from the soil, and land permeability degradation resulting from mismanagement of land.

The challenge of facilitating development involves, on the one hand, minimising the damage already materialised from poor land and water management in the past; on the other, it involves reducing the threats from those interactions with land and water which are necessary to supply the rapidly growing populations with biomass products and water. The solutions to this formidable task will require *an ability to integrate cross-sectoral issues, since both the causes and the solutions relate to a multitude of social sectors.*

3.2 *Environmental threats*

The environmental challenges and the ongoing misuse have produced a number of serious environmental threats:

- *depletion*, where withdrawal exceeds the natural recharge (for example, depletion of an aquifer by groundwater mining);
- *degradation*, either by deterioration in water quality resulting from bacterial and chemical pollution, which reduces the potential use of water, or by desiccation of the landscape following degradation of land permeability (*cf* the Cherapunji example already described), reducing the soil productivity by shortening the period during which soil moisture is available for crop production, and/or by diminution of the water-holding capacity of the soil as a result of a decrease in the organic matter content of the soil;
- *management deficiencies* through which the depletion and degradation tendencies are not curbed, leading to more rapid loops in the vicious cycle of resource utilisation, low or uncertain output, sustained poverty, etc..

3.3 *A matrix of landscape misuse*

In order to seek the new set of policies needed to cope with the present environmental predicament, and to reach the essential turn-around called for to reduce the massive poverty and to secure livelihood security for millions of poor people all over the dry Third World countries, the origin and consequences of the environmental threats have to be properly analysed.

The origin of the threats might be identified as hydroclimatic restrictions, the waste production that goes with all human activities, and land-use-related livelihood demands. Human behaviour in the landscape is influenced by human needs and societal ambitions on the one hand (Falkenmark & Suprapto, in press), and economic and legislative incentives on the other, in particular what has been described by the World Bank as perverse incentives pushing human behaviour in absurd directions (see Falkenmark, 1991b).

The *particular way of misuse and its material consequences* involves overexploitation of freshwater resources (in particular fossil aquifers) leading to depletion, poor waste handling leading to water quality degradation and inadequate exposure of the land surface to permeability disturbance leading to desiccation of the root zone. The *implications* are unsustainable resource use in terms of unsustainable water supply, threatening social balance generally; reduced usability of freshwater, threatening human health in particular; and shorter vegetation period due to limitations in terms of access to water in the root zone, threatening agricultural production.

The *actions called for* can be summarised by the three words: adapt — avoid — remedy. Phenomena related to the hydroclimate have to be *adapted* to, since nothing can be done with the climate as such. Instead different ways have to be sought to mitigate or compensate the effects from human activities. Overexploitation and pollution on the other hand have to be *avoided*, principally by demand control and better modes of waste handling. Fertility degradation has to be urgently *remedied* by changed agronomic measures in order to secure food supply for the rapidly growing population in the poverty-stricken areas. The full relationships between the various causes, threats, consequences and implications are summarised in the box below.

3.4 *Dual components for sustainable water use*

The environmental threats referred to above have various implications as seen from the user perspective in the sense that they lead to *reduced flexibility in water use in two major respects:*

(a) Water quality deterioration will reduce the *general usability of the water.* Even modest deterioration of water quality will, for instance, restrict household water

MATRIX OF LANDSCAPE MISUSE AND ITS CONSEQUENCES

Origin	Materialised environmental challenge	Way of misuse	Consequence	Implication
hydroclimate	scarcity	over-exploitation	depletion	unsustainable water supply
waste production	pollution	poor waste handling	water quality degradation	reduced usability
land use	fertility degradation	unprotected land surface	desiccation of the root zone	shorter vegetation period

use or will have detrimental effects, primarily on health. Pollution of water sources is severely felt in urban areas. In many of these conglomerations, the contamination is a threat not only to surface waters but also to groundwater sources. Together with the contamination which is added by the consumers themselves, the overall deterioration of water quality is a first rank health problem;

(b) degradation of land permeability and diminished water retention capacity of the soils will result in *reduced duration of periods of the year when enough water is accessible* in the soil or in the ground to secure food production (rain fed or irrigated with shallow groundwater). Another consequence is the dual increase in droughts and floods when the landscape no longer contains the 'brakes' to retard the through flow of heavy rains (Agarwal *et al.*, 1987). The reduction in the period of the year when enough water is available to secure successful crops will limit the options in food and biomass production and is likely to increase crop failures. It is a process which may turn otherwise productive and fertile land into waste land and barren areas. The dualism in environmental degradation is illustrated in Figure 4.

Depletion and degradation as described above represent fundamental threats to livelihood security and environmental care. Type (a) degradation is probably most seriously experienced in the urban context while type (b) is a problem in rural areas. The situation is perhaps most obvious in semi-arid and arid regions. Irrespective of rainfall amounts, however, the options for development and environmental protection are severely curtailed as a consequence of these processes.

4 Efficiency and Productivity — Significant Management Concepts

4.1 Rainwater partitioning

To meet the threats of a reduction of the productivity of the environment better, the dichotomy between land and water must be avoided. Land use, biomass production and terrestrial ecosystems should be discussed with proper attention to rainwater partitioning and its effects on soil moisture and recharge of aquifers and rivers. This is, however, often done following the practice in the temperate zone, where freshwater recharge is large enough to allow such influences to be neglected.

Things are different in the tropics and subtropics, because of the very large evaporative demand of the atmosphere (Falkenmark & Chapman, 1989). In the *dry tropics*, total evapotranspiration consumes the main part of the incoming rainfall, leaving only a limited fraction for recharge of aquifers and rivers (Szesztay, 1979). As a consequence, this recharge is sensitive to vegetation changes, as validated by the Australian experience of rising groundwater as a consequence of clearing the virgin vegetation (Water Authority of Western Australia, 1989), and the South African experience of afforestation as a major water consumer, reducing the mean annual runoff by up to 300 mm per year or more depending on the rotation period and the runoff formation (DWA, 1986).

In the *humid tropics*, interventions in the rain forests involve large changes in the water partitioning, with consequences for the local hydroclimate and for land fertility (Bruijnzeel, 1990). The vertical return flow from the trees is

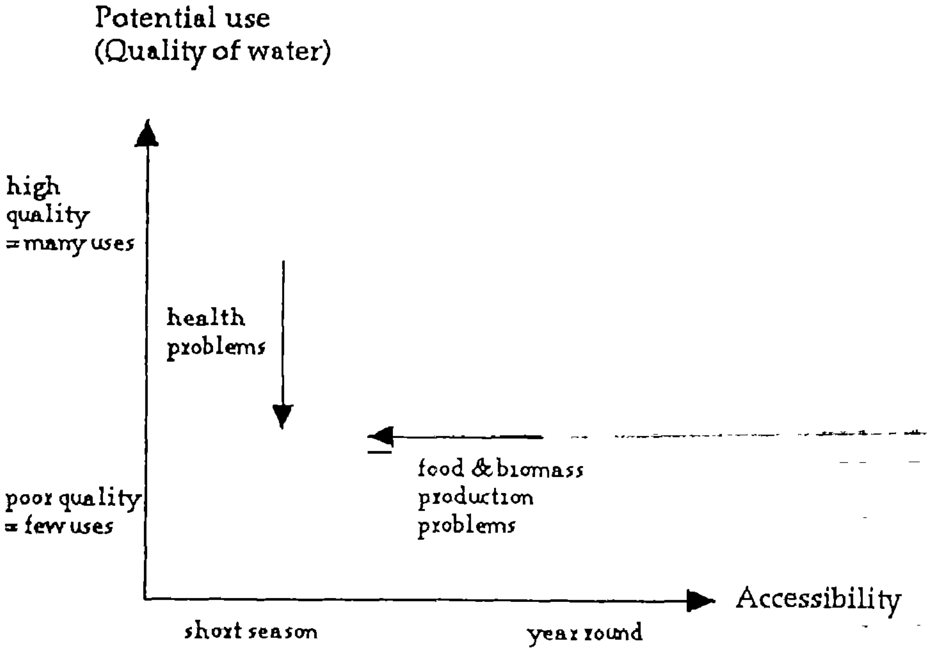

Figure 4 Two dimensions determining the potential use of water resources

an important moisture source for the atmosphere, changes in which may also change the precipitation over regions downwind. Already the conversion of rain forest land to well-managed grassland or annual cropping may produce increases in total water yield of 200-300 mm y^{-1} as a result of the differences in return flow between natural or (mature) man-made forests and most agricultural crops or grassland (Bruijnzeel, 1990, p. 179).

4.2 Two partitioning points cause confusion

The rather confusing debate regarding hydrological effects of afforestation is probably related to the fact that there are two partitioning points in the profile (Figure 5). The upper partitioning point determines the relation between infiltration to the soil as opposed to overland flow and flash flood formation. The idea that afforestation is good for local water balance emerges from this particular process. The lower partitioning point is in the root zone, determining the relation between the uptake by vegetation returning water to the atmosphere as transpiration, and the surplus left for groundwater recharge. The latter process explains the experiences of Australia and South Africa.

In a state-of-the-art report based on 94 catchments worldwide, it was shown that forests will lead to less water in both surface runoff and groundwater recharge than grasslands (Bosch & Hewlett, 1982). Hamilton claims that reports on a diminished dry season flow as a result of tropical deforestation are cases of "misunderstanding, misinterpretation, misinformation and myth" (Hamilton, 1983; 1990). Most probably the inhabitants of the area around Cherapunji would not agree with this standpoint. They would argue that deforestation will indeed lead to diminished dry season flow. Farmers in parts of Tamil Nadu have expressed a similar point of view (Lundqvist *et al.*, 1991) and so have farmers in the Dry Zone of Sri Lanka (Sandell, 1988).

Apart from a fairly widespread belief among farmers in a positive response to water resources availability, including dry season base flow as a result of afforestation, there are also a few scientific documents which support a positive link between afforestation and augmented dry season flow. Gupta (1980) describes a case from semi-arid regions in India and Bruijnzeel (1990) presents a case from Indonesia. In general, the studies of hydrological responses to large scale changes in forest cover have concentrated on the developed humid

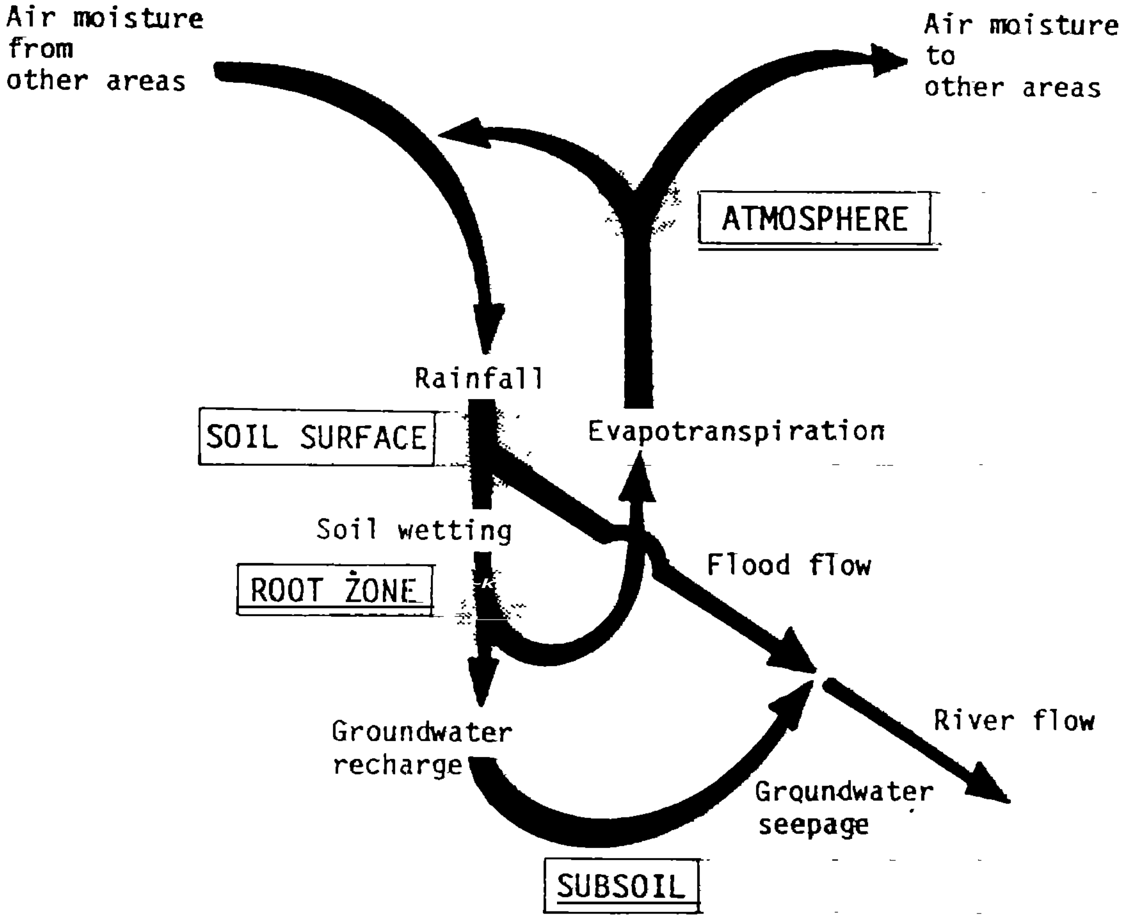

Figure 5 Rainfall partitioning in the zone of contact between soil and vegetation involves dual partitioning points.

and temperate world, while few studies have been carried out on conditions in tropical and subtropical watersheds (Reifsnyder, 1988). There is obviously a need for studies monitoring the effects on hydrological parameters of various types of afforestation project.

There are indications that restoration of degraded vegetation cover can be quite rapid. In a report from Ethiopia, for instance, it is argued that restoration and resource accumulation in the Wollo region were "dramatic"; a turning point "from resource degradation and depletion to restoration and resource accumulation" was reached within a period of four to five years, although the problems of the region were not solved within that period (Bendz & Molin, 1988). Experience from India is similar, especially with regard to the natural vegetation rather than man-made plantations, showing that regeneration can be quite fast (Vohra, 1990; Lundqvist *et al.*, 1991). To what extent, in what direction and how fast restoration of degraded vegetation cover will affect hydrological parameters has unfortunately not been clarified. Obviously the hydrological response from changes in the vegetation will depend upon factors such as species, topography, soil and the area regenerated. In conclusion, whereas it is generally sufficient to discuss water resources management in the humid parts of the temperate zone with reference only to the hydrological water flows, when discussing the tropics and subtropics it is necessary to consider vertical and horizontal water flows, including their interaction with vegetation and land use. *This is a key argument for integrating land and water conservation and management.*

4.3 Efficiency of rains

Increasing demand on finite water resources and escalating costs of supplying water to various uses have led to repeated pleas for more efficient management (Committee on Natural Resources, 1990). The discussions about efficiency are, however, often devoid of a broader water resources perspective. The implications of water availability from land

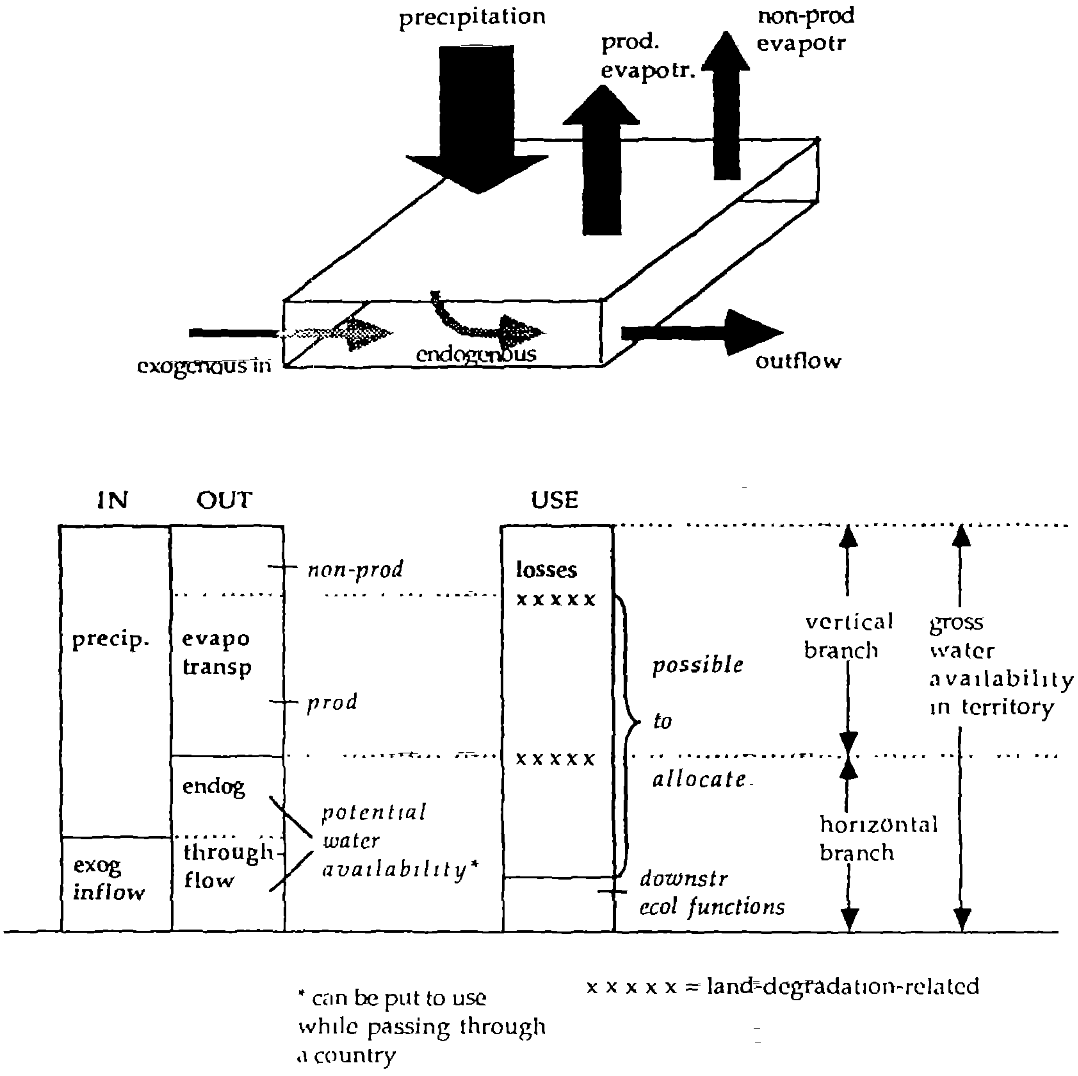

Figure 6 Horizontal and vertical components of the gross water availability in a basin or territory

use and landscape features, and especially the seasonal and quality dimensions discussed above, are not duly considered. To avoid the predominant unidimensional perspective on a fragile and interactive resource, it is appropriate to distinguish between two management aspects: those which augment accessibility and those which increase the benefits generated by allocation of the accessible water.

Efficiency should be seen as the proportion of the potential amount of water available which is made accessible for various purposes. The potential water available in an area during a particular period is the rainfall on that area plus the flow of exogenous water entering the area. Because of its land use, landscape characteristics, climatic conditions and soils, a fraction of the potentially available water will escape purposeful use in the area. The remaining accessible fraction of the total amount expresses the *efficiency in harnessing water from the rains* for various uses (Figure 6). Vegetation is a key component in this respect. It will determine the amount of water that is transpired back to the atmosphere, but it will also affect the rate of infiltration and surface run-off. As well as various landscape engineering or rainwater harvesting measures, such as construction of percolation ponds, check-dams and other gully plugging, contour arrangements or land levelling, vegetation may have a considerable impact on the efficiency of the rains in an area.

Low efficiencies of rain may be closely linked to desiccation of the landscape. Jackson (1989) reports that farmers in various parts of the world complain about reduced precipitation, but what they experience is in fact a reduction in the efficiency of the rains. The significant feature is not a reduction in the accessible amount of water in an absolute sense but rather a shortening of the period of the year during which the water is accessible (*cf* Figure 4). The immediate effect is an increased risk of crop failure. In addition, the desiccation of the landscape will promote erosion and further degradation of soil fertility.

4.4 Variations in productivity through alternative allocations

Apart from the efficiency of the rains, the allocation of the water between different potential uses means that the *productivity of water* varies. The return of each unit of water used, measured in terms of output in tonnes, economic value, employment generation, nutritional value, etc., varies considerably according to how it is allocated between different potential uses. Under the prevailing management practices in the agricultural sector, the productivity, expressed in tonnes per unit of water used, may vary by a factor of between 5 and 10 for various crops (Agarwal *et al.*, 1987; Committee on Natural Resources, 1990).

In general, there are few incentives to increase the productivity of water. In the rural sector water is generally supplied without charge or at a low, nominal or flat rate. Pricing of access to water has met with considerable difficulties in urban areas. Water is conveniently and traditionally seen as a ubiquity or as a gift from God. Attempts to treat it as an economic good, and thus to put a price on it which would mirror the costs involved, have met with practical problems (how to measure and control consumption, treatment of waste water, etc.) and with resistance to accepting it as a resource comparable to land.

By and large, the same problem is experienced in the Third World as in industrialised countries. Widespread cultivation of paddy or other water demanding crops, notably sugar-cane, in irrigation schemes illustrates the lack of incentives to augment production from a scarce resource. Attempts to put a reasonable price on water withdrawal have been thwarted by powerful lobbies in many countries. Electricity for the pumps which lift water is now free in water-scarce Tamil Nadu. A bill which was prepared in the 1970s to regulate the withdrawal of groundwater in the State of Tamil Nadu was never passed by the Indian Parliament (Lundqvist *et al.*, 1991).

4.5 Combining efficiency, productivity and equity concerns

Efficiency as interpreted above refers to management of a landscape in a broad sense. It is closely associated with productivity aspects, since land use will have hydrological as well as socio-economic consequences. Both concepts imply that water should be seen as an economic good. This is, of course, particularly relevant in areas where water is a scarce resource: the arid and semi-arid parts of the world.

These areas are, however, not only water scarce; they are also the areas where a large part of the population are poor and where the environment in which to create a decent livelihood is quite harsh. It is therefore essential that policies intended to increase efficiency and productivity of water resources consider the rights and the plight of the poor and disadvantaged sections of the population. One basis for allocation of water is to guarantee each member of the community a certain share of the water, irrespective of land ownership, whether it is collected in tanks or as groundwater. In Sri Lanka and India, among other countries, there are traditional and more recent allocation principles devised and tried with this intention. Needless to say, the possibility of achieving equal shares at the community level is very much dependent upon convincing the wealthier sections of the community of the advantage of this arrangement. NGOs may have an important rôle to play in this.

5 A Scenario of Urban Bias and Implications for Rural Development

5.1 Resource allocation and inevitable urban growth

The discussions in previous sections have referred to basic rural development challenges in large parts of the dry climate tropics and subtropics. They have focused on the experiences at a watershed level where interactions between water, land use (and thus vegetation) and landscape features are key factors in the design of environmental policies. However, as already mentioned, water management principles are also increasingly needed at the basin scale, which includes the rural-urban dichotomy.

The percentage of the population living in urban areas is increasing at a rapid rate in most countries. The average growth rate of the urban population in Third World countries is about 3.5 per cent, with substantial variation. In some African countries, notably Benin, Kenya, Mozambique and Senegal, the annual growth is as high as 8 per cent or more (HABITAT, 1991). The average growth rate began to fall from a record of 3.7 per cent in 1970-75, to 3.4 per cent in 1985-90 and a projected 2.3 per cent in 2020-25 (McGranahan, 1991). Problems of demographic statistics and proper delineation of urban and rural areas are, however, apparent.

The rapid rates of urbanisation have attracted a great deal of attention recently. The scale of simply implementing safe drinking water to the whole urban population in the Third World involves massive costs and logistic effort. Figure 7 relates the urban populations to be supplied in the next few decades with the achievements during the International Drinking Water Supply and Sanitation Decade. It shows that the effort has to increase by 2 to 2.5 times that of the 1980s. Apart from the well-known urban problems, there is also a positive perception of the role of the urban sector. Arguments are raised about the role of urban centres in the economic development of the entire nation: "Urbanisation and economic growth are mutually reinforcing and are dominant features of national economic development..." (HABITAT, 1991, p. 2). Similar arguments about the role of the urban economy on macroeconomic performance are found in other documents (see, for example, IBRD, 1991).

5.2 *Stakes associated with an urban bias*

If these perceptions are to be followed in future policies, there is an obvious risk that rural development problems and opportunities will be given comparatively less attention. The underlying assertion that urban economic growth will improve overall macroeconomic performance and thus also benefit rural development rests on hidden assumptions. The assertion that urban sector growth can be an 'engine' to macroeconomic growth, including the rural sector, conveniently bypasses the resource situation in large parts of the rural areas.

The current approach for channelling larger shares of resources to urban and industrial sectors obviously makes sense in a narrow economic sense. The costs of bringing water to urban areas are, however, escalating. According to World Bank calculations, the cost per unit (in real terms) of supplying water to urban areas is typically 2 to 3 times as high today as supplies made a few decades ago. With burgeoning populations in cities, the costs may continue to increase — even escalate as new problems are added to old ones — and the administration, operation and maintenance of physical systems will require increased resources (*cf* Figure 7).

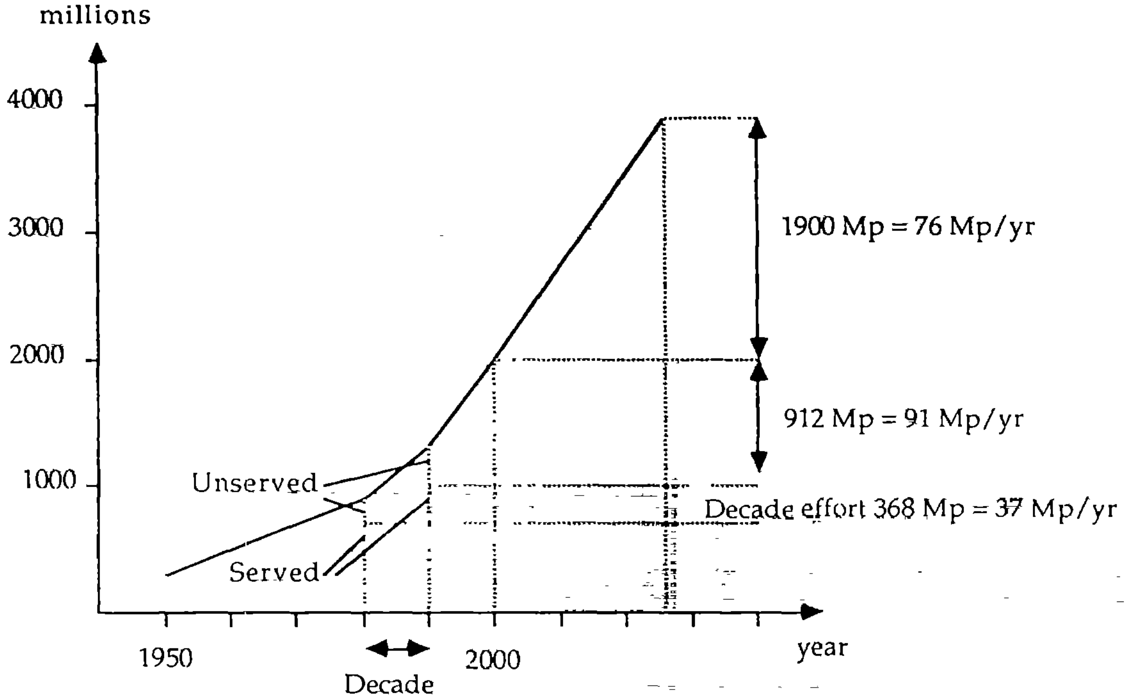

Figure 7 The massive challenge of providing safe water to the growing urban populations in Third World countries, with the achievements during the Decade given as reference (1 Mp = 10^6 people)

However, apart from the changing cost-benefit ratios, there are other stakes associated with this potential shift in policy. A more pertinent question is whether urban development can relieve the pressure on resources in rural areas, let alone 'solve' rural development problems. A related issue is what implications an urban bias in development policy will have on future rates of urbanisation. The UN projections of a reduced rate of urban growth may have to be adjusted once more, but in the opposite direction, if living conditions in rural areas do not improve.

The growth in the urban population is partly the result of a migration of people from rural areas. The rapid natural increase of population in rural areas, in combination with the ongoing depletion and degradation of land and water resources discussed above, will significantly affect living conditions in rural areas for the foreseeable future. Under these circumstances pressure on people to migrate from rural areas will persist.

5.3 New 'privileged solutions'

Whatever the rate of urban growth, the demand for water in urban centres will increase. Since the urban population is close to the representatives of the political and administrative systems, the media and opinion forming groups, they will exert a much more direct influence on water allocation policies than rural people.

In considering the allocation of limited water resources to industrial and other urban uses or to rural sectors, it may be illustrative to recapitulate some features of allocations undertaken in the recent past. A major part of investment in the water sector has gone to irrigation facilities and it is also in this sub-sector that the lion's share of the water is used. The opportunities forgone when using scarce water and investment resources to irrigate crops with a heavy demand for water are noticeable in an economic sense.

Although the public pressure for a review of the policy of water allocation is gaining momentum, the economics of this situation is not new. The tremendous amount of money that has poured into the irrigation sector must be explained through some other circumstance. Big investments have been made in irrigation facilities in Asian countries where the 'green revolution' technology has been comparatively successful. Through the 'green revolution' a remarkable increase in agricultural food production has occurred.

This success story was also a model for an irrigation boom in African countries (Moris & Thom, 1985). In most of the schemes in Africa, and particularly in some West African countries, the cost per unit was substantially higher than for equivalent schemes in Asian countries. At the same time, the performance was much lower than had been expected.

One explanation for the allocation of large sums of money to irrigation systems is to see it as compensation for the earlier allocations to industrial development. Preferential treatment for rural development was meant to compensate for the frustrations resulting from post-independence industrialisation. In this sense irrigation development has been seen as a "privileged solution" (Moris, 1987). Irrigation schemes have been perceived as a contemporary, appropriate solution to the severe problems that Africa has faced in recent decades in that they would remove food deficits, ameliorate the hazards of drought and reduce dependence on imports.

A significant and — in hindsight — quite astonishing implication of giving irrigation development a privileged status is that testing and modification of the technology was not considered necessary. Transfer of technology which performed comparatively well in an Asian context to the African continent has proved to be as problematic and frustrating as were the technology transfers from the humid to the tropical climatic zones.

It is of paramount importance that a shift in policy to favour the urban sectors will not lead to new types of "privileged solution" for other sectors. Today irrigation development does not enjoy the same privileged status (Postel, 1988). Reduction in support for irrigation is also found in industrialised countries. In the Western USA, for instance, the large cities of Phoenix and Tucson have expanded at the expense of irrigated agriculture (Checchio, 1988).

In a situation when rain fed agriculture is expected to supply an increasing share of the food production, it is crucial that appropriate policies are developed to support viable resource management options in that context and that rural areas are not abandoned.

6 Step-wise Analysis of Policies Needed

In order to improve living conditions in areas where part of the year is dry — where plant growth is water-limited rather than energy-limited — it is crucial to put the water brought into an area (by precipitation and exogenous inflow) to the *most productive use, without jeopardising the opportunities of the poor sections of the communities to have access to resources.*

It is essential to find ways to minimise the non-productive losses by evaporation from water surfaces, wet foliage and unvegetated soil, i e. to increase the efficiency of the rains. This can be said to be a *landscape management problem.* On the other hand, the remaining water, whether as soil moisture, groundwater or river water, must be used as productively as possible. Water is a resource common to all and its conservation and proper use should be the concern of people at all levels of society. In this article two main uses have been highlighted: (i) water requirements for development of the rural sector, where food and biomass production are the largest requirements, (ii) the escalating demand and mounting political pressure to supply water for use in other sectors, notably in the urban sector. The latter task is a ***resource** allocation problem.*

Thus the policy has to aim to secure the successful implementation of two main efforts: landscape management and water resources allocation. Issues related to the former include land-use zoning and land conservation to avoid unnecessary and unproductive water losses to the atmosphere and oceans. Issues related to the latter include decisions regarding regional and sectoral goals: the degree of food self-sufficiency, regional balance, environmental protection, etc. Balancing the various requirements will be at the centre of the formulation — or perhaps the lack of formulation — of water and other resources management policies. But unless the acute needs of food and other basic amenities are met, it is unlikely that environmental concerns will be met.

6.1 Coping with the environmental challenges

In order to address the parallel problems of environmental degradation and development retardation, it is essential to realise four different biases of the past:

- the North-South bias which has neglected fundamental hydroclimatic differences and their implications for development;
- the intercontinental bias in attempts to transfer "green revolution" technology from Asia, well-endowed with exogenous water, to Africa with mainly endogenous water;
- the preservation/conservation bias, focusing too much on the protection aspects and neglecting the opportunities of augmenting the productive capacity of the integrated soil/water/vegetation system;
- the urban bias, noticeable in key policy documents paying prime attention to the economic opportunities in cities but neglecting the resource implications of rural areas.

As a basis for water management policies, the following components should be considered: identification and analysis of methods and mechanisms for appropriate allocations (urban/rural; irrigation/urban supply); identification of land-use systems that minimise unproductive water losses and protect land productivity; means to mobilise a larger fraction of the potentially available water in aquifers and rivers by water resource development measures; avoiding or minimising pollution from human and industrial waste and waste water.

6.2 A matrix for policy analysis

What are the key measures to be organised in order to achieve the landscape management and water allocation needed to facilitate development accompanied by conservation of environmental productivity? (No attention will be paid to water pollution policies in this section).

The analysis may be divided into four steps:

- *what to do:* what has to be done, which are the solutions needed and the measures to be taken?
- *how to do it.* how are these measures to be implemented, what activities are involved?
- *how to make it possible:* how can the solutions and activities be made possible? What institutional and legislative measures are to be taken?
- *how to get it done:* how can the desired solutions be secured? What incentives are needed to get people and institutions to move in the desired direction?

In the matrix below, an attempt has been made to illustrate the various steps needed to identify the components of policy formulation and design.

	What to do	**How to do it**	**How to make it possible**	**How to get it done**
Landscape management	Soil & water conservation; regeneration of environment	Mobilisation of communities; extension; other external support; crop & species selection	Review legal & institutional systems; land tenure	Price & other incentives; monitoring & retrieval of projects & programmes; education & training
Resource allocation	Efficient, productive use of water & other resources; guarantee to poor	Water rights; apply basic need concept	Implement legal & administrative decisions; promote NGOs	(same as above)

Looking more closely into the different policy components in the field of *resource management*, the general aim is to minimise loss of water from the watershed, so that the water can be put to as productive use as possible in terms of biomass and social activities. Key measures are therefore revegetation of denuded areas with water efficient vegetation to limit the return flow of water to the atmosphere, and landscape engineering and management to facilitate infiltration, groundwater recharge and local water storage.

Activities needed to implement these measures include community mobilisation and extension services. Institutional support is needed to make the measures possible, primarily in matters of land tenure. The incentives needed to get the measures done would include pricing, marketing arrangements and extension services to secure the new awareness which is necessary for success.

Turning to the field of *allocation for socio-economic objectives*, the methods involve optimising the distribution of water use between urban and rural, biomass production and regular water use. The activities needed to implement this optimisation would include principles for water rights, opportunities to buy and sell water rights, as well as regular rationing. The institutional resources necessary to make these activities possible would primarily involve integrated land/water legislation. Finally, the incentives necessary would include pricing.

6.3 Key questions involved

Evidently, essential questions remain to be addressed in developing the chain of policy implications. A key question is *where the main stress should be put:* on basic support in the rural areas in order to minimise the pressure for urban migration; or on developing the urban systems, since they might emerge as better on the economic calculation sheets, being easier to quantify. But if most resources go into urban development the question is *what will happen to the rural areas in the long term?* The result may be that urban growth will spiral even more rapidly than today, creating insoluble questions of acceptable quality of life for the rural and urban poor. *The poverty issue is deeply involved in these balancing decisions.*

7 Conclusions

The paper has shown that an *extended water management* is needed in order to integrate environmental conservation with development-related efforts. The marginal hydrological conditions in the zone where most of the poverty-stricken countries are located makes it essential to review conventional water management based on the integration of a whole set of water uses, including the water consumed by rain fed agriculture. The reason is that any increase of the amount of water consumed may have significant qualitative and quantitative repercussions on the water accessible in aquifers and rivers for allocation to traditional water uses. In other words, both "vertical" and "horizontal" water uses have to be included.

The "Turn Around Decade" calls for a *holistic approach to both urban and rural areas*. Urban growth should be thought of as composed of an *unavoidable* part and an *avoidable* part. Rural poverty related to environmental degradation drives the avoidable growth through migration, roughly doubling the rate of urban growth. Thus, the past tendency to concentrate development efforts on *either* urban *or* rural areas has to be replaced by a *combined urban/rural planning and management approach*. There is also the fundamental aspect of developing the food production potential and determining the constraints in due time to prepare the global market for major changes in food flows.

Past efforts in the field of environment and development have been burdened by a set of *biases and misconceptions:* the climatic bias has been equivalent to blindness to the specific environmental conditions in the poverty-stricken countries which have to be understood in order to achieve improved quality of life; the intercontinental or South-South bias led to the uncritical transfer of the green revolution — ideas tested with a great deal of success in Asian countries — to areas in Africa where only endogenous water is available; the urban/rural bias involves a preference to satisfy urban water needs rather than those of the rural areas. The result has been that growing cities have started to buy water rights from the surrounding areas to bring water to the city, thereby excluding the potential water use from rural development.

Among agricultural scientists and funding agencies there has also been a bias in dry climates towards the "green revolution" and irrigated agriculture, rather than rain fed agriculture. A similar perception has spread to the environmental experts, who focus on the environmental hazards of rain fed agriculture rather than looking upon it as a basic livelihood condition for a large proportion of the people in Third World countries and as a significant supplier of food and other amenities.

The present scenario of continuous population growth poses one of the most serious threats to a successful strategy in the field of environment and development. The result of all these biases is that an *extremely precarious situation has developed*, with the majority of the poverty-stricken countries now lying in the dry tropics and subtropics. Land degradation has reached serious levels and numerous warnings have been voiced throughout the last decade. It is therefore absolutely essential to get away from these biases by changing policies as fast as possible. *The base of knowledge is good enough to get started, which means that the 1990s could really become a "Turn Around Decade"*.

SOME PERTINENT QUESTIONS

With reference to the *watershed level*, the following issues need to be addressed:

- What are the principal requirements for an integrated management and use of land and water resources so that degradation of the resource base in tropical and subtropical climates can be avoided?
- To what extent is sustainable development based on self-reliant food production at all possible, given the unavoidable population increase in the Third World?
- For how long must a degraded piece of land be left protected after restoration measures have been implemented before it can be used for biomass harvesting?
- Within a watershed, is upstream permanent vegetation (afforestation) feasible which does not jeopardise water availability, on a seasonal basis, for downstream crop production?

With reference to the *regional level* the following questions might be asked:

- How will demographic trends and changes in rural and urban population affect the future demands on water?
- What allocation principles are feasible between the various sectors, including urban and rural sectors?
- How can the principles of increased efficiency and productivity be combined with equity consideration, given the socio-political conditions and long term environmental protection goals?

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9

Water and sustainable development

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EXECUTIVE SUMMARY

1 Social and economic development in developing countries has stayed disappointingly behind expectations. Water-related problems are increasing in scale and intensity and make the outlook grim for a changing trend in the 1990s. Reduced quantities and deteriorating quality of available water result in an immediate reduced access to safe water for human activities as well as long-term environmental degradation. What is really at stake is the potential for sustainable social and economic development. Various UN organisations have renewed their commitment for the 1990s to improve water resources and their utilisation, in particular for low income groups.

2 Problems are not limited to developing countries. In many developed nations new discoveries of environmental degradation surface at an ever increasing rate. The accumulation of synthetic chemicals in groundwater, sediments and biota poses an increasing threat to future developments.

3 Solving these problems — either in developing or in developed countries — is hampered by economic and financial constraints. The problems are also compounded by inadequate and malfunctioning institutions at the national level and insufficient coordination at the international level. 'More of the same' is no longer a solution to these problems: fundamental changes are needed to increase efficiency in the use of available natural, human and financial resources.

4 In this paper integrated management means the management of water resources as an integral part of a nation's social and economic development. Water resources managers should broaden their scope of work. Instead of the traditional 'supply oriented approach' response to ever-increasing demands from different sectors of the economy, water resources management agencies should play a more active role in guiding and stimulating socio-economic development.

5 Demand management is considered an important tool, which should go beyond the improvement of technical efficiencies. It is more important to develop economic and institutional approaches to charge for the full costs of the utilisation and management of water resources. Implementation of such an approach will require more sectoral integration and will have considerable implications for organisations, staffing, institutional arrangements and corresponding capacity building.

6 Concerted actions are required at the international, national and local levels. Demand management and the corresponding institutional changes are high priority actions, which essentially belong to national and/or local responsibilities. The international community plays an important role in the development and implementation of international rules and legislation; research and technology development for more efficient water use; and awareness and promotion. In relation to developing countries, priority actions for donor organisations include: improved coordination, institutional support, education, and capacity building.

CONTENTS

1 Introduction

In 1977, the United Nations Water Conference in Mar del Plata showed a growing awareness and a clear consensus that water is a key element in the development process of many nations. A widely distributed Plan of Action was formulated which focused on improving conditions for low income groups. It initiated the International Drinking Water Supply and Sanitation Decade (IDWSSD) in the 1980s, which formally started in November 1980 through a United Nations General Assembly declaration. Expectations were high that properly managed water resources would greatly enhance social and economic developments in the decade.

Substantial efforts by national and international agencies could not prevent the 1980s, however, from becoming known as the lost decade for development. The problems are all too familiar:

- unchecked population growth;
- limited, or zero, economic growth in many developing countries;
- accelerating urbanisation and uncontrolled growth of mega cities with a lack of basic services, leading to cholera outbreaks, for instance;
- failure of irrigation schemes to meet planned production levels;
- drought and flood catastrophes;
- global environmental problems;
- inefficient institutions;
- mining of scarce natural resources and deteriorating water quality;
- accumulation of toxic materials in groundwater, etc.

The situation at the outset of the 1990s is disappointing for both developing and developed countries, as well as for the community of international organisations. However, many United Nations organisations have renewed their commitments for the 1990s (see Box 1 below).

Although the link between properly managed water resources, economic development and social well-being is widely recognised, policies for sustainable use of water resources have largely failed to materialise. In many countries the quantity and quality of surface and ground water resources are deteriorating. Water resources management policies to date have focused on the development of water resources to satisfy the ever increasing demands for water or water related goods and services, and on the mitigation or reduction of natural disasters such as droughts and floods. In this context, the environment has largely been viewed as a constraint to development. Environmental analysis is usually limited to a study of environmental impacts.

The issues that water resources managers will have to deal with in the 1990s, as outlined in this paper, call for integrated water resources management. Many developed and developing countries have national policies for integrated approaches and efforts are growing to implement these approaches. International organisations strongly support this changing focus. The New Delhi Statement on safe water and sanitation for the 1990s (UNDP, 1990a), for example, refers to integrated water resources management in two of its four 'guiding principles' (see Box 2). The statement first calls for protection of the environment and safeguarding of health through integrated management of water and liquid and solid wastes. The second reference to an integrated approach relates to institutional reforms. Other appeals for integrated water resources management policies can be found in the OECD's recent state of the environment report (OECD, 1991). This report recommends an integration of water quantity and quality management with environmental concerns of economic sectors. The report also considers appropriate pricing of natural resources a key tool for integrated water resources management. Similarly, the Asian Development Bank has adopted the integration of environmental management and natural resources planning

1 COMMITMENTS FOR THE 1990s

In 1987, the Administrative Committee on Coordination / Intersecretariat Group on Water Resources (ACC/ISGWR), the inter-agency coordinating body for the United Nations, recommended that a comprehensive strategy should be developed for action at national, regional and global levels for the implementation of the 1977 Mar del Plata action plan in the decade 1991-2000.

This view was shared by the Committee on Natural Resources (CNR) and the Economic and Social Council (ECOSOC), which in the same year requested the Secretary-General to formulate proposals for such a strategy. In 1989, ECOSOC reiterated the need for a strategy for the 1990s and requested that the strategy be submitted to CNR at its 12th session in 1991

In May of 1989, the Committee on Development Planning (CDP) stressed the importance of water in sustainable development and recommended that UNCED 1992 should include in its agenda a separate item on sustainable development of the use of water resources and take into account the strategy for implementating the Mar del Plata Action Plan in the 1990s to be formulated by CNR.

In 1991, regional assessments of progress and issues concerning key aspects of the Mar del Plata action plan have been completed by UNDTCD, FAO, WHO, UNEP, WMO and UNESCO, including recommendations, strategies and action programmes for the 1990s. They all expressed their commitment to the implementation of the Mar del Plata action plan in the 1990s (e.g. FAO, 1990).

2 SAFE WATER AND SANITATION FOR THE 1990s

The UNDP sponsored conference, "Global consultation on safe water and sanitation for the 1990s", hosted by the Government of India in New Delhi, 10 - 14 September 1990) resulted in "The New Delhi Statement" which made a strong "appeal to all nations for concerted action to obtain two of the most basic human needs — safe drinking water and environmental sanitation. To achieve full coverage by the year 2000 four guiding principles were formulated:

1. Protection of the environment and safeguarding of health through the integrated management of water resources and liquid and solid wastes;
2. Institutional reforms promoting an integrated approach and including changes in procedures, attitudes and behaviour, and the full participation of women at all levels in sector institutions;
3. Community management of services, backed by measures to strengthen local institutions in implementing and sustaining water and sanitation programmes, and
4. Sound financial practices, achieved through better management of existing assets and widespread use of appropriate technology.

and management into concepts of development planning (ADB, 1989). It can be concluded that 'integrated management' has been adopted by various national governments and international organisations, each from their own perspective, as the solution to a host of problems.

Without attempting to produce a definition of the often-used word 'integrated' as it relates to water resources management, integrated management will be assumed to have the following characteristics in this paper:

- Interaction between quantity, quality and biological aspects of both groundwater and surface water.
- Sectoral coordination: water demands and residual generation by different sectors of the economy are considered in relation to the sectoral development and management plans, objectives, and policies. Allocation of water resources should be in correspondence with the social and economic benefits of water utilisation in these sectors.
- Environmental sustainability: full account is made of the relevant on-site and off-site environmental issues, in particular the long-term carrying capacity of natural systems.
- Institutional arrangements: proper attention is paid to the tasks and responsibilities of all public and private agencies involved and to their linking mechanisms.
- Public participation: social and cultural issues are considered, including the role of women and the traditional use of water.
- Implementation aspects, including financing, monitoring and control, play a decisive role in planning for water resources management.
- Capacity building: institutional and human resources development for the execution of management tasks is an important component.

The main question addressed in this paper is:
how can integrated water resources management contribute to socio-economic development?

To answer this question it is important to review the context, or environment, in which water resources management is practised. The problems and issues likely to shape water resources management in the 1990s are reviewed in Section 2. The most important challenges that water resources managers will face can be grouped under the following headings:

- the scarcity of water resources, particularly in large cities;
- environmental degradation;
- economic and financial constraints;
- ineffective institutions.

The second question this paper addresses is: *what can — or should — water resources managers do in response to the new challenges ahead?* In Section 3 an attempt is made to outline some of the critical elements — or directions — for successful water resources management in the 1990s. Some of the elements listed there are not new, but have not been very well integrated into the profession to date, while others represent new directions that need to be further developed. The elements described in Section 3 are grouped under the following headings:

- sustainable development;
- demand management;
- sectoral integration;
- institutional arrangements and capacity building;
- public participation and stakeholder involvement.

The problem that remains is how these suggestions for the alleviation of the problems and issues outlined in Section 2 can be implemented.

Experts feel that the problems concerning the world's fresh and marine water resources are grossly underestimated. Worldwide public opinion and political interest appear concentrated on climatic issues. In 1988, during the VIth World Congress in Ottawa, Canada, the Committee on Water Strategies for the 21st century of the International Water Resources Association concluded that the Brundtland report *Our Common Future* tends to severely underestimate the water-related components of environmental problems and pays no attention at all to the galloping water scarcity now developing in Africa.

Possibly the most important reason why problems related to water resources are likely to increase in the foreseeable future is that there is no single, clear, tangible water problem easily definable such as 'energy shortage' or increase in the concentration of CO_2. The water problem actually consists of a host of diffuse issues that are intricately linked with many, or most, human activities, and that cannot be solved through a single global strategy.

The world's attention is more easily focused on the extinction of exotic species, the disappearing rain forests, famines, or holes in the ozone layer than on the apparently more mundane issues related to the sustainable use and development of water resources. Yet three-quarters of the world's population still do not have access to safe and reliable drinking water and most of the serious environmental problems are water-related.

In this setting it is important to try to answer the question: *how can the international community contribute to the development and implementation of the integrated water resources management concept?* Section 4 focuses on possible priorities for water resources management in the 1990s, both at the national and at the international level. The objective of this section is not to present a blueprint for action, but to generate a discussion on the effectiveness and the feasibility of possible measures.

Even though water resources management is essentially a national affair, there is a need, and scope, for concerted efforts by the international community. In the past the international community has played an important role in issues such as financing, technology development and training.

More recently, global issues — such as sea-level rise and the increase of occurrence of extreme events — have become important for water resources management. These need to be addressed on an international scale. Global issues are defined as problems that affect a large part of the world, and cannot be solved by any one country individually.

In addition, there is another important but less explicit and less clear role of the international community, which relates to the changing roles of national governments in water resources management. The global consultation on safe water and sanitation for the 1990s underlined that "a changing role of government is envisaged: from that of provider to that of promoter and facilitator" (UNDP, 1990a). This would have major and difficult consequences for developing country governments. The international community could play an important role in promoting and implementing corresponding changes. Without prescribing how governments should change, Section 4 includes elements and suggestions in this respect.

2 Changing Contexts: Issues and Problems

In the introduction it was mentioned that water resources management to date has focused on water resources development projects to satisfy the rapidly increasing demands from the various water-using activities, and on the mitigation of natural disasters such as floods and droughts. This is referred to in this paper as the supply-oriented approach.

Water resources management has, in fact, been largely concerned with engineering, that is, with the planning, design, construction and operation of water resources infrastructure. Gradually, over the last twenty years, it has become clear that water resources management needs to broaden its focus. The problems water managers have to deal with include environmental aspects (obviously), social, institutional and legal aspects, problems of integration among different water-using sectors and, increasingly, financing the provision of services in a climate of economic restraint.

In this Section the major issues that water resources managers will have to deal with in the 1990s and beyond are outlined. It poses the challenges that will face the profession but does not provide the answers. Answers — or directions, at least, in which the answers can be found — are presented in the next Section.

2.1 Scarcity of water resources

Water is only useful for human activities if it is available at the right time, in the proper location and if it is of satisfactory quality. If not, water is likely to be a nuisance rather than a resource.

A major part of the education of a water resources professional such as a water resources engineer has been spent on learning how to harness water resources: how to train rivers, build dams, provide water supplies and sanitation facilities, protect against floods, and irrigate and drain the farmer's fields. Until recently, it was generally understood that water is usually available — even in arid countries. The aim of water resources development, therefore, is to make sure that it gets to the user in a timely fashion, in adequate quantity and quality.

Without trying to prove this point, because most water resources professionals can give ample examples, it is suggested here that in many cases all water resources that could be developed have been developed, and more. In many places — just take the mega-cities with their still rapidly growing populations — it is hard to imagine just where the future water resources would have to come from to meet the rising demands. The best dam sites have already been used; groundwater levels have already dropped in the Po valley in Italy, in Sana'a, Yemen, in Mexico City, in Jakarta, in the Ogallala aquifer in the United States, etc.. FAO (1991) in *Agricultural water use* states that worldwide problems of real scarcity are imposing serious limitations to agricultural water use.

Water resources managers, or their successors in the next century, are very likely to encounter a different kind of water resources scarcity: a scarcity that cannot be solved by engineering measures. This scenario is exacerbated by the fact that all indications point in the direction of continued rapid population growth in many countries in the coming decades, and even faster growth of cities.

This water scarcity, which could be called 'the new scarcity' to distinguish it from the old scarcity that could be solved by engineering measures, will require different solutions from the water resources profession, including demand management. Demand management is discussed in detail in the next Section.

Internationally shared water resources

The new scarcity of water resources has also resulted in, and will continue to present, problems in internationally shared river basins. Continued water resources development will likely lead to increased competition, and conflicts, between countries over shared water resources. An example of a situation in which a country depends on others for its water resources is Hungary. Only 4 per cent of the surface water in Hungary originates in the country; the other 96 per cent enters the country as cross-boundary flow. A similar example in Africa is Mozambique. In the south of this country less than two per cent of the total available surface water originates in Mozambique territory (Euroconsult, 1989). Other examples refer to the River Rhine, which is shared by five European countries; the Colorado river, shared by Mexico and the United States; the Ganges, which crosses from India into Bangladesh, and rivers such as the Nile, Euphrates and Jordan.

No international legislation exists on how to establish shares of the benefits of such resources. The Helsinki rules (Helsinki, 1966) provided a useful framework but agreement between states or nations on shared water resources remain basically subject to direct negotiations. There is a strong need for more international guidelines to deal with such shared water resources, which should address water quantity and water quality problems alike. The draft Law of the Non-navigational Uses of International Watercourses, prepared by the International Law Commission, addresses this need (United Nations, 1991a).

2.2 Environmental degradation

The past two decades have shown considerable changes in views on the importance of the environment for economic development. Deterioration of environmental quality is no longer seen as an unavoidable cost of rapid economic growth but as a limitation or constraint for medium and long -erm prospects of sustainable development. The environment is widely recognised as a necessary component of economic development and nowadays development related policies, administrations, organisations and individual projects of national and international agencies invariably pay attention to environmental issues. In the decade between 1972 and 1982 the number of countries which had an environmental ministry or similar grew from 11 to 111 (Baum, 1985, p 523).

The World Bank formally adopted a new lending policy on projects that have damaging environmental side effects and, for example, will not finance investments that result in toxic waste discharge across international borders. In many countries environmental impact statements became a common and accepted prerequisite for different kind of projects and government policies. Other examples are the June 1991 conference on the environment among 41 ministers from developing countries (Beijing, 1991) and the attention the July 1991 Group of 7 meeting (London, 1991) paid to global environmental issues.

The resolution of global problems requires a fundamental policy re-orientation at the national level and cooperation at the international level. At a national level, policy decisions are difficult, for example because of insufficient knowledge of the nature of the relationship between water resources variables and the level and pace of economic activity. At an international level, the question of responsibility for the global problems creates a conflict between developing and developed nations.

The Beijing declaration is very clear on the position of the developing countries. They claim "the sovereign right to use their own natural resources in keeping with their developmental and environmental objectives and priorities" and do not accept that environmental considerations are used to introduce any form of conditionality in aid or development financing, or to impose trade barriers. The developed countries are considered to be responsible for the degradation of the global environment and consequently must take the lead in eliminating the damage to the environment as well as in assisting the developing countries to deal with the problems facing them: "there should be preferential and non-commercial transfer of environmentally sound technologies to the developing countries".

However, as mentioned above, such changes in the approaches and coordination of the developed world do not guarantee more efficient use of water resources in the developing world without substantial reorientation and structural changes on a domestic level.

A major concern for water resources management is that most of the international attention is focused on global problems and much less on universal problems. Global problems refer to problems that affect a large part of the world and cannot be solved by any one country individually. Universal problems consist of small-scale but globally wide-spread phenomena, which can be solved within a nation.

Environmental issues related to water resources encompass a wide range of concerns, including for example: public health, water pollution of surface and groundwater, lowering of groundwater tables, salt water intrusion, reduced sedimentation in flood plains, changes in river hydrographs, reduction of wetland area, increased river bed erosion, and coastal and marine pollution.

Water is usually considered to be a renewable natural resource, but most of the effects of water resources development and use have medium and long-term impacts — often adverse — which affect the future availability and access to water and consequently the conditions for a sustainable development. Mining of water resources should not only refer to the utilisation of aquifers beyond their natural recharge but to any situation where actual use limits the possibilities for future water utilisation. Examples are the accumulation of toxic materials in aquifers and bottom sediments of estuaries and the destruction of wetlands.

In developed countries, considerable efforts over the last decades concentrated on waste water reduction and treatment and on structuring a coordinated environmental management among countries, economic sectors and public and private entities. The success of all these efforts is limited but has started to materialise. For example, the pollution of waterways by organic substances has been substantially reduced and significant pathogenic microbial contamination of drinking water supplies has been virtually eliminated (OECD,1991). Conditions for sustainable development, however, are not improving. New discoveries of environmental degradation — on national and on global scales — appear to surface at an ever increasing rate. These problems change the context for water resources management continually.

Examples of high priority environmental issues include, for example: the build-up of small amounts of highly toxic man-made chemicals, nitrate pollution of water ways, and eutrophication of lakes. In particular the accumulation of synthetic, or man-made, chemicals in groundwater, sediments and biota poses an increasing threat.

These chemicals are often toxic in minute concentrations and extremely persistent. Once discharged, they gradually develop into a long-term irreversible time bomb that is likely to affect many uses in the future. Diffuse sources and large time lags between the start of discharges, first detection of impacts, formulation and implementation of remedial measures, and the effect of such measures, make it very difficult to convince decision makers to take timely action.

In developing countries, integration of environmental issues in water resources management is often only in a starting phase and less information exists on the dimension of the problems and their adverse effects on the potential for sustainable development. Pollution and over-exploitation of groundwater aquifers is widespread and threatens socio-economic development.

Considerable development in techniques for valuing environmental effects in the past decades enable analysts to improve on impact assessment (e.g. NOAA, 1984; Hufschmidt *et al.*, 1983). Reference can be made as well to growing efforts in developing methodologies for environmental resource accounting and in formulating indicators which will enable countries to assess their development, not with respect to its year-by-year economic performance, but in terms of its stock and efficient utilisation of its natural resources for long-term sustainable development.

In summary, most of the above mentioned environmental problems have the following common denominators:

- The trends started some time ago and presently have a momentum of their own which will be difficult to reverse.
- Solutions require international coordination and upgrading of national mechanisms and capabilities to deal with these problems.
- Most problems adversely affect the long-term prospects for sustainable development while for developing countries solutions might affect the short-term economic growth.

2.3 Economic and financial constraints

Water resources managers are in a situation in which the geopolitical and geoeconomic order is changing rapidly. As more and more countries move towards a free-market system, both in the former socialist countries and in the developing world, they would be well advised to ask what the consequences of this shift will be for the use of natural resources.

According to organisations such as the OECD and the World Bank there is an obvious incentive for developing countries to participate actively in the increasing world trade and open up their often protected markets.

This may well result in dramatic consequences for the exploitation and management of their natural resources. In the first place such countries will be tempted to exploit their resources rapidly to finance procurement of modern technologies for domestic developments and/or to solve part of their debt problems. A second, potentially devastating, effect could be that many social and cultural practices, for example in agriculture, continue to disappear at an ever increasing rate, because they are not competitive with modern practices in developed countries. This too can result in further deterioration of the natural systems they are part of, rather than sustainable development.

Both free market and planned economies incorporate failures which lead to inefficient use of natural resources, including water. Not just in planned economies, but in free-market systems as well, the prices of natural resources - including water - often do not represent their real value or scarcity. In free-market systems this may be caused by: (a) what economists call externalities, such as environmental problems, or (b) price distorting policies of the government, for example the Common Agriculture Policy (CAP) of the European Community. In centrally planned systems the pricing of natural resources is often independent from considerations of scarcity or environmental degradation.

In setting or influencing the prices of natural resources such as water, governments usually use a set of criteria which is strongly oriented towards short-term production targets rather than towards the long-term sustainable use of resources. Traditional economic discounting techniques used for evaluation of future time streams of costs and benefits of decisions and projects tend to disregard long-term effects. Long-term — in this context — is essentially anything over a generation or so.

The concern for water resources professionals is that proper criteria and methods are missing to develop and evaluate alternative courses of action with impacts on the long-term sustainable use of water resources. The challenge is to demonstrate to decision makers what the value is of sustainable water resources development — decision makers that are under constant pressure to produce economic development and have to operate under tight financial constraints.

Donor coordination

Government support goes mainly through bilateral and multilateral channels. The call for more and more effective support is increasing as resources become scarcer; the scale of the problems is growing and technological and economic gaps between developed and developing countries are widening. It would appear that the mechanisms employed for development support have not been particularly effective, and innovative new approaches have to be developed.

One example can be found in the evaluation of the results of the International Drinking Water Supply and Sanitation Decade (IDWSSD). Given the results of the Decade, it was estimated that to achieve full coverage by the year 2000 using conventional technologies and approaches would require five times the current level of investments (UNDP, 1990a). Financial and material support, however, from developed countries for countries in Africa, South East Asia and Latin America, is not expected to grow in the coming decade. Economic growth in developing countries appears to have stabilised or be limited, while developments in Eastern Europe and the USSR will compete for the same development funds.

The challenge for donor countries and agencies in the 1990s appears to be to reach an increased level of efficiency in the use of available resources and to develop appropriate institutional arrangements for donor coordination. UNDP (1990a) calls for a reduction in costs of services through increased efficiency and the application of low cost appropriate technology. In an analysis the World Bank states: "The role of the World Bank may require modification. More important than lending for projects or for structural adjustments may be the development of innovative approaches to address international and domestic institutional problems" (World Bank, 1990).

This implies that international organisations are expected to play a more important role in the 1990s. Bilateral aid tends to focus on "more of the same". Most of the bilateral donors do have their own specific objectives, approaches and political targets, which may result in isolated actions and corresponding inefficient use of resources. Real changes, which require better coordination and integration appear to have more chance through international agencies. There are some examples of successful donor coordination, however, such as the preparation of a Flood Action Plan for Bangladesh (see Box 3).

3 DONOR CO-ORDINATION: THE BANGLADESH FLOOD ACTION PLAN

Bangladesh has seen many decades of donor assistance in the water sector by international organisations, bilateral cooperation and NGOs. Until recently, most of these donors followed their own individual objectives and guidelines for assistance. These guidelines were also prone to frequent revision as views on development cooperation changed. This made it difficult for Bangladesh to coordinate the ongoing and planned activities in the water sector. As a result, in spite of decades of international assistance, Bangladesh remains vulnerable to large river floods, such as the ones in 1987 and 1988, and for even more devastating coastal floods, such as the recent cyclone of 1991.

Poor donor coordination, whether in Bangladesh or elsewhere, is the rule rather than the exception. Countries are often not strong enough to refuse aid that is offered, even if a project does not fit well into the recipient's policy. Examples can be found in cases where flood protection for agriculture (financed by one donor) adversely impacts urban flood protection (financed by another), or situations where several donors support projects that jointly over-exploit the available water resources.

There is some good news, however. Since the disastrous floods of 1987 and 1988, the Government of Bangladesh undertook a comprehensive review of its flood policy, leading to a request to the World Bank to co-ordinate a five-year Flood Action Plan (1990-95) in which all interested donors participate and which is used as a framework for further action. The idea was endorsed at the G7 Summit held in Paris in 1989, and the programme is presently in full swing.

The problems to be addressed are immense. One of the most controversial issues is whether the large scale flood protection works are environmentally, socially, financially and economically sound. It is very doubtful whether this issue can be effectively dealt with without an integrated approach to water resources management.

2.4 Malfunctioning institutions

Most water resources studies focus either on projects (usually water resources development projects) or on planning (such as water resources master plans or regional development plans). Rarely do these studies pay explicit attention to institutional issues or institutional reform or to implementation incentives. Implementation incentives are measures that aim to provide incentives to water users to change their water-using behaviour.

UNDTCD (1991) in *Lessons for the 1990s* analysed water management since the adoption of the Mar del Plata action plan and concluded that little has changed since 1977. Common problems remain, such as a dominance of unregulated use of resources; inadequate and inefficient water resources management; failure to retain staff, and inappropriate and inadequate water legislation.

There are strong indications, however, both at the project level and at the overall policy level, that improved performance of the water resources sector will depend on institutional reform — that is, changes in organisations, in laws and regulations, in linking mechanisms between sectoral agencies, etc. — rather than in additional technological improvements or more infrastructure.

This is true for irrigation systems, for instance, (Ahmed & Bamberger, 1989; Cummings *et al.*, 1989) and for water supply and sanitation systems, according to WHO's evaluation of the International Drinking Water and Sanitation Decade (see Box 4). The most important institutional issues are outlined hereafter.

Lack of sectoral integration

Traditionally, the organisation of administrations is such that ministries correspond to sectors of the economy. Their task is to optimise the production in such a sector. Sustainable development and the integrated management of natural and water resources require coordination among such sectors which is often missing or functioning badly.

Decentralisation of government

There is strong pressure in both developed and developing countries to decentralise government management. At lower levels, knowledge and understanding of social and environmental issues is more detailed, while lines of problem identification, decision making and implementation are shorter. Lower levels of government are more organised through general agencies and less compartmentalised. Experience shows that such agencies are better equipped to care for such aspects as social issues, monitoring and control than national government. At the same time, however, aspects such as equity between social groups or regions, national policies on export and import, or central government financing, require the involvement of the national government. Water resources planners and managers should be able to advise governments on the most appropriate level of decentralisation in specific instances.

Privatisation

Another difficult institutional issue is how far government should be in control of the water resources sector. Government involvement is clearly needed to safeguard public interest in water resources management, particularly to compensate market failures. This can relate to, for example: the regulation and control of overexploitation or pollution of resources; the provision of public goods; the management of common property resources; or the provision of a socially required minimum level of water supply to low income groups.

Beyond socially required minimum levels, there is no absolute need for governments to be involved in, for example, the production of water for public supply. Such services could be privatised, as was done recently in the UK, provided

4 THE INTERNATIONAL DRINKING WATER SUPPLY AND SANITATION DECADE

Global water supply during the decade has kept up with population growth but not by a wide margin. According to WHO information (UNDP, 1990a) the number of people remaining to be served was substantially reduced in the rural areas, but the urban unserved grew. Eight key lessons were formulated.

1 Encourage active participation and growing self-reliance to enable people to provide their own services.

2 Governments should concentrate less on direct intervention and more on enabling public and private institutions to deliver services.

3 Improve the understanding of what services people want and are willing to pay for.

4 Appropriate pricing is an important tool to improve sector performance.

5 Technological innovations are essential for coping with sector development problems.

6 Focusing on the role of women can enhance the sustainability of improvements in water supply and sanitation.

7 Establishment of achievable targets and effective monitoring systems are instruments for enhancing efforts.

8 Improve co-ordination through building national and international collaborative networks.

the necessary safeguards to control monopolies are in place. In many other countries some combined form of public and private management has been established. There are indications that privatisation of some of water-related services would result in more efficient use of resources. Water resources professionals will have to be able to analyse the advantages and disadvantages of different levels of privatisation to suit individual countries.

Impacts on stakeholders

Planners have also learnt a costly lesson, that it pays to analyse carefully what the impacts of various water resources plans will be on the various stakeholders. Stakeholders, that is, everybody with a stake in water resources management, from water users and water managers to politicians, have to be involved in planning and management. This goes both ways: planners need to involve decision makers in the development of plans, just as much as they need to ensure public participation. Water resources planners of the future will need to be able to carry out social impact analyses as well as economic analyses. The emergence of the role of women in development projects as an important issue for planning and management can serve as a case in point.

3 Integrated Water Resources Management for Sustainable Development

The connotation of the word 'integrated' in relation to water resources management has evolved slowly, representing the broadening scope of water resources management in the past. In relation to sustainable development, the meaning of the word 'integrated' clearly goes beyond such traditional concepts as the coordination among water management agencies, the interaction between groundwater and surface water, or a planning approach which considers all possible strategies and impacts. Section 1 presents a first overview of the main characteristics of integrated water resources management, viewed as an instrument for sustainable development. Integrated management in this sense refers to the fact that water resources should be managed as an integral part of a nation's social and economic development.

This differs substantially from a traditional approach where water resources management has been supply oriented in pursuit of ever increasing growth scenarios, with efforts mainly focused on providing the proper conditions for socio-economic development aimed at removing water shortages before they occur. According to *our* concept of integrated management, water resources managers could play a more active role in stimulating and guiding sustainable socio-economic development through concerted actions towards both supply and demand.

The main concept of this approach is represented schematically in Figure 1. Definitions of water resources system, management and planning are included in a text box in this section. The horizontal axis in Figure 1 represents the interaction between the water resources system and its users: the system supplying water and conditioning water resources in response to demand from water users. The axis provides the management 'spindle' which is controlled through supply and demand oriented management measures. Broadly speaking the 'kernel' shows the input-output features of the water resources system and the water users, and relates these to environment and the social and economic conditions of the society.

The environment includes the natural environment and the man-made infrastructures, while the social and economic conditions refer to the population, their economic activities, cultural heritage and political and administrative structure. Relations are two-directional: outgoing arrows from the water resources system and users represent 'impacts on and contributions to'; ingoing arrows mainly refer to 'conditions for'. The 'state' of the environment and social and economic development provide triggers for water resources management actions.

Apart from the 'supply arrow', outgoing arrows from the water resources system refer to the direct and indirect effects on the social economic development and the environment. Examples of such effects are: the scouring in river beds and the forced migration of people due to the construction of reservoirs; and the lowering of groundwater tables and corresponding salinity intrusion which causes a reduced availability of groundwater for public water supply in coastal zones.

Management and demand are considered to be inputs to the water resources system. Other ingoing arrows refer to the conditions set by the environment and the social and economic development to the performance of the water resources system proper. Examples here refer to the natural water availability, the existing physical infrastructure, and to the institutional and human resources involved in management of the water resources system.

Similar relations exist between the water users and the environment or social and economic development conditions. Relations with the environment refer, for example, to the generation of residuals and constraints related to the availability of natural resources. Agriculture-related examples of relations with social and economic development are: the production of food and the social and cultural characteristics of agricultural practices.

Of course all these considerations are not new, and considerable effort has been dedicated to all aspects and relations mentioned above. FAO, for example, gave explicit and extensive attention to water demand and institutional issues in the beginning of the 1970s (FAO, 1972a, b and c).

The focus was, however, mainly on the technical aspects. In other situations with emphasis on exploitation of resources to provide socio-economic development, the environment is, at best, taken as a constraint. Approaches where the emphasis lies on the sustainability of the system, and where

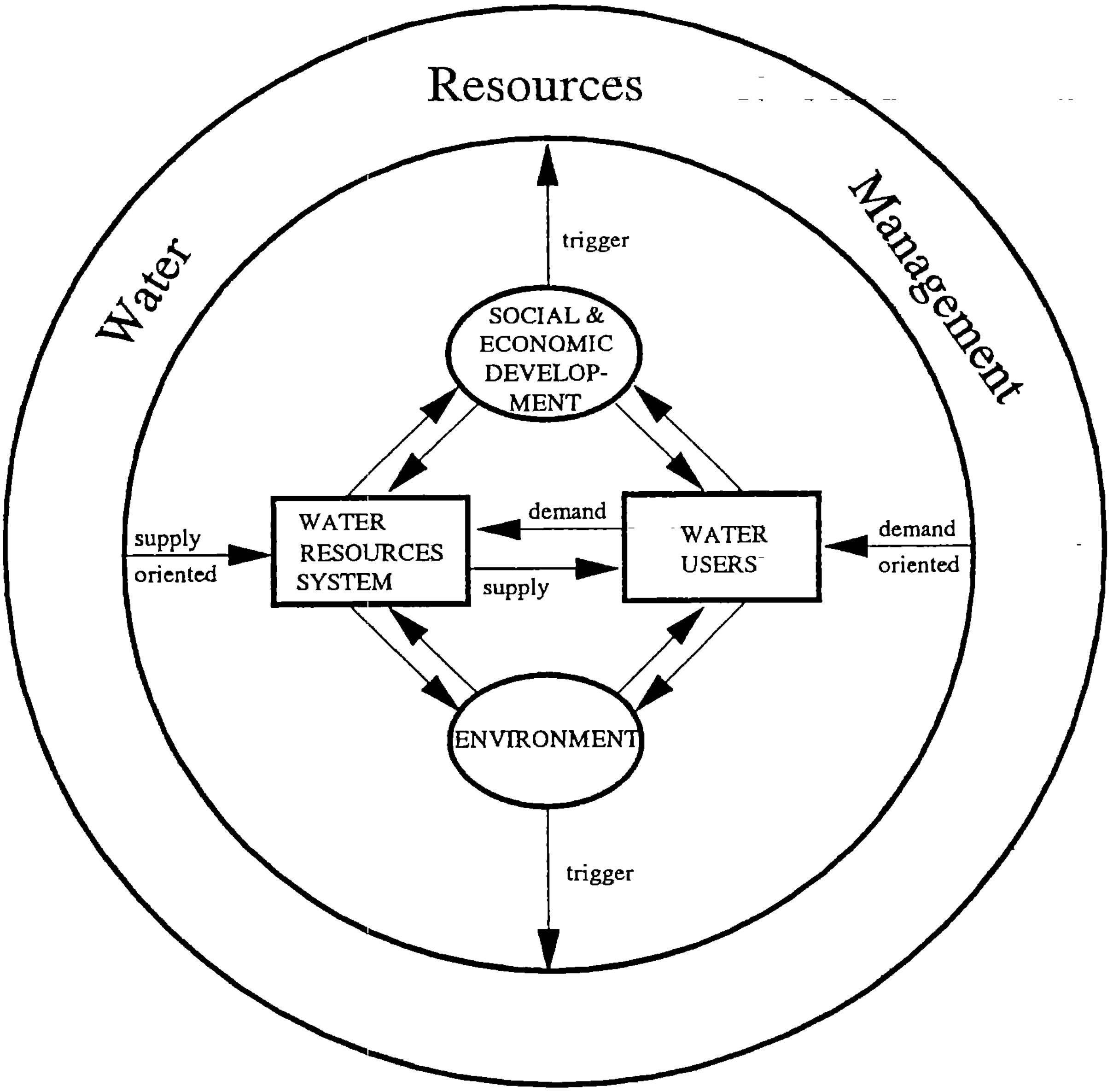

Figure 1 Schematic representation of integrated water resources management

the interaction between the sub-systems is determined by the carrying capacity of the socio-economic development and the environment, are favoured by conservationists.

It must be emphasised that the concept of integrated water resources management which is presented here in relation to sustainable development goes beyond these technicalities and the mere identification and consideration of all these individual relations. Water resources management which really focuses on sustainable development would substantially broaden the scope of work of the water resources manager and would place him in a different position than in the past: a new role in interaction with other sectors of the economy and with considerable implications for management activities, which should be reflected in organisations and staffing.

It should be recognised, for example, that providing more water is not always the best solution and that measures to increase the efficiency of water utilisation, or to improve the operation of water resources agencies, should be considered as realistic alternatives. Demand management will become an important factor in the management of scarce resources.

In setting priorities, where to improve access to water of good quality, and for whose benefit, water resources management is an important means of regional planning and an important tool in socio-economic development and its related aspects of equity.

The development of water resources management in the Netherlands, for instance, can serve as an illustration of the gradual shift in focus from flood protection exclusively, to sustained use of water resources (see Box 5).

5 WATER RESOURCES MANAGEMENT IN THE NETHERLANDS

In the Netherlands water plays an important, if not dominating, role in the social and economic structure and development of the country. An old and efficient water resources management tradition exists in protecting the lower part of the country against flooding from the North Sea and the Rhine and Meuse rivers. In the last decades the scope of water resources management has been drastically changed as modern problems emerged, related to the rapid deterioration of the environment in general and water in particular. For The Netherlands these problems have considerable international dimensions, as a great deal of the contamination is imported through three European rivers: the Rhine, Meuse and Scheldt.

Water management structures and planning efforts have been adapted through the centuries — and in particular in the last decades — to cope with environmental problems. The following four stages are illustrative for this process of change (RWS, 1989):

- The first period, which started in early mediæval times, focused exclusively on ***protection against floods.*** Local water boards were created which became more and more powerful as population and economic assets to be protected increased over the centuries.

- During the second period, which started in late medieval times, ***conditioning of the soil*** through controlled water supply and drainage became economically attractive and technically feasible. Gradually, the existing infrastructure of canals and regulated rivers, which dominates The Netherlands, took shape, mainly for agricultural purposes. The network thus created also provided an important backbone for the commercial development of the country. As the scale and scope of water resources management increased beyond the possibilities and responsibilities of the local water boards, provincial and national government water management agencies emerged.

- In the third period, which started after the second world war, exploding industrialisation and agricultural developments resulted in an ***unprecedented contamination of waters and soils.*** Far reaching institutional arrangements completely changed the structure and functioning of water resources management in the Netherlands. New agencies (and changing the tasks of existing ones), new legislation and regulations, international co-ordination, and considerable investments in treatment facilities, all concentrated mainly on improving water quality.

- The fourth period started in the middle of the 1980s when ***multifunctional and sustainable utilisation of water resources systems*** was formulated as the main objective for water resources management. Triggers for this development were twofold: first, experience with the Dutch Delta Works showed that through active management the potential for utilisation of water resources systems by human and economic activities can be considerably increased; and second, water quality and environmental problems shifted from short-term quality to long-term accumulation problems (sediments in estuaries and the North Sea and groundwater aquifers). Such long-term problems can not be solved any more through (relatively) quick cleaning operations. Current approaches focus on all kinds of institutional arrangements with an increasing emphasis on: (a) co-ordination among sectors; and (b) demand management. Progress is extremely slow, in particular as other environmental problems such as air and soil contamination and the growing concern and involvement in global environmental problems require increased attention from government agencies

In the following paragraphs, special attention will be given to those aspects of integrated water resources management that are not yet widely applied and which are considered essential for the integrated approach. These are:

- Sustainable development,
- Demand management,
- Sectoral integration,
- Public participation,
- Capacity building.

3.1 Sustainable development

Since the presentation of the Brundtland Report *Our Common Future*, (UNEP, 1987), the concept of sustainable development, although not entirely new, has become widely recognised as the most promising approach to developing our resources without depriving future generations of their opportunities to enjoy the earth's natural resources and its environment.

The Report has had a considerable impact on the thinking of a great many individuals who had always been quite negative about environmental assessments and the value of nature conservation. Over the last few years an environmental revolution has taken place in several international organisations. The World Bank, for instance, which not so long ago supported projects that were often quite damaging to the environment, has set up an environmental department

6 DEFINITIONS

The **WATER RESOURCES SYSTEM** is considered an input output system, which includes all elements to produce water and related goods and services to meet final and derived demand from society Such systems essentially consist of the following four components: (i) the total of water and its physical, chemical and biological constituents, (ii) the natural subsystem, including rivers, lakes, vegetation and soils, (iii) the man-made infrastructure such as canals, diversion weirs, dams and water treatment plants; and (iv) the administrative subsystem including the existing legislation and regulations as well as the institutional framework consisting of agencies and their linking mechanisms.

WATER RESOURCES MANAGEMENT comprises the totality of tasks required to produce water and water related goods and services. Such tasks include planning and analysis, research, monitoring, direct production of water, provision of information, issuing regulations and standards and assessment of available resources. Typically, WRM is executed through a variety of public and private entities. The ultimate objective of water resources management is optimal socio-economic development and maximisation of societal wellbeing. This implies that WRM belongs to the responsibilities of governments. It is emphasised that WRM objectives include long-term considerations related to sustainable development.

The general **OBJECTIVE** of Water Resources Management is to develop and utilise water resources in an efficient, environmentally sound, economically sustainable and equitable manner to satisfy the demand of society for water and water-related goods and services.

PLANNING FOR WRM refers to the formulation, analysis and presentation of strategies for WRM, consisting of the following components:

I ***Supply oriented physical measures***, which refer to water resources infrastructure and corresponding operating rules to change time, location and quality characteristics of supplied water and to handle, modify and dispose wastes.

II ***Demand oriented implementation incentives***, which aim to induce water users to a desired behaviour through a set of economic and regulatory measures such as: charges, taxes, permits and zoning.

III ***Institutional arrangements*** to implement I and II, specifying responsibilities and tasks of executing agencies and the modes of interaction between such agencies and the private sector.

to define criteria for the Bank's lending that will promote environmentally-sound development.

The real value of the concept of sustainable development is that it emphasises that the potential, or carrying capacity, of resources should be examined first, rather than just planning and minimising the adverse environmental impacts later. This is a type of bottom-up approach that starts with the productive capacity of the natural environment, rather than a top-down approach in which the environment is looked at as a constraint to development. When seen this way, the concept of sustainable development is also a valuable tool for water resources planners and managers to deal with the real scarcity of water resources that can be expected in the future.

An approach as set out in Figure 1 could be a good working model for sustainable development. In this approach, the management of water resources is stimulated through triggers stemming from the environment and society's socio-economic well-being, acting through both supply- and demand-oriented actions directed at a system that has found a balance between impacts and carrying capacity. The danger of imbalance, however, remains ever present. In times of economic recession, people and politicians are inclined to attribute more weight to socio-economic development and accept that future generations pay the bill. The scheme of Figure 1 needs constant support of organisations that are not influenced by political and economic instabilities, such as international organisations.

3.2 Demand management

The concept of water as an economic resource has long been promoted but is far from universally shared. In many countries and cultures, water is still considered a free good which should be provided at low costs in the amounts and qualities desired. WHO (1991) on 'Water quality' rightly states in its strategy for the 1990s: the perception of water as a freely available public good must be abandoned altogether and its limited supply and competitive economic value fully recognised. Demand management, on the other hand, entails the formulation and application of implementation incentives to limit demand and increase efficiency. It should be considered as one of the most important components of integrated water resources management strategies (the others being physical measures and institutional arrangements). Implementation incentives can be grouped in two main categories.

- Economic instruments, which include: charges; subsidies; taxes; and regulations which create markets where water and emission rights are traded (see Box 6).
- Legal instruments, including for example general quota or individual licences for extraction or discharges, and ambient water quality standards. Such regulations are often combined with financial enforcement incentives such as fines and penalties.

Traditionally, for demand management, government agencies have merely used legal instruments, applying a command and control approach: direct regulations coupled with systems of monitoring and sanctioning of non-compliance.

The general principles of economic instruments and their importance for integrated management, however, have been widely studied and accepted as potentially powerful tools. Discussions about their use in practice started about 25 years ago, but there appears to be a general reluctance (or lack of political will) to implement these instruments. OECD (1987, 1989 a, b, c) summarise the experience in OECD countries:

- Licences - legal instruments - are common, including licence fees to generate revenues to pay for water control and supply works. Charges over and above such licence fees, to account for the value or scarcity of the resources, are less common. The main reason for the application of charges is revenue for the treasury.
- Economic incentives are only used in combination with direct regulations, but economic efficiency is seldom a stated goal of economic instruments (emission trading rights form an exception).
- The charges that are implemented in many countries (including France, Germany, Italy) are far below the desirable level from an economic efficiency point of view. Where effluent charges have been closer to such an economic efficiency level, the effect has been a substantial reduction in industrial water use and discharges.
- There is a general reluctance to implement economic instruments. One important bottleneck is the administrative effort that is required initially. The change from a situation where only few polluters pay negligible amounts to one in which more firms pay much higher rates, will only be acceptable when this is seen to be necessary and justified.
- The most effective charges appear to be effluent and user charges which are directly related to the quantities of water used. Metering is essential.
- Tax differentiation appears to be another effective instrument. It invites comparison of alternatives by the consumers and is often administratively simple because it uses existing tax systems.
- Subsidies are mainly used in practice to compensate for adverse effects of direct regulations and not as economic incentives to promote more environmentally-friendly behaviour.
- Emission trading has been widely applied from the point of view of economic efficiency. It implies a shift in decision-making responsibility from authorities to individual activities (industries, treatment plants).

7 INSTRUMENTS FOR IMPLEMENTATION INCENTIVES

CHARGES may be considered as a price to pay for the utilisation of water resources (intake and discharge of residuals). The incentive effects depend on the total costs in relation to the production costs of the activity involved. Charges are used for both financing and regulation.

- ***User charges*** are paid for utilisation of water or the use of public facilities such as treatment plants, based on volumes or hectares of land.
- ***Effluent charges*** are paid on discharges into the environment.
- ***Product charges/tax differentiation*** are applied on final products or some product characteristic (sulphur content in mineral oil, sugar in alcohol).
- ***Administrative charges*** such as control and licensing fees are payment for government services.

SUBSIDIES refer to financial assistance, such as: grants, soft loans; and tax allowances and exemptions. Examples are accelerated depreciation or tax exemptions if certain measures are taken Tax differentiation works through product prices.

MARKET CREATION refers to the creation of a market where water and/or emission rights or products and residuals can be traded.

- ***Emission or water rights*** is a trading alternative to effluent and user charges respectively.
- ***Market intervention***, for example subsidies in case market prices fall below certain minimum, are important in agriculture and can have a considerable impact on water consumption.
- ***Liability insurance*** establishes. (i) liabilities for environmental damage; and (ii) a market in which risks of damage penalties are transferred to insurance companies, which might calculate lower premiums when industrial processes are more secure.

FINANCIAL ENFORCEMENT INCENTIVES are closely related to legal instruments, but with financial implications for compliance or non-compliance.

- ***Non-compliance fees*** are imposed after non-compliance, for example, related to profits made during non-compliance.
- ***Performance bonds*** for example refer to a refund after compliance

Substantial cost savings have been recorded, but the administrative burden on the government is high.

It can be concluded that there is a growing understanding that the application of demand-oriented measures will be crucial for future water resources management.

3.3 Sectoral integration

Most water uses, such as public water supply, agriculture, navigation, recreation and mining, represent different sectors of the economy, managed through corresponding responsible ministries and agencies. Such entities have their own production-oriented objectives, such as total volumes of potable water, food, transported goods, recreational facilities and mined products.

National, regional or sectoral development plans generally assume that water is available at low costs or even free: costs of access to water do not often play an important role in sectoral investment and operational decisions. Consequently, little attention is paid to an efficient use of water, or — more generally — to an efficient use of natural resources. Cross-sectoral planning efforts such as water resources and land use planning, which aim explicitly at development for society as a whole, attempt to fill this gap. Implementation of cross-sectoral plans, however, still depends on sectoral agencies.

Dramatic examples are groundwater developments in countries of the Middle East and in coastal plains of such countries as the Philippines, Thailand and Taiwan, which mainly result from uncontrolled or unrestrained agricultural and urban growth policies. In Yemen, for example, recent change to a more open market economy makes traditional agriculture on the steep western slopes of the central highland economically inefficient, which causes the migration of population in search of jobs in urban centres and abroad. Lack of a proper agricultural policy now results in a rapid decline of a centuries old agricultural system based on water harvesting through terraces, which play such an important role in soil and water conservation and water supply to groundwater aquifers.

In summary, there are two main reasons to strengthen the coordination of water resources management with other sectors of the economy.

i Water managers should be able to assess, and charge for, the full costs of water resources management involved in sectoral and overall economic development plans. If the ability to pay is low, subsidies could be applied, but preferably not through reduced prices for water services.

ii Agencies in charge of, or responsible for, individual economic sectors should be instrumental in the implementation of integrated water resources management plans.

In most countries, the political will to increase the coordination among sectors in the above sense is low, though generally some kind of structure for coordination exists. What is lacking in most situations is the capacity for implementation; most of these coordinating bodies produce (master) plans, which end up gathering dust on shelves. Important decisions on, for example, who pays how much for water, are taken elsewhere.

Still, an important impact of all coordination exercises, even if they are not successful, may well be a considerably increased understanding by technical officers of the need for and issues of improved coordination. Improved data and planning techniques may eventually result in a situation where integrated management might become a more and more technical affair.

3.4 Institutional arrangements and capacity building

Institutional arrangements, defined in the second text box of this chapter, refer to tasks and responsibilities of agencies on different levels of government, the corresponding linking mechanisms between them, and the laws, standards and regulations that form the institutional framework in which these agencies work.

Proper institutional arrangements are important for all tasks of water resources management. This includes planning and analysis, monitoring, construction and implementation. As mentioned, ministries in both developed and developing countries traditionally focus on productive growth of the economic sectors they represent. Utilisation of natural resources for sustainable development is not an issue that fits into that structure. Environmentally sustainable development requires coordinated decision making on planning and implementation issues, which in many countries is missing or not working.

To create an institutional arrangement in which coordinated decision making can be implemented, three possible linking mechanisms can be envisaged.

i A single entity which has overall supervisory responsibilities. This does not mean that the entity could undertake all water management tasks itself; many of the tasks of 'integrated' management can be delegated to other entities, but these would be hierarchically subordinate to a supervisory agency. In theory, a water management authority could be created in this model, but it would have to take over power from many other agencies, and it would therefore be quite unpopular with the sectoral agencies.

ii Where no agency with overall supervisory responsibility for water management exists, one of the many agencies involved could be given the responsibility for heading a joint task force, working group, or coordinating committee on a continuous basis. Such a task force could be comprised of representatives of the various sectoral government agencies, as well as representatives of local and provincial government. This is the model followed in the Netherlands for the development of management plans for the Eastern Scheldt, Western Scheldt, Krammer-Volkerak, and Haringvliet-Hollandsch Diep-Biesbosch areas.

iii Another type of linking mechanism is represented by the Delaware River Basin Commission (DRBC) in the USA.

This is an interstate-federal agency which combines the powers of the states with the powers of the federal government. The legislation establishing DRBC gave it broad powers, both supervisory and operational. DRBC has the specific responsibility for integrated planning. This is accomplished by developing and maintaining a comprehensive plan, and by reviewing all activities proposed by other agencies which could significantly affect the water resources of the basin. DRBC has authority to veto any proposal which it considers to have adverse impacts on water resource management in the basin.

Two comments merit emphasis:

i One of the most difficult problems with respect to the implementation of water resources management plans involves integrating land use plans by local governmental agencies with water resources management plans. As long as land use planning is the responsibility of the local government agencies, implementation of some of the necessary measures to achieve the desired outputs from water resources will not be possible.

ii The extent to which integrated analysis can be achieved is to a large extent dependent on the training and interest of the individuals who are doing the analysis, and the context in which the planning is done. The evolution of planning in the US Corps of Engineers is illustrative. For several decades following the passage of the Flood Control Act of 1936, the planning by the Corps included consideration only of physical structures for reducing flood damage, for improving water quality, and for provision of public water supply. No 'non-structural' measures, including 'demand management' measures, were considered. Only after many years, substantial external pressure, rejection of Corps proposals which excluded consideration of such alternatives, and the addition of personnel with broader training and backgrounds in other disciplines, did the planning by the Corps include a much wider range of possible options.

Capacity building

An important aspect of institutional arrangements is to create the capacity to implement effectively integrated water resources management. The capacity building effort refers to the financial, administrative and technical capabilities of the institutions involved and a favourable policy environment.

WMO and UNESCO (1991) state that an important aspect of capacity building is the ability of a water authority to collect, analyse and elaborate information on water resources. This should include environmental and socio-economic information which is essential for integrated water resources management.

One important aspect of capacity building is the supply of human resources. There is an urgent need for adequately trained professionals who can work in the multi-sectoral environment of integrated water resources management. In addition to the understanding of the technical disciplines related to the various water users, the future water resources manager should be knowledgable about economics, ecology, and legal and social analysis in a far more dense and complex society. Here lies an important task for universities and educational institutes to prepare the next generation of professionals for the immense tasks that they are facing. Tasks that are far more complex than we can envisage today. One of the problems is that the teachers who have to educate the future generation make use of experiences gained in a less complex world. In addition, trained professionals should be able to work in an enabling environment with good career opportunities and incentive structures. If that is not taken care of, a costly brain-drain will follow.

In this paper the issue of capacity building is only addressed briefly. At the UNDP symposium on Capacity Building held in Delft, in April 1991, this issue has been addressed at length. Here it suffices to state that capacity building is an integral part of integrated water resources management.

3.5 *Public participation and stakeholder involvement*

Stakeholders can be defined as people, organisations or institutions that have a direct interest in the water resources system. Some stakeholders are water users, others are politicians, influential persons, pressure groups, research institutes, etc. In planning water resources development, the involvement of stakeholders can be essential to make the plan work. The involvement of stakeholders is a prerequisite for commitment. A distinction can be made between formal and informal stakeholders. Often the influence exerted by informal stakeholders, although opaque, may be very important.

Water users, probably the most important group of stakeholders, play a dual role in water resources management: on the one hand they are the ultimate beneficiaries of the water made available, but on the other hand they are the ultimate water managers, whose behaviour in terms of water use and waste generation has a decisive influence on the state of the water resources system as a whole.

Changes in the availability of water may considerably alter relations in local communities or families. For example: water resources projects often affect the value of land. This can start off uncontrolled social processes which bring project benefits to non-target groups. The introduction of groundwater pumps at low costs to farmers, for instance, decreased in many countries the value of surface water. In countries where women are responsible for getting water and farming the home plot, reduction of walking distances often resulted in an increased productivity in agriculture, family income and family hygiene. Declining water tables of aquifers and corresponding increased pumping costs forced lower income farmers to sell their land to large land owners.

The position of stakeholders and related social issues are crucial in integrated water resources management. Planning that does not pay sufficient attention to these issues has little chance to be successfully implemented. There is a great deal of truth in the saying that planning requires both strong planning mechanisms on a national level and a strong social structure on a local level. A desired behaviour of stakeholders can be stimulated through proper economic incentives and regulations, but it can never be completely enforced by government agencies and always will depend on cooperation and commitment.

Both an improved understanding of the role water plays for the identified stakeholders, and their effective participation, are essential for demand management and could substantially contribute to the acceptability of the adverse effects of the project, the formulation of alternative or additional measures, and a justified distribution of costs and benefits in relation to both willingness and ability to pay.

Social impact assessment and public participation efforts are widely practised for many projects in developed and developing countries. For example, in the USA they are required for virtually every federal water resources project. Many techniques have been developed in the past decades for both the planning and the implementation phase. Examples are Social Impact Matrices (SAM) and public hearings. SAM represent extensions to economic input-output models in horizontal and vertical directions, presenting an indication of how costs and benefits of economic developments are distributed over households of different income categories, different kind of firms and governments agencies.

Many water resources projects in the recent past, however, still show a considerable lack of public participation or consideration of social issues. Many river basin projects, for example, concentrate on dam construction and the direct benefits of a regulated river flow. As a result, productive land may be lost, population may have to be resettled and riverine production systems downstream, including flood water agriculture, and fishing, may be seriously damaged. Examples are the Kariba Dam on the Zambezi river, Lake Kanji in Nigeria, Keban Dam in Turkey, and the Ubolratana Dam in Thailand (Scudder, 1989; El-Hinnawi *et al.*). Other examples relate to Bangladesh, where polder construction has generated unequal benefits between farmers and fishermen, or among different farmers. Fights and destruction of dikes have occurred on numerous occasions.

Fortunately, the news is not altogether bad. In many areas the awareness of the importance of public participation and the use of local knowledge is growing. In Bangladesh considerable efforts are made for local participation in flood control and drainage projects. In Nepal, in the Terai, recent studies of flood protection and irrigation make ample use of local knowledge and techniques, while introducing new technologies in close cooperation with the local farmers organisations. The responsibility for implementation, operation and maintenance of such systems lies principally with the local authorities and farmers organisations.

4 Priorities for Action

Concerted actions are required at international, national as well as at local levels. Essentially, water resources management is a national responsibility. A sustainable use of natural resources that is economically efficient as well as equitable, implies that decisions need to be taken to allocate financial as well as natural resources among competing users or groups of users, decisions that will affect the availability of the resources for future generations. Such decisions are typically the mandate of national governments. Consequently, a strong organisation at the national level, including experienced and trained staff, and operational linking mechanisms between all agencies involved, are prerequisites for adequate water resources management.

The institutional structure at the national level should be complemented and supported through institutions at the local level. This refers, for example, to village communities, irrigation associations, and water boards. Socially desirable use levels for the various uses can be stimulated through management actions, but cannot be enforced without the understanding and participation of the water users.

The relation between national and global issues is relatively new; water resources managers increasingly find themselves confronted with global environmental phenomena beyond their control, such as extreme weather events, sea level rise and cross border impacts of water use and waste water emission.

4.1 Priorities for water resources management

Integrated water resources management, as discussed in Section 3, may contribute to an enhanced role for water resources in socio-economic development in both developed and developing countries. Such development will need to be sustainable from an environmental as well as a social point of view. Proposed priorities — or promising new directions — to improve the development and use of the water resources system are formulated below. Accurate, reliable, and well managed data and information should be considered a prerequisite for successful water resources management.

Demand management, based on the principle that water is not a free good, should be developed into an operational alternative for supply-oriented management. Water should be considered as an economic resource, and consequently adequate pricing should be implemented where applicable. The price of water should not only cover the direct costs of production, but should include its scarcity value as well. In the development of water pricing systems special attention should be paid to: (i) pollution and over-exploitation (mining) in relation to long-term sustainable use of the water; and (ii) social aspects of equity concerning the access to water and the ability to pay of low income groups.

Public participation and community management. Large scale infrastructure has proven to have large scale — and often adverse — social and environmental impacts. Water resources developments should pay significantly more attention to the self-reliance of local communities, based on traditional approaches — which are often socially acceptable and environmentally 'sound'. This requires public participation at all stages in the planning process. In addition, community management should be considered as a viable alternative to complement the necessary strong government coordination and planning.

Functional *institutional arrangements* (structure and linking mechanisms) are crucial for implementing integrated water resources management, including these issues:

- coordination with other sectors of the economy and the overall economic development planning process, including the development and operation of cross-sectoral information systems;
- implementation of the planned actions, in particular in relation to demand management; and
- enforcement of regulations.

Careful planning and adequate supporting analysis is an important vehicle to prepare for successful implementation of integrated water resources management. Proper planning can improve decisions on investments and on allocation of water. Planning is not a blueprint exercise but should be an open-ended cyclical process. What is required at the national level is a capability for planning rather than cook-book master plans. A capability for planning would include: (i) the availability of and access to reliable and relevant data — including monitoring and control data on implemented measures; (ii) proper institutional arrangements as defined below; and (iii) adequate and well-trained staff.

Monitoring and control is important for both supply and demand management and should relate to both the water resources system and its users. With respect to the water resources system, attention should focus on water quality issues, such as: sources of pollution, distribution and accumulation in ecosystems, and harmonisation of sampling and analysis procedures. However, not only the performance of the water resources system should be monitored. Water Resources Managers should enforce a strict compliance with regulations governing the behaviour of water users and the impacts of water utilisation on the natural environment. Without such monitoring and control, demand management is not likely to be successful.

In particular in developed countries, *integration between water, air, soil and coastal management* should be improved. Interactions to be considered are not only physical, chemical and biological, but also in terms of utilisation and regulation. For example, successful air pollution abatement measures might well result in an increase of water pollution.

Although the need for — and the objectives of — integrated water resources management appear to be widely supported, translation of such awareness into the implementation of policies for the sustainable use of water resources is difficult and time-consuming.

4.2 Action plan for the international community

An action plan for the 1990s for the international community of national governments and international agencies, with the objective to promote, develop and implement integrated water resources management, should concentrate on the following areas:

- Improved *coordination of donor support* for water resources development in developing countries. Long-term support to implement sustainable development and use of natural resources is needed instead of short-term support for project implementation.
- The further development and *implementation of international rules and legislation* on shared rivers and river basins as proposed by the International Law Commission, should have high priority.
- *Research and technological developments for more efficient water use* are strongly affected by government policies and actions. On an international level such actions can be supported and coordinated. Of special relevance are: waste and pollution control technologies; water saving technologies in agriculture and industries — including re-use of water; and public health aspects of irrigation projects.
- *Institutional support.* Institutional arrangements on a national level are crucial for proper implementation of water resources management. Existing knowledge and experience should be mobilised and used to support individual nations to strengthen their institutional arrangements. Long-term programmes, preferably through international United Nations organisations, should be developed and promoted to this end.
- *Education, training and capacity building* are essential for a new approach and implementation of water resources management. Education and awareness of the importance of an efficient use of water resources for sustainable development is at the root of the understanding of water users that water is not a free resource any more. Training of water resources managers is instrumental in passing the concept of integrated management and providing them with the tools for implementation. Managers are needed with a firm grasp of economic, social, environmental, and legal aspects as well as engineering.
- *Awareness and promotion.* Continuous efforts are required to increase the awareness of water resources problems in relation to sustainable development and to develop and promote integrated water resources management. Studies, publications, workshops, creation of new institutes or support of existing ones, are among the main instruments in this respect. It may be necessary to mount a strong lobbying effort to give the issues of water resources management and sustainable development a higher priority on the international environmental agenda.

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10

Scientific and technological challenges

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EXECUTIVE SUMMARY

1 Water is the lifeblood of national development processes, and without careful management of the available water resources, and without adaptation of societal demands to them, a sustainable development is not possible. The political leaders of all nations are challenged to give highest priority to the preservation, management, and equitable distribution of drinking water and water for industrial and other uses.

2 Large natural disasters, such as floods and droughts, can cause social upheaval which can set back national development by many years. The planning for prevention or mitigation of disasters and their adverse effects must have the same priority as other measures for safeguarding the health and well-being of the people.

3 Most technical problems associated with the design and construction of structures for water resources systems, as well as many methods for cleaning polluted waters, have been solved and are available for application. However, direct application of technologies developed for one particular climate region or societal structure to a region with different climate conditions and different societal traditions must be guarded against.

4 Engineers and scientists of all nations are challenged to develop methods by means of which sustainability can be secured in water resources systems. Innovative and adapted technologies for different types of societies and different climate regions are to be developed. Interdisciplinary approaches to include water resources development, environmental improvement, and ecological preservation are demanded, for which appropriate scientific and engineering methods must be developed.

5 The need for water management, and the methods of proper management must be made transparent through education of and information to the people at all societal levels from villages to nations. International and national professional societies are challenged to contribute to the process of information exchange.

6 The scientists and engineers of the home country should assume a leading role in the development of the local water resources. Their experience should be made known and information transferred to them through appropriate exchange mechanisms.

7 The necessity of treating water resources projects in their connection with all sectors of society, and in its interaction with nature leads to the conclusion that traditional sectoral approaches to water projects must be augmented by interdisciplinary work. The request for interdisciplinary project development must be strengthened through an interdisciplinary link between all water-related professional and research associations. To serve this purpose, COWAR was created.

CONTENTS

1 Introduction

The world population grows in numbers and in demands at a rapid rate. A number of important studies on the limits to growth have shown clearly that the limit of the support capacity of planet earth is approaching at an alarming rate. In many regions of the earth a threshold has already been passed to a state where resource depletion and population pressure have destroyed the natural basis of sustainability. Such regions become more extensive every year.

To reverse this trend, all countries are challenged to change traditional thinking, to find ways to stabilise societies in conditions which guarantee sustainability, and to solve the extremely demanding task of achieving sustainable development for all people in order to reach a state in which generations of people can live a full life in peace and in harmony with the environment.

It has been commonly understood as a fact of life that most of the earth's natural resources are finite, but it is a long way from this appreciation to the creation of a new world order of sustainable development. A new way of thinking is required, which starts by acknowledging that the finiteness of natural resources affects all sectors of human activity. A new value system must be developed. This cannot be the value system of a few privileged individuals or groups, but must be accepted by the majority of people in order that it can be translated into legal and political actions. It must yield rules and regulations in every country for all human activities, which in many areas will be in conflict with the basic human desire for a better life.

An area where this conflict enters only marginally is the area of water resources development, and therefore the planning and operation of water resources systems can serve as a valuable test case for studying methods and concepts of sustainable development.

Sustainable development of water resources is by no means a small factor in a future of stable human development. Water permeates all sectors of society, and its efficient and economical use is a precondition for development in many other areas. Sustainable development of water resources implies new criteria for planning, designing, operating and maintaining water resources systems. Important criteria for structural and non-structural projects are:

- Projects must be considered as integral parts of the societal system, in which all interactions of the projects with society and environment are taken into account by experts from all appropriate disciplines,
- Projects must be optimally adapted to local conditions: to local living conditions and to local environments. Also, they must be so flexible that they can be adjusted if future changes in needs or of purposes are required,
- Projects must be sustainable, which implies a state in which structures or institutions with proper maintenance last indefinitely, or in which structures, once destroyed by a rare event, can be reconstructed with minimum effort, at an affordable cost to the communities.

Such criteria must be applied to all kinds of water resources systems ranging from local systems, such as the water supply of a village from a local well or spring to vast multi-structure and multi-purpose systems such as systems of large dams which are built to control floods, generate power, and irrigate thousands of hectares of land and affecting more than one nation. Society as represented by its political bodies is challenged to demand that such criteria are being met, and to set the legal and political framework for enforcing them. In requesting these criteria to be satisfied, society broadens the demands on water resources planners, engineers, and managers beyond traditional techniques and skills. Research and development is asked for to supply these persons with the necessary tools to meet these criteria.

The Committee on Water Research (COWAR) of the International Council of Scientific Unions (ICSU) and of the Union of International Technical Associations (UITA/UATI) has initiated the preparation of a report on the role of water in sustainable development. COWAR represents the international water-related non-governmental associations.

The field of water resources today is divided into many subareas, in which different aspects of the water resources of a region are treated separately. This separation has an old tradition, reflected in the scientific and engineering methods and design rules, which are, at least in their terminology, field specific. Nationally, and internationally, different associations represent different subareas. One of the oldest international associations is the Permanent International Association of Navigation Congresses (PIANC), for port and harbour problems. The International Council on Large Dams (ICOLD) concentrates on construction and management problems for reservoir systems, the International Council on Irrigation and Drainage (ICID) deals with all problems associated with agricultural water management, the International Association for Hydrological Sciences (IAHS) deals with the theoretical foundations for describing all components of the hydrologic cycle and its interaction with other cycles: that of energy and of matter, the International Association for Hydraulic Research (IAHR) focuses on laboratory practice and on fundamental and applied research in hydraulics and hydraulic modelling, the International Association of Hydrogeologists (IAH) deals with groundwater and its utilisation, and the International Association for Water Pollution Research and Control (IAWPRC), the International Water Supply Association (IWSA) as well as the International Water Resources Association (IWRA) represent their respective fields.

The COWAR report is intended to be a supplement to the report "*Our common future*" (the report of the Brundtland Commission on Sustainable Development), in which the subject of water was not dealt with exhaustively. Preparatory COWAR meetings have resulted in a plan according to which representatives of international nongovernmental water-related associations are contributing to the subject from their point of view. The report is based on concepts developed during a meeting of all authors which took place in Karlsruhe in August 1991. Two days of intensive discussions brought forth a large number of issues related to water management and water research, which are summarised in the present paper.

2 Water Resources Systems for Sustainable Development

2.1 Water and society

Water demands Water is the most vital of natural resources. Water demands are increasing as populations proliferate (as is the case in the developing countries), as *per capita* water use rises with the development of irrigated agriculture and industries, and as other latent demands of developing areas become a reality. Solving water supply problems requires the sustainable development of water resources on local, regional, and international scales. It is very evident in many development plans that the inextricable linkage of water and development is not very well understood. The system of man and his environment is driven by water, and an efficient plan must include an appropriate role of water.

On a global basis, there is sufficient water for all foreseeable future purposes. There is enough fresh water, on the global average, to provide sufficient water for drinking, food and energy production for a much larger human population than that limited by other resources. However, the problem lies in non-uniform distribution of fresh water in space and time, and the need either to redistribute the water, or to redistribute populations, which requires not only sufficient economic resources and cultural flexibility, but also capable water managers, engineers and technicians. Irreversible losses of available water and land resources can only be avoided if understanding and adequate institutional frameworks exist. Since water supply and sanitation are inseparable, every water supply system should be part of a broader water resources system, in which disposal of waste gets the same priority as supply of water.

It is apparent that in many poor countries water ranks low in national priorities. A balanced water management will therefore not be provided at standards comparable to those of countries with sufficient resources. Traditional ways of helping such countries, by providing assistance for setting up water supply and sewage disposal systems as used in the European tradition, may not be the best way of helping. It could be more important to develop techniques based on available local skills and traditional techniques. It is a challenge to engineers and managers alike to look for local ways in which the goals of water supply and sewage disposal can be reached in an efficient and adapted manner. Standards or techniques from other countries should not be imposed: instead local engineers and technicians should learn the ability to identify the requirements in these areas and to find ingenious and adapted ways to meet them.

Water pricing is a very effective way of reaching water management objectives in a region. Water may be provided free to all, as part of a communal service on the one end of the scale, or it may be charged for at a price which covers all costs involved in collecting and distributing water. If water is delivered at cost, drinking water is likely to compete with water for other uses. For example, if high quality drinking water becomes a scarcer commodity in local areas, either because of general water shortage, or because of the quality of the available water supply source, it is likely that the price will go up, especially for high quality drinking water. A result will be that other users will also have to pay more. A pricing policy must be found which assures balanced economic development. Joint planning of water use for agricultural, industrial and domestic purposes is needed, including the environmental needs to maintain sound ecosystems and satisfy their water demands.

Because of the critical priority for drinking water, it is expected that the balance of water distribution between domestic/municipal, industrial and agricultural sectors will change in favour of the first of these sectors. A comparison of the percentage distribution among these three prime users clearly shows the difference between countries with high water use for industries and others which use 80 to 90 per cent for agricultural purposes.

The greatest strain on water supply systems will come from the mega-cities which are growing at a fast pace. Historically, civilisations developed along major rivers, and most large cities exist in such locations today. However, the water from rivers no longer suffices, in particular because of its quality, and many of the new mega-cities are created without consideration of local water availability. They will therefore have to be supplied with water from reservoirs, transported by aqueducts and tunnels often from areas far from the population centres. By the year 2000, about 50 per cent of the world's population is expected to live in these urban areas.

Inefficient water use Competitive and inefficient use of limited regional water supplies by irrigated agriculture and industry is a major threat to sustainability of water supplies. Very often, the conveyance losses of conduits (unlined channels, or leaky pipes) are much too large a percentage of the available water — 30 per cent of losses is common in irrigation systems, and many urban water supply networks have losses of similar magnitude.

Another cause of inefficient water use is the emphasis on meeting demands by constructing new supply facilities, rather than improving the efficiency of existing supplies, conserving water and pricing it in accordance with cost. The recognition of the degradation of existing water supplies must lead to more efficient use of existing systems.

During the International Decade of Water Supply and Sanitation, large scale investments were made in new facilities, resulting in a favourable expansion of service coverage in many countries. However, inefficient operation and poor maintenance of systems continue to present serious problems in many less developed countries, calling into question the long-term sustainability of the gains that have been made. Problems are rooted in the continuing weakness of public and private institutions, in terms of (operation and maintenance) costs *vis à vis* (water rate) income. An enabling environment must be created and the capacity of sector agencies must be built up to deal with these problems appropriately. Otherwise systems will continue to deteriorate, resulting in declining levels of service and waste of investment funds.

Demands on water quality Water quality is fundamental to the health, efficiency and well-being of individuals and societies in all countries of the world. It is threatened by almost all modern interactions of man with nature. The great benefits from modern irrigated agriculture and industrial processes are offset by serious water contamination. Irrigation of heavily fertilised land has resulted in runoff from agricultural fields rich in nutrients, which reduces, through algae growth and other biological process, the oxygen in rivers and lakes. Eutrophication has become one of the biggest and most widespread water pollution problems. The deposition of organic waste and man-made chemicals (often of a persistent nature) in the water environment are life threatening. Discharges of industrial sewage into rivers, or the deposition of toxic waste in toxic waste dumps, which in the past have been inadequately protected from contact with groundwater below, create in effect 'time-bombs' of groundwater pollution. Highly toxic substances now appear in groundwater and in aquatic and terrestrial ecosystems. Water supplies from groundwater sources are becoming increasingly important, but are threatened by over-exploitation and by contamination. Also, the sediments of the rivers are depositories of toxic waste, which result in long term effects through mobilisation of pollutants and release of nutrients from bottom muds.

Drinking water supplies must provide clean, safe, potable water in a sustainable and most economical way. Water quality and environmental concerns have added new dimensions to water resources management. Vast funds are needed to clean water and to dispose of the end products of the cleaning process in an orderly manner. For providing water of drinking water quality, a staff of technicians as well as layers of management ranging from plant supervisor to revenue collectors from users is needed — again pointing to the fact that for an adequate and economically viable water distribution system an infrastructure of sufficient capability is needed which can keep a system working in an orderly and sustainable fashion.

These requirements have affected policies for source-selection as well as structural, regulatory and legal aspects of water control. Introduction of the necessary policies should receive wide public support resulting in an effective infrastructure and competent institutions.

Environmental concerns Water resources systems at all scales affect the environment. The projects associated with them are needed, but only few projects have a wholly beneficial impact. The construction of new water works to provide more and better supplies of water, to apply modern treatment technology, and to carry water to areas of need interferes with natural conditions and cause a variety of unavoidable impacts on the environment. Engineers are learning to adapt their techniques to the requirement of minimising negative impacts, thus responding to the growing concern of people in the regions concerned for adverse environmental impacts, which is evident around the world. While there is an urgent need to preserve our planet in as unspoilt a state as possible, the need of the people has priority, and therefore environmental groups should learn to work with the engineers in creating an optimum environment, in which human needs are weighed against environmental concerns.

Setting priorities It is an important task of political decision makers to weigh the benefits against the negative effects, and to set priorities. In the list of priorities, public health ranks highest, and water-related diseases, which continue to be major health problems in some tropical areas, must be avoided at all costs. However, politicians must resist public pressures which are based on unfounded conclusions. For example, frequently people oppose water supplies possessing detectable contaminants, even though they meet local public health standards. An efficient procedure is required in which public works construction is evaluated for the benefit of the people by experts and administrators, and which ensures that all important issues which may concern people are properly evaluated and given due regard.

2.2 Water resources systems planning for sustainable development

Sustainable systems The traditional view sees water resources systems as a system of structures and information links which connect all aspects of water supply with all aspects of water demand. The system consists of reservoirs and basins for changing the temporal distribution, pumps and dams for changing the vertical, and canals or pipe networks for changing the horizontal distribution of water. In the context of sustainable development it is first of all necessary that operation rules and maintenance are considered as essential for the sustainable use of projects. But more important is that water resources systems are seen as integral parts of a net of interwoven relations between man and nature, which in order to be sustainable requires an accounting for the numerous interactions of the water system with all other subsystems involved in shaping the fabric of society.

Water-management strategy for sustained growth and development should be optimised by strategic planning. Instead of seeing water resources systems as closed, we must realise that they are open systems. For example, it is necessary that development plans for water supply include an integrated water supply management and re-use strategy, as well as a comprehensive management for all aspects that affect the human environment. Such comprehensive water quality and quantity management can not be handled effectively without an integrated multi-disciplinary approach, which in turn requires a suitable infrastructure.

Schematics of water resources systems planning The process of water resources systems planning is outlined in Figure 1 (from UNESCO, 1987). It consists of four stages, ranging from the plan initiation stage to the design stage. The traditional approach to the design of water resources is that a need is projected in response to a political demand and the demand of a planning horizon is identified. The design then proceeds in an orderly fashion, from an inventory of resources, augmented if possible by an extensive program of collecting and measuring relevant data, through the formulation and quantification of project alternatives, until the final project is selected by means of the political process. Objectives from other plans are introduced as constraints.

People involvement in the planning process A project planning process based on sustainability concepts must, according to the definitions given in the introduction, be a part of a hierarchical development plan, which embeds the water resources planning process into the general development strategy of a country. Such a general development plan should not be developed by experts and administrators alone. Because structures built for water resources systems are often very large and involve essential changes in many parts of society, it is necessary also to involve the public as much as possible, so that the decisions on water resources systems are carried by a wide consensus among all concerned. A well known asymmetry exists in the fact, that the decision "not to build a dam" can be repeated many times, but the decision "to build a dam" can only be made once and results in a structure which is practically irreversible.

A precondition for decision finding under involvement of the people is a legal and political process which assures that the optimum solution is indeed found. Ways must be found in the socio-political arena to arrive at effective project-related decisions. Those directly affected should be involved in developing project concepts. Planning on a multi-disciplinary basis, rather than an interest-group tug-of-war, should lead to mutual problem solving. Most developed countries have developed the legal framework for conflict resolution through a continuous process of problem recognition, political legislation and legal and administrative actions. However, hardly ever is a decision in water resources a clear cut one, because it involves many different interests. The principle of sustainability must be translated into legal requirements, which overrule special interests. This principle should not only guide conflict resolution within countries but should apply also to international water related disputes. An important need exists for solving conflicts regarding water supply, river pollution and contamination of groundwater on international river basins and groundwater sources.

Planning for changes Sustainable development of water resource systems relies on their planning, construction and operation so that they remain desirable and viable over prolonged periods of time. Important aspects which need to be considered are the susceptibility of the water resources development goals to changes: it is important that the system has the flexibility of being adjustable to future needs. On a local scale, this means that the system should function even if the data base changes, which may be because the original data base was insufficient — it is a truism that sufficient field data are usually not available for the proper evaluation of water resources and for finding solutions to all water related and environmental problems. Or it may be that the climate conditions change: the man-induced climate changes may not be as critical as local changes induced by changes in land use. A deforested area may have a much higher runoff coefficient than the originally forested area.

The engineer's role in sustainable development requires a multi-disciplinary approach, including looking at risk assessment of projects and their operation, and at the effects on human activities. He will have to answer important questions such as: will the foreseen development of the country, as it perhaps develops from a rural society to a more industrial one, require the planned water resources system in its planned form, or might not other requirements change its uses? Are the structures of the system built in such a way that they can be repaired easily in case of damage; is the plan complete enough to incorporate maintenance into its operation rules? Are the structures guaranteed to maintain their function indefinitely, at reasonable cost? For example, a dam which is being built to supply water for irrigation in an arid country is likely to be subject to siltation. Consequently, it is foreseeable that the reservoir will fill up with sediment. What happens if the reservoir is filled so much that the system can no longer operate? Perhaps it is better to improve existing methods of agricultural production rather than to introduce, through the system depending on the dam, an agriculture which can be maintained for a limited time only. A silted up reservoir not only has the disadvantage of being a useless capital investment, but also of having disrupted the society of the people whom it is supposed to serve. During the lifetime of the dam, local farmers adjust to irrigation

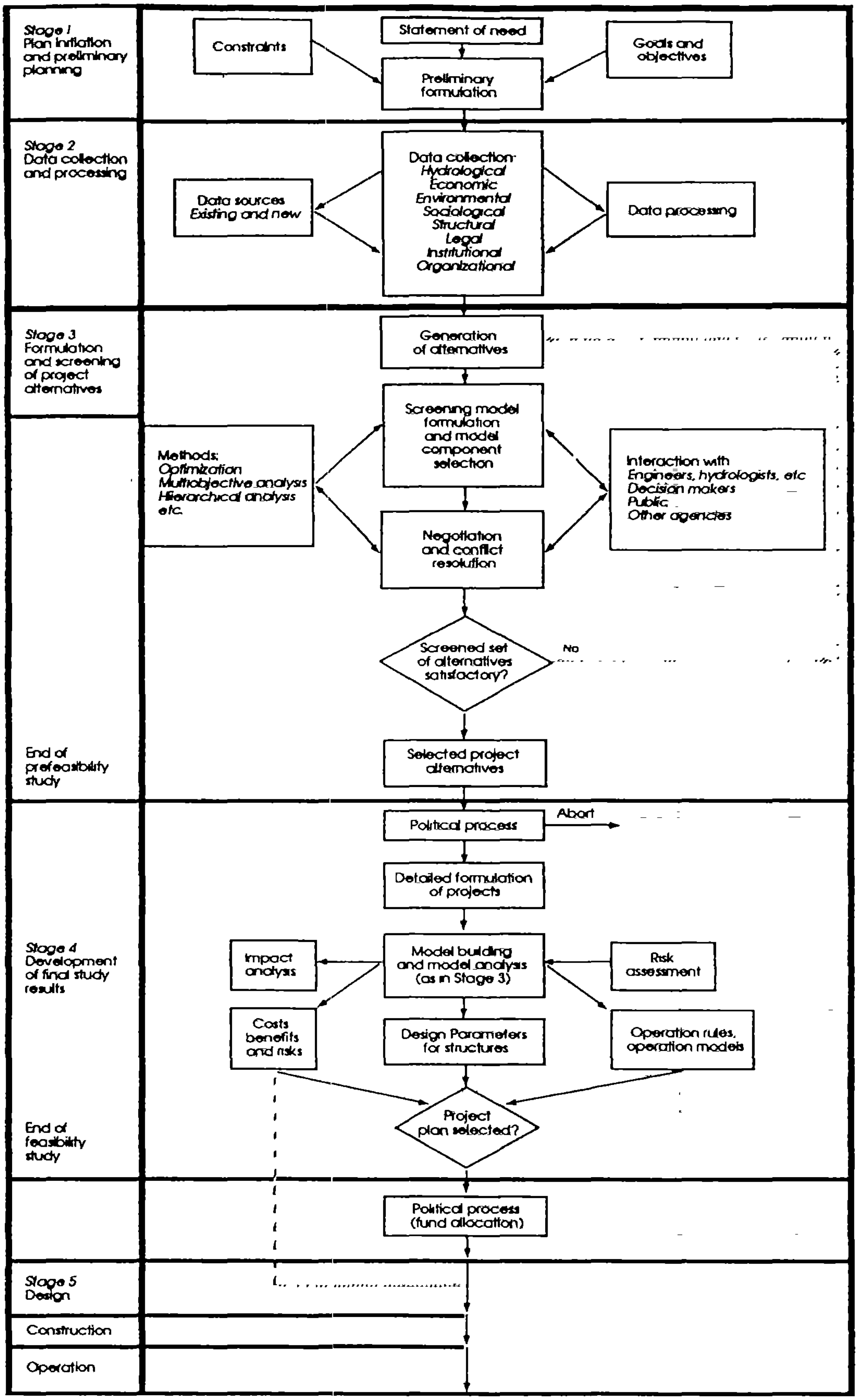

Figure 1 *Stages in the water resources planning process (from UNESCO, 1987)*

practices from the reservoir, requiring a change in lifestyle and in working habits, and while the dam is still in operation, the traditional approaches are being forgotten and experiences in sustainable and adapted agricultural practices are lost. When the reservoir is filled with sediment, they are needed again, but they are no longer available. Such a disruption in lifestyle and in supply will have an effect on the stability of whole nations. For an orderly and peaceful development there must be supply-reliability both in quantity and quality thereby bringing about confidence in the system, which is a prerequisite for proper respect for operation rules and care for the physical plant of the system.

3 The Challenge of Sustainable Development of Resources

3.1 *Applying existing knowledge*

Available knowledge The majority of the methods and techniques necessary for planning water resources systems for a sustainable world are available. Traditional knowledge accumulated in the textbooks of engineering schools is readily accessible and forms the basis for all branches of water resources engineering. However, the field of water resources is a very active area of research, in which the research problems are shifting from considerations of water quantity, which require solid knowledge of hydraulic structures and hydraulic design, to water quality issues. The basic chemical and biological processes are studied and quantified by specialists, but engineers and water resources scientists are challenged to consider process functions from these fields in their models for design.

A large amount of scientific knowledge and practical experience is already available as a basis for action. It is an important task for scientists and engineers working in the area of water resources to make these techniques known and to develop them so that they can be applied by practising engineers in the field without requiring a deep study of the fundamentals. As an example, one may consider the alleviation of droughts. The technical knowledge is available to prevent most water shortages caused by droughts. For the implementation of this technology three conditions must be fulfilled which are as important as the technical know how: a favourable institutional framework, the necessary finance and qualified people. The following examples are taken from the fields of water supply and technology, irrigation, dams and hydroelectric power.

Water supply engineering Water supply has traditionally been taken from surface waters, for which dams and canals have been built. The technology for such structures is well developed. Modern challenges are, however, to make sure that the water supply lines and the reservoirs interfere as little as possible with the ecology of the region. It is a truism that water supply and sewage disposal are two sides of the same coin: wherever water works are being constructed, only a small part of the water is consumed, whereas the rest is contaminated by the users and returned to rivers and other water bodies.

Groundwater may well be the most important source of freshwater in the future. It is estimated that at any time more than 95% of all fresh water in the liquid state is lodged in groundwater, about half of which is in the top 800 m depth of the earth's crust, while only 1.5% is contained in rivers and lakes. In many countries, a change has taken place to rely less on traditional sources such as lakes and rivers and to turn to the extensive use of groundwater.

The use of groundwater has many advantages, notably the year-round constant temperature (corresponding roughly to the average annual temperature of the region) and the purifying action which takes place when the surface water infiltrates into the soil.

Development of groundwater resources helps to satisfy current water needs both in developed and developing nations. If it is used only to the extent that it is replenished by rainfall, it is a key resource for sustainable supply of water for drinking purposes and for agricultural use. Current technology permits the reliable quantification and sustainable development of groundwater resources, but it is not always properly applied. Groundwater resources may be poorly assessed or the consequences of groundwater exploitation wrongly analysed. Furthermore, lack of technical understanding and inadequate institutional frameworks is likely to lead to an irreversible loss of existing available groundwater resources by pollution from point and diffuse sources.

Groundwater reserves should therefore be conserved to extend water supplies in drought prone areas, by using them sparingly, and by recharging them for future generations. However, an erroneous and over-conservative assessment of the groundwater potential should also be avoided, as it may result in not using a valuable resource, and therefore introducing more costly alternate solutions to drinking water supplies. Technologies have been developed to use surface and ground water in conjunction, using groundwater as the basic supply, which at times of large demand is augmented by water from reservoirs. Water may be taken from polluted rivers by the method of bank filtration, or artificial recharge of groundwater is possible by means of infiltrated surface water diverted from rivers.

Important steps towards more efficient water use are made through water saving activities, such as re-using water, or reducing water use in industry, or through water saving devices in households and public facilities, such as swimming pools. Economists have made available studies which show the role of water prices in resource protection and water saving, and politicians are challenged to use these instruments to preserve the water resources of regions.

Water Technology Water technologies have been developed in the industrialised countries both for processing drinking water and for sewage disposal. Drinking water is routinely controlled for quality and for the presence of harmful substances, such as disease vectors. Drinking water has been obtained by desalination of sea water and brackish groundwater, and the technology exists to transport water over long distances. Significant advances have been and continue to be made towards sewage treatment, water re-use, and solid waste disposal. It has been realised that waste discharge and biological activity are interconnected in the land-water-ecosystem, in particular in the intertidal zones along the coastlines, lakes, reservoirs, riparian zones along riverbanks, wetlands, flood plains, and estuaries.

Hydroelectric Energy Water power is the most beneficial energy available on earth. It is the only form of truly economic solar energy. The sun not only provides the energy by evaporating water from the earth surface, nature also provides the energy collection system through the system of rivers and streams. The enormous hydro-electrical potential in the world can be developed with existing technology. The negative consequences of this form of energy are strictly local and in most cases can be overcome by careful planning and adequate design of structures. Of the approximately 15 million GWh y^{-1} of exploitable energy, only about 14 per cent is in operation, with 3.2 per cent under construction and another 7.4 per cent being planned. The largest potential is in South America and the USSR, with most of the active planning going on in China, India and the USSR, followed by Brazil and Canada.

Irrigation Irrigation is one of the oldest methods by means of which man compensates for variability of the natural rainfall-runoff processes. A tremendous amount of experience has been gained locally by trial and error, and by irrigation engineers working in many different regions. It is vital to realise that irrigation and drainage must go together in order to avoid salinity problems in the irrigated areas. It is also vital that the structures associated with irrigation systems are properly maintained and kept in functioning condition, but once these principles are heeded long sustainable irrigation systems can be developed, and have been developed using present practices.

Numerous examples exist all around the world of well-functioning irrigation systems, where operation and maintenance go hand-in-hand with the use of the system. The counterexamples of irrigation systems destroyed by siltation of the supply reservoir, or by salinisation of the soil are usually the results of faulty application of well-known rules, or of negligence, or of incomplete development: omitting the drainage, for example, in order to save on capital investment.

In managing agricultural areas, attention has to be given to prevention of loss of fertile soil due to erosion by wind and discharge of rain or melting snow. A worldwide exchange of experience in this field is desirable.

The largest improvement in existing irrigation systems is generally to be expected through direct application of known principles and by transfer of technology in order to improve the efficiency of irrigation systems. It is generally assumed that only about 30% of the water in a reservoir is actually transpired by plants: the rest is lost by seepage from leaky canals or by evaporation. The application of drip irrigation (water conveyance through pipelines rather than through open and unlined canals) and other efficient water supply techniques are expected to lead to a major change in the design of agricultural projects. Such methods will be particularly important where irrigation water is in competition with other demands, so that collective water use must be optimised in accordance with local needs rather than with agricultural production only.

3.2 Development in the basic sciences

General Approaching water resources systems in an integrated manner, extensive research has made the tools available for solving the problems associated with traditional development of water resources. Planning used to be the domain of the hydraulic or agricultural engineer, who developed the methods which he needed for his designs — by means of hydrology, hydraulics, structural engineering. The number of scientific fields included in the planning and design processes has increased, and the planning process outlined in Figure 1 must now be handled by a team. Furthermore, in the course of adapting to new demands, the basic sciences have broadened their activities, as will be illustrated briefly by some important areas of water resources development.

Hydraulics Hydraulics has been completely changed through the possibilities offered by the computer. The traditional approach of hydraulic model studies and formulae based on one-dimensional approximations with empirical coefficients is gradually being extended by methods based on directly solving the partial differential equations of fluid mechanics. Applications include all important areas of man-made and natural water systems, including the estuarine region and adjacent coastal areas. Its applications have expanded from studies of hydraulic structures and river training works, to include not only morphological processes, but also biological and chemical processes which permit the solution of pollution problems in rivers, groundwater and other water bodies. A body of techniques for solving water quality problems was summarised in a recent publication of the International Association for Hydraulic Research (IAHR, 1991).

Hydrology Hydrology has emerged as one of the fundamental natural sciences, with applications extending into all geosciences and into many engineering fields. This has been made clear by a recent publication of the National Research Council of the USA (NRC, 1991). Its traditional role of supplying data for hydraulic systems design is still one of the main tasks, but the data needed for design include not only point data of distributions and extreme values, but also the dynamics of the rainfall-runoff process, as captured by event based models (such as the unit hydrograph method) and long-term simulation models.

Data acquisition by means of stream gauges and rainfall networks, as well as groundwater monitoring, form the subject of operational hydrology, for which procedures for hydrologic analysis have been developed, e.g. time-series analysis of precipitation and stream flow data and related statistical computations, determination of extreme events and their probabilities, as well as analytical and numerical models for groundwater flow and contaminant transport and watershed models. Current technology permits the reliable quantification of surface and groundwater resources.

Hydraulic structures Water resources systems contain a network of structures, which are designed according to well known principles of hydraulics. For most applications the types of structures and their design have evolved over many decades. Only for extremely large structures (e.g. high dams or navigation locks with very high lifts) or in unusual circumstances (such as high discharge spillways — i.e. with a design discharge of 150 to 250 $m^3 m^{-1}$, or diversion structures in geologically young rivers with sediment discharges which contain large size boulders) do engineers face problems which require new solutions for conventional situations. New fields such as value engineering and probabilistic design support economically balanced developments.

The most frequently discussed structures are dams for water storage. For them, the basic technologies have been developed. A variety of water uses and re-uses are being accomplished with multipurpose dams: water supply for domestic, irrigation and industrial uses; flood protection of lives and property; hydro-electric energy generation for economic growth; improved navigation by increasing water depth, and creating lakes for recreation and fisheries. Over 200 dams higher than 15 m are completed each year. The world's 36,000 dams store about 6000 km^3 of water. Dams are indispensable structures for regional development, and recent concerns have been strongly directed to make these necessary structures compatible with local conditions in order to cause as little disruption of the local social and natural conditions as possible. Environmental, social, safety and cultural aspects of dams and reservoirs are being addressed in the early planning stages.

3.3 Risk assessment and the International Decade for Natural Disaster Reduction

Hazards and risks A hazard is the potential for an adverse event to occur. Man is subjected to a multitude of natural water hazards, such as floods, rain-induced landslides and droughts. When a hazard actually happens and leads to extensive losses in property, or to losses of human lives, then it becomes a disaster. It is not economically feasible to prepare against all potential hazards nor to design all water resources systems, including hydraulic structures, to withstand any conceivable hazard. It is necessary to weigh the consequences of a disaster against the cost of preventing it. In many cases prevention may not be the best course of action: instead one should attempt to mitigate potential disasters.

A large number of methods is available for disaster mitigation which range from forecasting and warning systems to disaster resistant construction and disaster zoning, in which regions of high potential disasters — such as flood plains — are prevented from being inhabited. Man also has to face, and be prepared for, disasters caused by accidents or long-term negligence. Consequences of disasters due to chemical spills or nuclear accidents may be extremely far reaching.

The method by which this weighing process is accomplished is risk management. Risk is defined as the average potential consequence of a disaster. It weighs the consequence of a disaster, such as loss of lives or monetary losses, against the probability of occurrence of the disaster. Risk management should be an important aspect of all water resources systems planning. A poorly managed disaster can disrupt the social structure of a region for many years: in fact, natural disasters and wars are the two factors which most strongly disrupt any development.

The International Decade for Natural Disaster Reduction Disaster mitigation practices, ranging from structural measures to well-developed relief organisations for handling local disasters, exist in most developed countries, which have also developed traditional methods of disaster management. Unfortunately, many of the most disaster prone areas of the world exist in the least developed and poorest countries, where disaster management methods are often also poorly developed. It is therefore one of the most important aspects of sustainable development to develop local warning systems and local prevention and mitigation measures in all countries. To reach this objective, the United Nations have declared the decade from 1991 to 2000 to be the International Decade for Natural Disaster Reduction.

Recent major floods in China, as well as tidal waves and the resulting backup of rivers in the flood plains of Bangladesh, have made it evident that great efforts are required to make the world a safer place to live in. Because of the urgency of preventing the consequences of natural disasters, engineers and scientists working in water resources systems planning, construction and management strongly endorse the International Decade for Natural Disaster Reduction (IDNDR) and its objectives.

3.4 Institutional requirements for sustainable development

Institutional requirements The management of the water resources of a country requires a staff of well-trained water managers and technicians, as well as a force of labourers to do maintenance work. The priorities for this task have to be set in the national political environment, for which water engineers and scientists can help to provide the background. Indeed, the more a country has achieved stability and has set itself on a course of peaceful evolution, the more the necessity of competent water management becomes evident as one of the main supports for sustainable development.

The role of national professional societies National professional water associations play a major role in creation of national awareness that disasters and water shortages do not have to be taken for granted, and in national capacity building for service improvement and sustained maintenance of assets. Wherever such organisations exist and have strong backing by professionals they have had great influence on the development of a country. Experience over the past several decades has shown that they have contributed to this goal in the following ways:

- By providing a mechanism for the continuous updating of professional knowledge and skills in all aspects of water development.
- By working in close collaboration with national decision makers in defining national policies, as well as setting realistic targets and standards.
- By acting as a link between public water and sanitation agencies and private manufacturers, consulting and other companies active in the sector.
- By promoting national and international exchange and co-operation in the areas of research, training, technology and overall strategy.

For many years, international professional non-governmental associations as well as the relevant UN bodies serve as link between professionals in developed and developing countries. Numerous cooperative projects and activities testify to the success of this approach.

4 The Challenges for the Future

4.1 The tasks of the future

General comments Water science and engineering cannot look forward to spectacular new findings which could vastly increase the basis of sustainable development. Progress in this area is made in small steps: it consists of patiently worked out details of intricate concepts based on observation and hard thinking. To be sure, research is needed on many specific topics to improve existing techniques, and many local benefits can be derived from such research. Research and technology for sustainable water supply and sanitation should aim at 'operation and maintenance friendly' design, not only in new designs, but also when the important task of rehabilitation and retrofitting existing systems is approached.

Among research topics of benefit are energy-efficient desalination, water-economic irrigation methods, water resources modelling and scale-problems of extrapolations, water transport of pollutants and nutrients. Research in these areas will result in environmentally beneficent dam design. A challenge for advancing the state-of-the-art in water engineering and science lies in the task of developing new technology, especially for the third world, e.g. low-water-use sanitation; more economical (e.g. drip) irrigation; erosion-sedimentation-flood control measures; techniques of more economical water extraction, storage, transport and pumping (e.g. groundwater recovery and artificial recharge in catchments using wind and water power). However, these areas offer only small-scale gains of regional importance and can only make essential contributions to sustainable development through worldwide application of new-found methods and design concepts.

The most important task therefore is the transfer of existing knowledge from the scientific and engineering community, amplified by scientific research which closes important gaps. Some of these gaps deserve special mention.

4.2 Research topics to fill knowledge gaps

General Water engineering rests firmly on two scientific foundations. The first is basic science: physics, mainly in the form of hydraulics and fluid mechanics; chemistry, in the form of water chemistry, and biology. The second basis is in the earth sciences, mainly in the form of hydrology. Progress in water engineering must be accompanied by progress in the sciences on which it rests. However, the most important task of the scientific and engineering community is not the generation of new knowledge, but the organisation of the existing knowledge into such a form that it is readily accessible.

The increased knowledge of the profession has resulted in over-specialisation and consequently a loss of order in dealing with water-related problems. The gaps between research and engineering, between 'physical/experimental' and 'numerical modelling' techniques, have widened and must be addressed. Some scientists feel that the answer lies in knowledge-based decision support systems, or in expert systems, in which the computer assumes the role of the memory, which stores all necessary knowledge and which provides the answers to suitably formulated design questions. Others feel that the answer lies in learning to work in teams of experts, who pool their expertise to solve partial problems in a water resources planning scheme through systems analysis.

The systems approach is the one most commonly advocated, in which a water resources system is subdivided into sub-systems, each of which can be handled by an individual expert. All inputs are combined by system experts, who could well be hydrologic engineers or water resources planners, into a computer model. They provide final systems configurations and prepare decisions for further action, in the sense of the model description of Figure 1.

Research is also necessary on integrated water resource management methods, adapted to the particular needs of different regions of the world for both rural and urban areas. Information and decision support systems must be set up to determine the desired level of integration of distinct parts. To reach all water resources development objectives, scientists from many different specialities must work together; these may not be available in every country. It may therefore be necessary to coordinate and support national and international research according to agreed priorities.

Hydrology One of the most active areas of development is hydrology, which faces challenges from new problem formulations, new ways of thinking and new methods. The greatest scientific challenge is posed by the inclusion of climate variability into hydrological models. Any climate change must be reflected to some extent in the design criteria which are used for water resources systems, and which form the basis of water resources system management. It is perhaps not really an important question, in the short run, what causes the climate change. Traditional methods of design have started from the assumption of the stationarity of natural processes, and if this assumption proves to be invalid, then important changes in methods are required to predict and to manage the non-stationary data series on which future designs must be based.

However, the possibility must also be considered of climate change through human interference with natural processes, which may also affect the hydrologic cycle. In order to control and manage this trend, full knowledge of the interactions of life on earth with this cycle is necessary. It is of vital importance to identify significant factors, i.e. climate change, soil fertility deterioration and deforestation. This must be accompanied by a worldwide observation network, for instance through a Global Climate Observation System.

It is necessary to expand the partial information now available about the regional hydrological conditions to global scale interactions of hydrological processes with the biosphere, i.e. to extend the local-level studies on the hydrological cycle to the world meteorological scale in order to supply hydrological information, for example on evaporation rates, to Global Circulation Models. Through these models, one should be better able to predict changes ranging from climate to simultaneous rainfall forecasts for large areas. It is recognised that land surface phenomena can be better integrated into Global Circulation Models at the temporal and spatial scales used by meteorologists. Hydrology should then use the results of the GCMs to make local short-term and long-term predictions of the interactions of hydrosphere, atmosphere and the biosphere.

Better understanding of the recharge processes in semi-arid areas is needed to improve the quantification of groundwater where it is the predominant resource. World groundwater availability maps should be prepared on a regional basis. The technology for extraction of deep groundwater is not adequate and should be improved.

Better understanding is also needed of the local and regional structure of the hydrological cycle, such as obtaining inventories of water quality and studying the fate of contaminants in surface water and groundwater. The effects of snow and ice cover of rivers must also be included. Improving the hydrological data-base and expanding the assessment of water resources with emphasis on groundwater is a key factor to success of regional water schemes. There is a need for data banks and geographical information systems for the acquisition of field data. Data acquisition which is operable and accessible in developing countries has to be developed. In this regard it is essential to develop and maintain national hydrological services.

In the course of growing into a world science, hydrology seems to have lost much of its connection with regional water resources development, and hydrologists are challenged to devote much effort to hydrological questions which need to be answered for the development of regions ranging from village areas to continents. This kind of hydrology is more than the mathematical description of the physics of the hydrological cycle. It obtains its unique and challenging character through two basically non-mathematical aspects.

The first aspect is that local features have to be incorporated as boundary and initial conditions into hydrological models. To do this properly, one must have a very thorough knowledge of the natural conditions of a particular area. Knowledge of geographical features should not be limited only to the information available from maps and geodetic surveys, but must include details of the agriculture and the climate. One must have good knowledge of geological features, such as stratification and the mineral and hydraulic properties of the layers, the existence of faults and other geological land changes. One also needs to know the human inputs into the region, such as structures and highways.

The second aspect is the need to see such hydrological investigations as a part of regional development. Studies of the hydrology of a region obtain their main justification from the application of their results. Applied hydrology is an essential part of local water resources planning, development, or maintenance. This is of paramount importance, in particular for those developing countries which stand at the beginning of a comprehensive use of their water resources.

Hydrology, ecology and hydraulics The greatest challenge for the water engineers of the future lies in the development of environmental engineering, where water science and technology is linked with ecological processes. The understanding and control of these processes, involving scales of influence which range from the local to the effect on climate, is essential for the management of a sustainable life-system, and sets the limits within which large scale projects must be planned and designed. For these objectives, water resources engineers need foundations laid in cooperation between many basic sciences. Relationships between hydrological and ecological characteristics have to be established to develop design guidelines for both surface and groundwater exploration, and to undertake the modelling of water/life systems comprising both aquatic and terrestrial eco-systems.

In a number of European countries, hydraulics and hydrology are used to convert the landscape into a more natural environment, by reshaping small rivers, which have been straightened and narrowed to serve the needs of agriculture, into a more natural shape which is in basic agreement with the natural ecological condition which had existed in earlier times. To do this, not only do the static hydrological conditions which exist on the river have to be known, but also the response of the plants comprising the ecosystem to the dynamics of the rainfall runoff process. Engineers must learn to create, through hydraulic methods, the desired nature-like conditions. Natural vegetative bank protection is one of the goals which is needed to reduce maintenance work, especially in navigation canals, which are subject also to the forces exerted by ships' bow waves.

The ecosystems of watersheds should be mapped and biological studies should be conducted to determine their vulnerability and resilience characteristics. Acceptable discontinuities in the ecosystem should be defined to determine the impact of hydraulic engineering works and the scale of interference. Monitoring networks and related information systems are necessary to assess impacts on aquatic ecosystems and water quality.

An understanding of the interactions of hydrology and the ecosystem is also needed to determine the dependence of aquatic ecosystems on the hydrological cycle in order to determine the limits of sustainable development of groundwater. This is an important aspect because the aquifers of groundwater bodies are frequently used as recipients of effluent such as sewage or storm water. In some cities sewage is conducted onto partially agriculturally used infiltration fields, under the assumption that biological processes in the soil decompose the sewage, and that the valuable fertilisers contained in the sewage are used by agricultural products. Other applications are based on the separation of rainwater and sewage: the sewage during dry days is conducted to sewage disposal plants, where stormwater runoff is infiltrated.

Sewage disposal is indeed one of the most challenging tasks, in particular for developing countries, and here the challenge to find new and innovative solutions is particularly necessary. Niemczynowicz (1991) has pointed to interesting experiments that have been made in sewage control through source control, zoning, and in particular by using ecological solutions, whereby sewage is cleaned through biological actions in natural water courses. Experiments have shown, that basins covered with water hyacinths are effective sewage removers, and many other natural environments are useful in disposing of different kinds of effluent.

It is evident that much of the research needed for solving problems associated with eco-hydrology, climate change, regional water resources systems planning, as well as development projects of water supply and sewage disposal systems for mega-cities require team effort and research cooperation on an international scale. To serve these purposes, the establishment of coordination centres has been proposed, where priorities of research and development are set for a region which are then approached through coordinated research of teams consisting of members of many different specialties. At present, an integrated approach seems to be missing for solving such urgent problems as mega-city effluent disposal in the oceans: where the effluent discharge and characteristics have to be matched to the carrying capacity of the ocean.

Environment and pollution Accurate linkages must be established between water and land-use management and air and water quality control. A better understanding is needed of groundwater pollution processes, especially organic pollution from point and diffuse sources. New processes for control of environmentally unacceptable pollution and biogenetic and toxic materials should be developed to restrict or eliminate local distribution.

The capacity of oceans, seas, lakes and rivers to receive effluent should be assessed, distinguishing between local and regional effects. Micro, meso and macro mixing phenomena and effects on the physico-chemical and biological status are to be included.

Sedimentation and erosion problems continue to challenge scientists and engineers, who have not learned yet to understand the basic process of sediment transport, and to handle the large natural variability of sediment transport phenomena. Fluvial, estuarine and coastal morphological and dynamical processes require further understanding to form a base for long-term prediction and for methods to counter adverse effects. For example, in order to control reservoir sedimentation better it is necessary to improve methods to minimise the deposition of incoming sediment loads, including the ecological effects of sediment yield. Assessment is needed of the long-term impacts of reservoir sedimentation on downstream physical and environmental characteristics, as well as an evaluation of its economic impact and of alternatives to mitigate these impacts. Sediments in rivers are also depositories of substances carried by the river, and the remobilisation of such substances by floods, which causes large scale environmental disturbances, has not yet become predictable.

Development goals The conversion of existing scientific principles to new tasks must continue to challenge engineers and scientists. There is always room for a better design, a better or cheaper construction process or an improvement in management strategies. In the following some of the problems are listed, that invite the ingenuity of engineers in many different areas of water resources development.

Of high priority is the improvement of the efficiency of irrigation systems. Once water for irrigation becomes more scarce and thus more valuable, new methods will be found to convey water, for example through pipe systems instead of through unlined canals. This is expected to lead to a major change in the design of agricultural projects, so that collective water use is optimised in accordance with local needs rather than with agricultural production only. The criterion of increased efficiency for optimising cost and yield also applies to hydro-power projects, where research is necessary to optimise the cost of new dams and hydroelectric projects in the context of overall regional development.

We must also learn to change design rules so that they are no longer based on the design life, but meet the criteria of sustainability set forth in the Introduction. For example, research must continue to assure the safety of older dams, especially by upgrading them to handle larger floods and resist seismic events; hydrologists and meteorologists are still challenged to provide the vexing maximum probable flood. Topical research on dam design should include non-linear behaviour of materials under static and seismic loadings, determination of seismotectonic features and assessment of design floods for dams, hydraulic energy dissipation and dam break analysis.

Continuing analysis of dam failures and near-failures (including tailing dams) is necessary to enhance dam safety. Design of instruments for monitoring the structural behaviour of new and existing dams is needed. Risk analyses should be performed for all new and old dams and emergency plans prepared, for which simplified methods based on scientific principles must be developed. Time-dependent changes of structural properties should be determined and procedures developed for the detection and assessment of ageing of dams, foundation and other materials, and structural and material solutions are to be found for, for example, the repair of cracked concrete structures. For new dam design, a probabilistic approach should be incorporated.

For all types of hydraulic structures, methods must be developed for evaluating correct environmental impacts, and decision models for drawing consequences from environment impact assessments must be found. A special challenge is posed to countries which share the water resources of international river basins. Agreement between countries sharing such rivers should be based on a thorough evaluation of the rivers potential, and on research on technical aspects for the purpose of planning, design, construction and operation of future dams on these rivers.

In such plans, navigation should be considered an important aspect, because the transport of bulk cargoes is particularly economical in terms of energy, and should therefore be a part of sustainable development. An inventory should be prepared of waterways for the year 2025 to assess global navigation requirements, on which future decisions can be oriented. Research is needed on the environmental advantages of sea and waterway transportation, including the means to combat oil spills.

Institutional needs Capacity-building in developing countries should be expanded and improved and interdisciplinary training of water experts should be promoted. To utilise water resources optimally, it is desirable to find and introduce new ways of interdisciplinary education and transfer of knowledge to developing countries. It should always be realised that traditional approaches as used in the developed countries may not be effective in finding solutions to problems in the developing countries (UNDP, 1991).

The growing body of national and international legislation on water, pollution, and the environment presents a challenge for future water managers, and requires broad training and exchange of professional information.

4.3 Education and training

The need for education and training Education towards improving the water consciousness and water management ability of all nations should be promoted. Education of the public concerning the management and protection of groundwater should be encouraged. Unless people understand why this is necessary, institutional controls will not work.

Extensive educational programmes should be instituted at all levels in society to promote prudent use and conservation of water as one of the indispensable natural resources. Water consciousness at grass-roots level should be fostered through all stages of education to ensure self-help support of rural water schemes created by regional authorities, especially in developing countries. Linkages should be established with good health and domestic hygiene practices.

Education and training programmes should always be reviewed and adjusted in light of the following considerations:

- Why should there be a training programme?
- What should be the subject of training?
- Which people should be trained?
- Who is paying for the training?
- Who should do the training?
- Who will be paid for the training?
- Where should the training take place?
- When should the programme be held?

The role of the international experts in knowledge transfer The cumulative experience of engineers and scientists all over the world forms the solid basis on which water resources development rests. The dissemination of this knowledge to colleagues around the world challenges the professional world community. It has been and is one of the most important tasks of the International Associations in the water field.

For this transfer of information, the scientist or engineer of the developed country should make every effort to concentrate on the needs of his colleague in the developing country, and try to become a true partner. Thereby he may find that a lot can be learned from colleagues in developing countries. For water sciences combine physical, chemical and biological principles of universal validity with local geographic and geological conditions, reflecting the unique situation which exists in each region of the world. For the inclusion of the regional factors one has to go onto the land and study the local conditions, and in obtaining this information, the scientist of that region will be the leader.

The conclusion is that, for water resources development of a region, a person is needed who has an excellent knowledge of the social and natural local conditions. In fact most hydrological or water resources models that have been applied anywhere were developed in response to a local need, and they incorporate the most important features of the local situation. The laboratory in which the methods have been tested is the country in which the hydrologist or engineer or water scientist has worked. The most competent expert is most likely to be a person who knows his or her country inside and out, who knows its people and their needs, and who also has in his professional toolbox the applicable fundamental methods.

The foregoing applies also to the development of professional competence. The practice has been to bring in foreign consultants to evaluate the water resources and to let them plan for the needs of the local people. In future the local scientists and engineers should be trained and motivated to solve their own problems. The expert from the developed country assumes in this scheme a more modest role, that of a partner who may also serve as advisor or teacher. He may have the advantage of better access to basic methods, but his local partner should have, or acquire, the knowledge of the regional situation.

Such a partnership will become a necessity in the future. Only in recent years have we recognised the breadth of the interactions of man with land, water and life, and obtained the means to understand and quantify them. Water resources development today is an integrated activity, requiring an integrated approach. This approach differs from the prevailing fragmented approach to individual problems associated with the use of water in human society. The challenge is posed to the scientific and engineering community to invent new ways for the collection, transfer and application of knowledge to be used in integrating water resources development. They must learn to understand water resources development, not only as a local problem confined to a small region, but as an activity affecting a river basin, a continent or even the whole world, and which must be comprehended as one of many factors in creating a viable environment.

5 Basic Recommendations for Sustainable Development

5.1 Achieving a demand/supply balance

Efficiency and conservation To limit increasing water withdrawal, conservation and efficient use are essential requirements for reaching a balance between growing demands and finite supplies, and should be first development goals before alternative supply projects are constructed. This approach does not require new techniques, but rather more effective use of existing technology, better management, and effective transfer of knowledge and experience. Reduction of water withdrawal, consumption, and waste will also reduce the negative effects of excessive use of water, e.g. decrease wastage in agricultural applications with the important side effect of reducing salination and waterlogging. Professional governmental and non-governmental organisations have much to contribute to 'finding better ways of doing things'.

Non-structural solutions It is imperative for an efficient management of water resources to use non-structural approaches, such as demand management to reduce peak consumption, optimum operation of existing systems through rehabilitation and software applications, and management of land use in flood plains. A multidisciplinary approach must be used for implementation.

Surface and groundwater development Optimisation of water availability on a sustainable basis required conjunctive planning, development and utilisation of ground and surface water resources. All possible sources of water supply should be identified, located and quantified, starting with the hydrologic cycle and including groundwater and exotic sources (i.e. trans-watershed diversion, rainfall and artificial run-off augmentation, importation of water and even of icebergs). While increasingly applied in some areas, desalination is not yet a compatible source for fresh water supply.

Pollution control There is an unfortunate tendency to regard water pollution control as the skilful design and operation of sewage treatment plants regardless of the receiving water's absorption capacity. Instead, standards must be set for land-occupation and air-water use, and direct linkages must be established towards both pollution-control and resource-management. Clear guidance models and management tools of systems analysis for new concepts of water pollution control should be produced for developing countries.

Pollution-prevention should be given preference over reducing or eliminating its consequences, e.g. by means of removing potentially polluting activities, elimination of polluting sources and integrating watershed management. The design of industrial facilities must reflect improvements and knowledge to control micro-pollutants. Contaminated dredged materials must be managed.

The minimum quality of water must be considered where large quantities are used. The introduction of separate systems for supplying potable water as against industrial and agricultural applications may well have to be recognised in the near future.

Environmentally sound projects Environmental, social and cultural considerations should be included in the planning, design, construction, and operation and maintenance of water projects. Projects should be designed to be modified if uses change, or if climate changes may make it necessary. Methods should be developed to include both positive and negative environmental and social effects in project planning, particularly for comparative economic evaluations. Environmentally sound projects for water collection, storage, transport, use and disposal must be identified and developed. State-of-the-art treatment, recovering, recycling, and dilution techniques have to be incorporated to avoid negative effects such as eutrophication, salination and pollution.

5.2 Appropriate management

Project management Planning for development projects should be undertaken by central governments, but their implementation and operation, maintenance and management must be decentralised, and delegated to local entities. Appropriate management techniques and processes must be developed for various cultures, and a universal code of ethics and standard operating procedures should be established for worldwide use.

River basin management Conflicting demands on flows in rivers controlled by dams and reservoirs impose constraints on the distribution, especially during minimum flows. Integrated management of river basins and estuaries, inland seas and lakes should be promoted within national and across international boundaries to share common resources.

Groundwater management A better institutional framework should be promoted to ensure that management and protection of groundwater is incorporated in land use planning. This usually involves developing vulnerability maps, protection zones around sources, and keeping waste dumps and potable water sources apart.

5.3 Overcoming constraints

Human and political factors Research and development on more effective water-use practices must address local conditions, including the attitudes and opinions of water users, especially of farmers, because human attitudes and tradition often are major impediments towards changing established conventions. For example, communication between engineers and farmers is essential, to assure that water scheduling for irrigation is carried out effectively. Human, institutional and political restraining factors have to be overcome in many instances before existing technologies can be applied, adjusted or improved.

Financial needs Financial constraints impose the severest limitation on development of water resources. They not only affect implementation but also education and training activities. In developed countries, new investments become difficult, and can only be overcome by giving high priorities, based on satisfying basic needs, disaster reduction, or disease prevention. For developing countries, financial support on a large scale is required from the international donor organisations to promote the transfer of technology on efficient use of water supply, pollution control and waste management. Financing institutions must be created to support water supply and waste water treatment projects, similar to the successful Planasa Project in Brazil.

To overcome financial constraints, water must not be regarded as a free commodity. Private financial mechanisms should be established for drinking water distribution and waste water treatment facilities, for urban as well as for rural areas. Incentives to cover costs of development and operation can be introduced in the form of staggered price controls. One-time capital costs and recurring operation and maintenance expenses should be introduced on a 'user pays his fair share' principle. Far greater attention should be paid to the involvement of the private sector and to providing appropriate financial incentives to improve the performance of personnel in the water supply and sanitation sectors in developing countries.

5.4 Institutional adjustments

Socio-political interaction Political will-power is needed more than new technology to solve the water resources management problems of the future, such as the huge water and solid-waste point source problems of heavily fertilised agriculture and of the mega-cities. A continuing dialogue between engineers and decision makers should be established in the socio-political arena to assure that the water users' interests and attitudes are taken into account in the development of new water systems. Non-Governmental Organisations (NGOs) should speak up for the people, because a balance is needed between governments (including international units) and the citizens affected by development projects.

Transfer of technical knowledge Fundamental research has led to detailed knowledge of many individual processes related to the water system. The benefits of this extraordinary progress to public health protection through improved water treatment technology and sewage disposal, has yet to reach many of the increasingly urbanised areas of the world. The corresponding detailed and complex models should be incorporated into the information needed at the decision-making levels.

Academic and professional education Teachers should also instruct students about the impact of development engineering on the environment - both factual and philosophical. There is a need for thinking in terms of 'systems'. Academic programmes should be structured to be more effective in meeting the demands of society, for example the US National Research Council Report and the ASCE study of integration of water and environment of Egypt.

International aspects Water-related problems are usually of a local or regional nature, yet where rivers or lakes cross international boundaries, or where seas separate countries, the problems of water consumption and pollution take on an international character requiring a common approach towards finding acceptable and effective solutions. A worldwide exchange of experience in addressing local, regional, national and international problems of water supply and pollution control would be useful. This is particularly true for cases where constraints to their solution have been effectively overcome.

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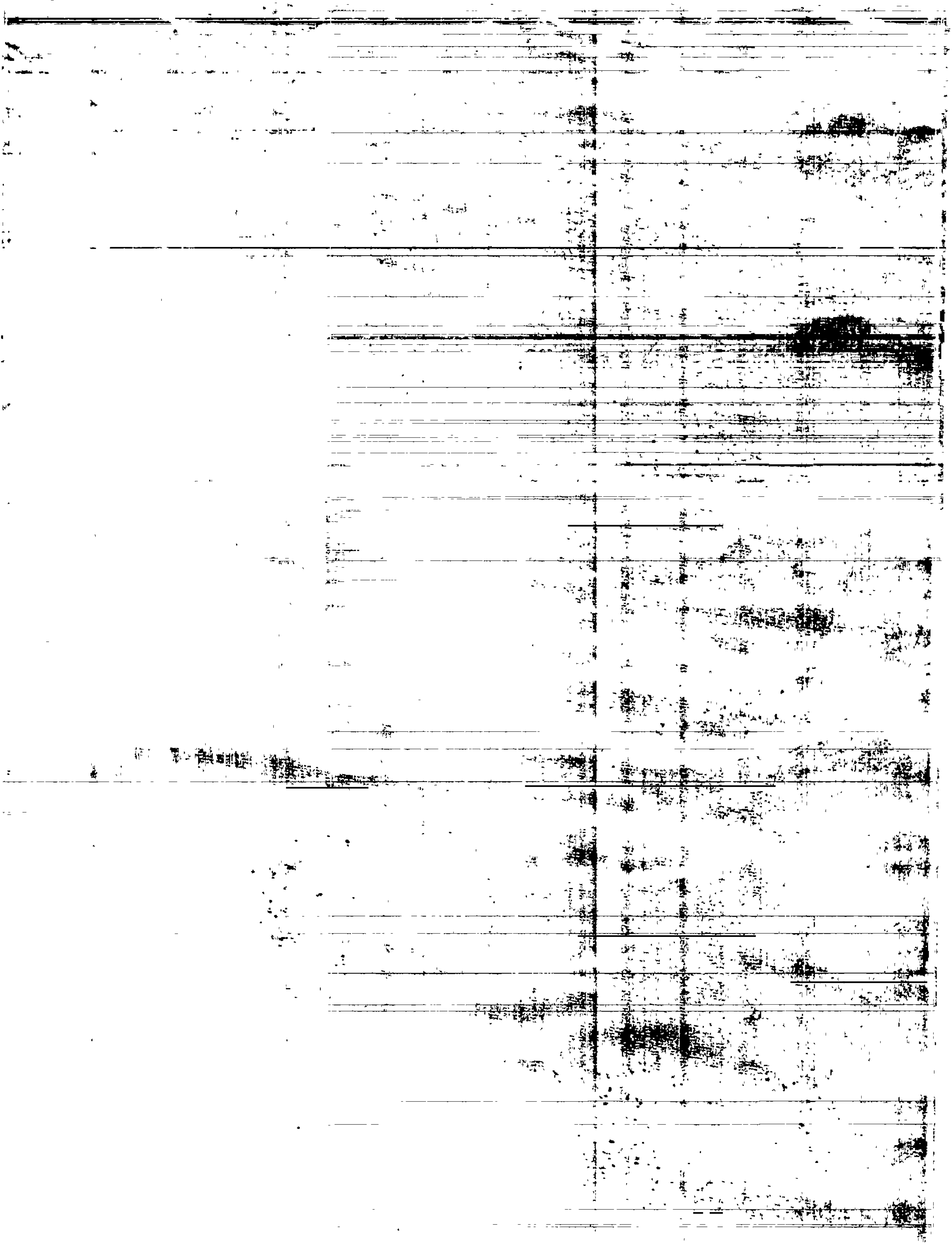

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