L HYDROLOGICAL PROGRAMME

Committee on Water Research
COWAR

Water in our common future

A research agenda for sustainable development of water resources

J. Jordaan, E. J. Plate,
E. Prins and J. Veltrop

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Committee on Water Research

(COWAR)

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Report prepared for the Committee on Water Research (COWAR)

J.M.Jordaan*, E.J.Plate**, J.E.Prins***, J.A.Veltrop****

Chapter 1: THE CHALLENGE OF SUSTAINABLE DEVELOPMENT

Humanity is confronting a self-generated environmental crisis. The perception of the crisis in which we find ourselves is contained (and possibly overstated) in the "Limits to Growth" scenario of the Club of Rome and in the subsequent models developed for and described in the report "Global 2000" (US Council on Environmental Quality, 1980). These reports convey the message that economic development has been in conflict with the environment, and that, if this trend continues, the ultimate downfall of human civilizations under the cumulative effects of population increase, resources depletion, and degradation of the environment is only a question of time.

The conclusion of these reports is substantiated by statistics accumulated over the years, which show clearly a deterioration in global resources. Furthermore, civil strife and migration of people, no longer supported by their native lands or fleeing from natural disasters, are in the news every day. All scientists have seen statistics on energy consumption, on air and soil and water pollution, on increase of greenhouse gases in the atmosphere, on ozone depletion in the upper part of the atmosphere and ozone accumulation in the lower part. And they know from model calculations of atmospheric chemistry that the ozone hole passes excessive amounts of solar ultra violet radiation, and that general circulation models predict global warming and a rise of the sea level. Something must be done, and it must be done on a large scale.

A plan of action and a more optimistic assessment of the crisis is given in the report "Our common future" of the World Commission on Environment and Development (the Brundtland Commission, Brundtland et al.,1987). The Brundtland Commission's report reviews the present pattern of development and economic growth.

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It sets a framework for action by promoting the all-encompassing concept of sustainable development. To quote:

> *"Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs."*

The Brundtland Commission showed that development and environment need not be in conflict, provided that humanity adjusts to the requirements imposed by sustainable development. What this means has been elaborated by Bruce (1992):

> *"First, development must not damage or destroy the basic life support system of our planet earth: the air, the water and the soil, and the biological systems. Second, development must be economically sustainable to provide a continuous flow of goods and services derived from the Earth's natural resources, and thirdly it requires sustainable social systems, at international, national, local and family levels, to ensure the equitable distribution of the benefits of the goods and services produced, and of sustained life supporting systems."*

The report of the Brundtland Commission has given the world a direction for development and a road to an acceptable future, accordingly, it has resonated on all political levels. It ultimately led to the large United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, in June 1992.

Sound and effective management of water resources has a key function in sustainable development. The Brundtland Commission did not recognize specifically the importance of water as lifeblood, and as a factor that limits development. However, this important omission was remedied through subsequent actions on the way to Rio. The general scientific aspects relating to environment and development were discussed in Vienna during the Conference ASCEND 21, organized by ICSU in November 1991. Water issues related to sustainable development were covered in January 1992 in Dublin, during the International Conference on Water and the Environment - Development Issues for the 21st Century (ICWE). The results from both of these preparatory conferences were introduced to UNCED. During UNCED, the issues were clarified, and the actions to be taken were identified in broad outline. The fresh water issues are summarized in Chapter 18 of the AGENDA 21, an outcome of UNCED. The details of how these actions can be performed in the real world are left open; they must be worked out by contributions from all political levels, and from all professions.

Water engineers and scientists are confronted with the challenge of sustainable development and have to translate it into concepts useful in designing, operating and maintaining water resources and water projects. Chapter 2 shows that the most important contributions to efficient and sustainable water use must come from politicians and management. We are keenly aware that most of the problems can be solved with existing technologies, but an appropriate management structure must exist. Water resources engineers have a well developed arsenal of tools available for solving the problems of collecting, distributing and cleaning water. Water research and the collective experience of generations of water engineers have provided them with most of the requisite methods. However, old design concepts must be revised, and new methods must be tested to meet objectives of sustainability - which indeed may require a new understanding of the interactions of nature and society. From this understanding a catalogue of problems arises, for which answers have to be found: answers which require investments in research and technological development.

A primary consequence of sustainability is that the sectorial approach, in which the different categories of water problems - water supply, water quality, hydropower etc. - are seen and solved sectorially, must give way to a more integrated or holistic view, in which water resources problems are intertwined with societal problems at many different levels, and in which scientific problems arise in many different water applications. The sectorial view has an old tradition. The field of water resources even today is divided into many subareas, in which different aspects of the water resources of a region are treated separately. This separation is reflected in the scientific and engineering methods and design rules which are, at least in their terminology, field specific. This approach is reflected also in the national and international organisations which represent sectorial approaches. One of the oldest international associations is the Permanent International Association of Navigation Congresses (PIANC), for port and harbor problems. The International Committee on Large Dams (ICOLD) concentrates on design, construction, and management problems for reservoir systems, the International Commission on Irrigation and Drainage (ICID) deals with all problems associated with agricultural water management, the International Association of Hydrological Sciences (IAHS) deals with the theoretical foundations for describing all components of the hydrologic cycle and its interaction with other cycles such as those of energy and of matter, the International Association for Hydraulic Research (IAHR) focuses on simulation methodology and on fundamental and applied research in hydraulics and hydrodynamics, the International Association of Hydrogeologists (IAH) deals with ground water and groundwater utilization, the International Association for Water Quality (IAWQ) represents scientists and engineers engaged in water pollution research and the control of water quality by technical means, and the International Water Supply Association (IWSA) as well as the International Water Resources Association (IWRA) represent their respective fields. Finally, the International Union of Pure and Applied Chemistry (IUPAC) and the Societas Internationalis Limnologiae (SIL) cover water chemistry and fresh water ecology, respectively. All of them cultivate their specific connection with environmental processes.

The Committee on Water Research (COWAR), of the International Council of Scientific Unions (ICSU) and of the International Union of Technical Associations and Organizations (UATI), has been created to serve as a forum for information exchange among the international non-governmental associations working in the field of water. For these associations COWAR has summarized the research needs arising from the concept of sustainability for the water sciences.

COWAR's results are presented in the following chapters. In Chapter 2, water resources development is presented from the perspective of different scales: the global scale, which gives a brief account of world wide balances and issues, and the regional scale, on which water resources decisions need to be made, and the local scale on which most problems occur. Sustainability is more than the ability to obtain technical solutions: other considerations must enter. These are described in Chapter 3, in which an attempt is made to identify the aspects that make water resources projects sustainable, as exemplified by the supply and demand structure of water resources development for different water uses. Chapter 4 reviews the research requirements and lists the contributions that research can make towards obtaining sustainable development. It shows the close linkages between water research and water resources, hydraulic and sanitary engineering: the solution of water problems for development is primarily an engineering task. In the context of sustainable development the role of the scientist is to provide the engineer with the information which he needs for planning, designing, operating, and managing water resources systems. It is imperative for the challenge of sustainable development that engineers and scientists are seen and act as partners. All international associations represented by COWAR see this common duty as part of their responsibility, and they are active in creating links between engineering and science. How this is accomplished is summarized in Chapter 5.

In preparing this report, many members of the international associations have contributed. Special mention should be made of reports, prepared by P.J.Reynolds, on behalf of IWRA, by A.Müller, for IAHR; T.Milburn, for IAWQ; and for IAH, by M.R.Llamas, W.Back and J.Margat.

Chapter 2: WATER RESOURCES DEVELOPMENT: ISSUES

"The concept of sustainability implies limits: not absolute limits, but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effect of human activities"
(Brundtland Commission, 1987).

The picture that more than any other has shaped our vision of the world in which we live is that of our planet Earth, as seen from a space craft. The blue sphere, with its swirling veil of clouds, silently and beautifully moves through the emptiness of space: a small speck of dust in the infinity of the universe. Its dominating features are the oceans: the Earth is the Water planet. The clouds are a reminder that in an endless cycle of evaporation from the oceans and other water bodies the water is transported by the winds to the continents; the rain from them fills the rivers and the pores of the ground, and it erodes the mountains and washes them into the oceans. During the short time of its residence on and near the surface in the course of this cycle, the water is the basis of support for all life on earth.

In pictures taken from space at night, one can see the lights of the cities with which man has sprinkled the continents. Their area has already covered a substantial part of the inhabitable earth, and no end is in sight of further growth, in number and in demands made by the human populations. The World Bank estimates that about 5.3 billion people now inhabit the earth, and the growth rate is 1.7% per year. Populations are expected to stabilize at some figure between 10 and 23 billion by the middle of the 22nd century (World Bank, 1992). Some interference of man with the water cycle is inevitable: the changes of land use and the use of water for irrigation, for industry and for human consumption must affect the processes of the water cycle and consequently the availability of water. And industry and the many people, will affect the quality of water and change its composition.

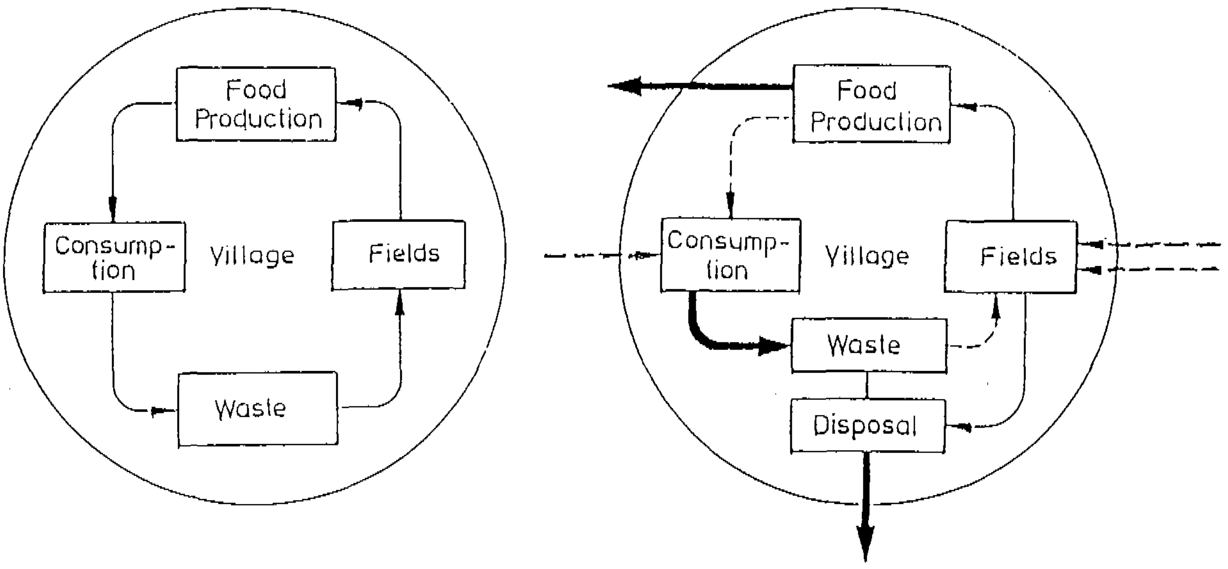
Evidently, sustainable development implies not only economic and resource policies, but also ethical aspects. The value systems of societies everywhere are involved, and water resources management is only one strand in the complicated fabric of development. An accurate definition of what constitutes sustainable development is difficult to formulate. However, if one looks only at water, one can define water resources projects that are sustainable, if water of sufficient quantity and quality and at acceptable prices is available to meet demands now and in the future without causing the environment to deteriorate.

Scales of development of water resources

The translation of sustainability into actions depends on space and time scales. The smallest space scale is that of the village. It is the basic unit of a sustainable interaction of man and his environment. In it, in ancient times, food production, human consumption, and waste disposal were linked in a closed cycle, as schematically indicated in Fig.1a. In theory, such a cycle could be truly sustainable if a stable population would wisely maintain a social structure in which consumption is restricted to the production, in which productivity of the fields is stable, and in which the population did not exceed the carrying capacity of the village land.

Disturbances of this cycle through climatic changes - like that suffered in the Pueblos of the American Southwest, or through overexploitation by increasing populations - as with overgrazed fields or overutilized forests - was felt directly by the local people. They were forced to take corrective action by adjustments of local habits, by moving to another location or by expanding the area of habitation. If such corrections were not made by the people themselves, nature would force them to happen. For example, archeologists studying the habitation pattern of ancient people on the Western shores of Lake Constance found that villages there grew in cycles of about 400 years: settlements started near the shore and villagers gradually exploited more and more of the surroundings, until the overutilization of the land had reached such a wide radius around the village that land use became too cumbersome, (or wars and diseases weakened the population). The village was then given up, only to be resettled after a few generations of recovery in a regular ecological cycle. In such a way, displacements from an equilibrium position of sustainable habitation were compensated as part of a typical ecological feedback loop.

In later days, people began developing technologies for changing the environment to suit their needs. To meet water demands in regions not blessed with sufficient rainfall, ingenious methods were developed to increase the water supply. Ancient Egyptians learned to live with the annual floods of the Nile river, ancient Persians invented underground collection of water by means of qanats. These techniques of water utilization developed by trial and error, and they evolved into viable alternatives to other techniques in use today. In this manner, the small disturbances of the village ecosystem could be damped, in particular in combination with larger units or groups of villages with compensating needs.



a. Internally closed system

b. Sustainable open system

Source: Plate's own design (no reference)

Fig.1: Ecological cycles of sustainable village systems

When man learned to specialize, the local feedback loop was broken, and the village became an element of a larger system. The farmers of the villages became food suppliers of other parts of society, excess population moved to other destinations - mostly to cities, and today the ecological system in which the farmers work is no longer closed, as shown schematically in Fig.1b. Cities and villages and, on a larger scale, whole regions and nations form new ecological systems. Sustainability of a village depends on the sale of its products for acquiring machinery and the fertilizer needed to produce excess food; and wastes are no longer completely disposed of locally. Instead, they are discharged into rivers or transported to dumps. For such a system, local departures from sustainability are strongly affected by an interdependence with the outside: they can be compensated for, or they can be aggravated by, actions in the outside world - that is, in the world outside the field of vision or experience of the local people. The farther the interactions reach, and the larger the interconnected system becomes, the less possible it is for a person to sense the feedback effects of local actions. The city dweller knows little of what his demands do to the villages, and the citizen of one nation knows even less of how his actions influence citizens of other nations. Apart from economic and sociologic implications, this lack of knowledge gives rise to a critical lack of awareness of ecological consequences. A demonstration of this interaction, which is quite obvious in hindsight, is the use of the Syr Darya and Amu Darya rivers for irrigation, as described in Box 1 (from the World Development Report, 1992). Man in modern civilizations no longer recognizes large scale ecological impacts of his local societal actions. Hence, people who live in seemingly peaceful and stable communities (as in the Western world) are not aware that the inputs they require from external sources may cause deterioration of the ecological basis elsewhere.

Box 1: The Aral Sea: Lessons from an ecological disaster

The Aral Sea is dying. Because of the huge diversions of water that have taken place during the past thirty years, particularly for irrigation, the volume of the sea has been reduced by two-thirds. The sea's surface has been sharply diminished, the water in the sea and in surrounding aquifers has become increasingly saline, and the water supplies and health of almost 50 million people in the Aral Sea basin are threatened. Vast areas of salty flatlands have been exposed as the sea has receded, and salt from these areas is being blown across the plains onto neigh-bouring cropland and pastures, causing ecological damage. The frost-free period in the delta of the Amu Darya River, which feeds the Aral Sea, has fallen to less than 180 days-below the minimum required for growing cotton, the region's main cash crop. The changes in the sea have effectively killed a substantial fishing industry, and the variety of fauna in the region has declined drastically. If current trends continued unchecked, the sea would eventually shrink to a saline lake one-sixth of its 1960 size.

This ecological disaster is the consequence of excessive abstraction of water for irrigation purposes from the Amu Darya and Syr Darya rivers, which feed the Aral Sea. Total river runoff into the sea fell from an average 55 cubic kilometres a year in the 1950s to zero in the early 1980s. The irrigation schemes have been a mixed blessing for the populations of the Central Asian republics - Khazakhstan, Kyrghyzstan, Tajikistan, Turkmenistan, and Uzbekistan - which they serve. The diversion of water has provided livelihoods for the region's farmers, but at considerable environmental cost. Soils have been poisoned with salt, overwatering has turned pastureland into bogs, water supplies have become polluted by pesticides and fertilizer residues, and the deteriorating quality of drinking water and sanitation is taking a heavy toll on human health.While it is easy to see how the problem of the Aral Sea might have been avoided, solutions are difficult. A combination of better technical management and appropriate incentives is clearly essential: charging for water or allocating it to the most valuable uses could prompt shifts in cropping patterns and make more water available to industry and households.

But the changes needed are vast, and there is little room for manoeuver. The Central Asian Republics (excluding Kazakhstan) are poor: their incomes are 65 percent of the average in the

former U.S.S.R. In the past, transfers from the central government exceeded 20 percent of national income in Kyrghyzstan and Tajikistan and 12 percent in Uzbekistan. These transfers are no longer available. The regional population of 35 million is growing rapidly, at 2.7 percent a year, and infant mortality is high. The states have become dependent on a specialized but unsustainable pattern of agriculture. Irrigated production of cotton, grapes, fruit, and vegetables accounts for the bulk of export earnings.
Any rapid reduction in the use of irrigation water will reduce living standards further unless these economies receive assistance to help them diversify away from irrigated agriculture. Meanwhile, salinization and dust storms erode the existing land under irrigation.

This in one of the starkest examples of the need to combine development with sound environmental policy.

Source: World Development Report 92

From this (of necessity simplistic) view, one becomes aware that people's perception of sustainability, and thus their motivation for action, depends on their ability to understand the interactions of processes on very different scales. The scale that is best perceived is the **local scale** at which a person can see and understand dependencies. Somewhat more abstract is the **regional scale**, as exemplified by the combination of city and surroundings or by a small river basin. The least comprehensible scale is the **global scale** of international or even larger interactions that an individual can only understand in an abstract way; it is so far outside his experience that he cannot see the connection between his actions and their effects (these scales are roughly equivalent to those identified by Falkenmark and Lundquist, 1992).

At the local scale, people are best motivated according to the standards of their community, they contribute to local development and they are most willing to make sacrifices for maintaining or shaping the local environment, within the constraints set by the outside. The prototype of the local scale is the village, but larger systems including cities can also be overseen and successfully managed - even though, as many examples of cities including some in the Western countries show, large cities often exceed the local scale and become difficult to manage.

The regional scale is the scale of societal actions, at which the individual is a partner in a regional endeavour, for example a regional water resources development project. With a well conceived action of sustainable development, the benefits from the increase in well-being of the majority of the people exceed the costs, and the interests of the individual are subjugated to the interest of the region. In such actions, many early civilizations had their origin, and many of the important projects of today are developed on this scale.

The survival of human civilization will ultimately be determined by the ability of the people to master sustainability on a global scale. Sustainability is characterized by small interactions over large distances whose effect can be detected only in world statistics, and which may be overlain by other influences. Does the burning of fossil fuels in Europe contribute to water shortage in Africa? Up to the present, the reports of increasing vulnerability of far away regions, or of long-term changes in environment, have had little influence on individual life styles. An example of far reaching and not well perceived impacts is the state of the water quality of the North Sea (Box 2). Although most of the countries bordering this part of the ocean have large parts of the population that are concerned about environmental degradation, the actions required for protecting the North Sea involve difficult national issues and are progressing very slowly.

Box 2: Aspects of North Sea Pollution

The North Sea is the most densely navigated sea in the world. Besides shipping usage, there is the offshore oil industry, telephone cables criss-cross it and there is military and recreational use. It is a rich and productive sea with resources which include not only fish but crucial minerals such as oil, gas, sand and gravel. These activities are important to the surrounding countries for they play a crucial part in their economies.

As a sea used on this intensive scale and surrounded by advance industrialised countries .which produce large waste flows, pollution problems are serious. The main pollution sources include: - rivers and other outfalls; dumping by ships of dredged materials, sewage sludge and chemical wastes; operational discharges from offshore installations and from ships. Atmospheric pollution entering the sea is an other and major cause of pollution.
Those parts of the sea at greatest risk from pollution are where the sediments come to rest, where the water replacement is slowest and where nutrient concentrations and biological productivity are highest. Included in these are Netherlands coastal waters, particularly the Wadden Sea, the German Bight and parts of the sea of the Danish west coast and Norwegian southern coast. The central and northern areas of the North Sea, are so far relatively free from pollution.

A number of warning signals have been received from the North Sea as it reacts to the stresses which are caused by the pollution which pours into it. These include:

- algal populations have changed in number and species. There have been large algal blooms, caused by excessive nutrient discharge from land and atmospheric sources;
- species changes show a tendency towards more short living species of the opportunist type and a reduction, sometimes drastic to the point of disappearance, of some mammals and fish species and the sea grass community, polychaetes, coelenterates and meiofauna, but a decrease of ray, mackerel, sand eel, and echinoderms. Reductions due to eutrophication have also reduced plaice, cod, haddock and dab, mollusca and scoter. The negative impact of eutrophication could be due to enforced competition. Sole is the only fish species which benefits from eutrophication.
- However the impact of fishing activities is also considerable. It has been shown that fish stocks are mainly affected by fisheries, whereas mammals and birds are mainly affected by pollution and zoobenthos by eutrophication. Fisheries do, though, contribute a great deal to disturbance in mammals and bird populations as well aszoobenthos. It is not yet clear whether big differences observed between 1930 and contemporary fishing etc. stocks is caused by fisheries or pollution.
- particular concern has been expressed about the Wadden Sea which exerts a nursery function for many North Sea species. PCB contamination, for example, almost caused the disappearance of seals in the 1970's. Also the 1988 massive seal mortality in the North and Wadden Seas, although caused by a viral disease, is still thought by many to have a link with marine pollution.
- fish diseases off the Netherlands coast and in the German Bight are being seen increasingly as a manifestation of marine pollution.

Although the North Sea is sick enough to need radical and lengthy treatment it is not a terminal case.

The crucial question is: are people willing and prepared to follow the courses of action necessary for global sustainability, particularly in the First World? Can they be convinced, even when the urgency of actions appears locally to be contradicted by the evidence: in Europe life expectancy still increases almost everywhere, instead of decreasing, and are costs of basic foods and raw materials not increasing? The answer to this question will depend on the ability of scientists to convince political leaders, and of political leaders to convince their constituents, to follow unpopular actions whose benefits accrue in far away places or in the distant future, and to subjugate their personal well-being to the larger requirements of a sustainably developing world.

Water use: The global scale

Water is both a chemical substance vital to life on earth, and thus a good that is consumed, and a carrier of other substances or properties, such as heat, disease vectors, pollutants, energy, and a means for navigation. Consumption of water does not mean its conversion to other chemical forms but implies conversion of water to vapor, heated water, or polluted water. Whereas the total quantity of water on earth remains constant, its quality can change. Such a change might be very slow: the conversion of rainwater to the salty water of the sea is a result of the erosion of the land over a geological time scale. The pollution of water by human actions acts on a much shorter time scale. It is felt in surface waters, ground waters, and in the near shore regions of the oceans. The fixed amount of water available on earth sets an absolute limit on water use.

Table 1: Water resources of the earth

The circulating water constists on the average, i.e. without distinguishing the specific differences of continents, of:	
towards the continents:	
- precipitation	110,000 km^3/year
away from the continents:	
- evaporation	70,000 km^3/year
- discharge into oceans:	
by rivers	14,000 km^3/year
by groundwater flow	26,000 km^3/year
The stored water consists primarily of the water that is easily accessible, being pre-eminently the source for society and its environment:	
Sources with easy accessibility:	
rivers, canals	1,700 km^3
moors	3,600 km^3
lakes	120,000 km^3
reservoirs	5,000 km^3
top layer groundwater	65,000
	195,300 km^3

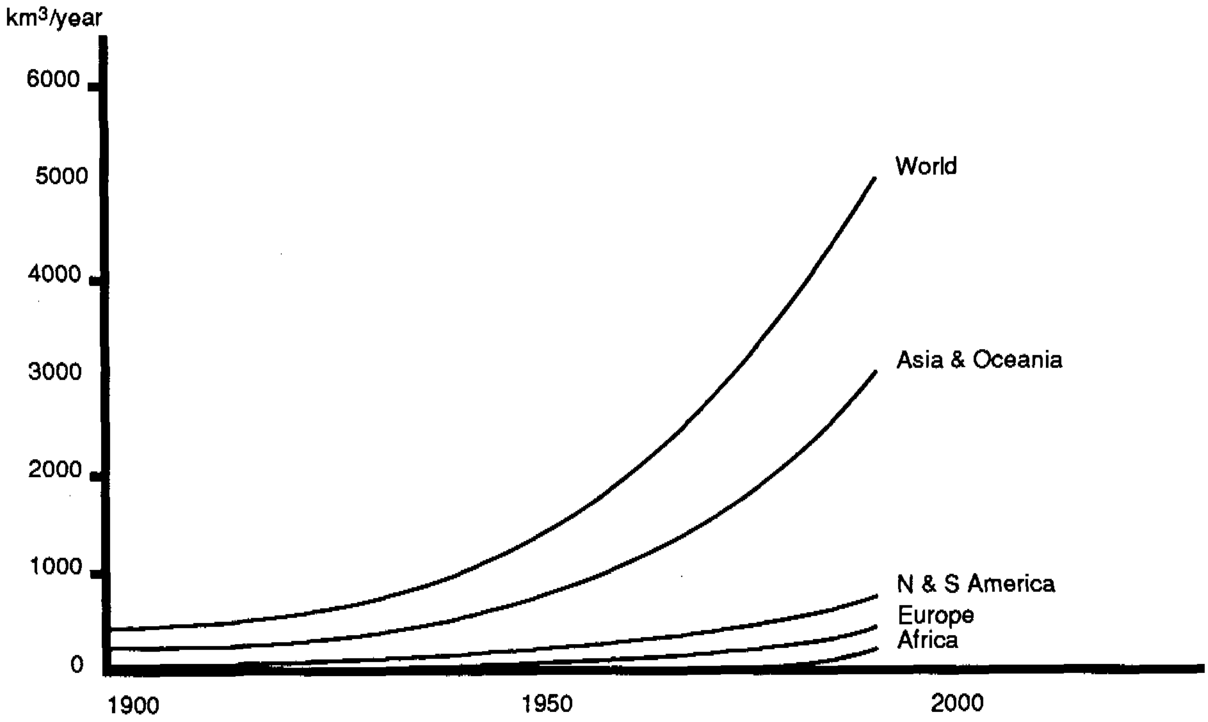
Water consumption. - The consumption of water is the basis of all life. On a global scale, the amount of consumable fresh water is sufficient for all foreseeable purposes. There is enough drinking water and water for food and energy production for a human population much larger than the limits set by other resources. As shown in Table 1, only a fraction of the total fresh water is used for human needs. However, a large part of the water is not directly accessible because it is either trapped in polar ice or in deep groundwater aquifers, so that recovery is possible only at high costs. The usable water at this time is taken mostly from surface waters. More than 95% of all fresh water is lodged in ground water, about half of it is within the earth crust down to a depth of 800m; only 1,5% is in rivers and lakes. As a consequence, groundwater may well become the most important source of freshwater in the future. For human consumption, a total volume of freshwater from all sources of some 4000 km^3/year was used in 1980, but this volume is to increase to about 9500 km^3/year in the year 2000 AD. Foreseen trends in water demand are illustrated in Fig. 2.

Water consumption is not, however, a question of global quantity, but rather one of local availability; the latter is governed by a non-uniform distribution of fresh water in space and time, and the need to redistribute either the water or the populations. The usable fresh water per capita of the world population is about 7000 m^3/year, whereas the minimum need is only about 2000 m^3/year. However, in many countries, in particular in the Middle East and North Africa, a high percentage of the population has less than 2000 m^3/year per inhabitant.

Water demand globally is primarily that for irrigation for the production of food. For example, it takes about 1000 tons of water to grow one ton of grain, and 2000 tons to grow one ton of rice. Of the total water demand foreseen for the year 2000, 80% is for irrigation, and 20% for all other uses. The total irrigated area in the world is about 250 million hectares, of which about 160 million ha are in developing countries. Agriculture is by far the largest consumer of water, especially so since the water that serves rainfed agriculture is not counted in these figures. Irrigation served only about 15% of all the lands of developing countries, but it produced about 36% of the yield, and estimates [FAO, 1989] indicate, that the food for the increased populations in these countries came almost exclusively from the expansion of irrigated land. A cause of concern therefore is the trend for the rate of development of irrigation to decrease; partly because of water logging or salinity enrichment many irrigated areas have had to be abandoned, or have had lower yields. On a global scale, no less than 200.000 ha are lost every year to water logging and salinity. Also, new irrigation must rely on less valuable or less accessible land. The decline in the rate of expansion is shown in Fig.3 (from FAO, 1989). In the long run, water demand for irrigation is limited not only through water supply, but more and more also through the amount of suitable land.

TRENDS IN WATER CONSUMPTION (in km3 / year)

	1900	1940	1950	1960	1970	1980	1990	2000	%
AFRICA	41.8	49.2	56.2	86.2	116	168	232	317	6.1 %
EUROPE	37.5	70.9	93.8	105	294	435	554	673	13 %
N + S AMERICA	84.5	249	345	475	641	774	874	1012	19.5 %
ASIA + OCEANIA	416	689	869	1237	1543	1940	2480	3190	61.4 %
WORLD	580	1060	1350	1980	2590	3320	4140	5190	100 %

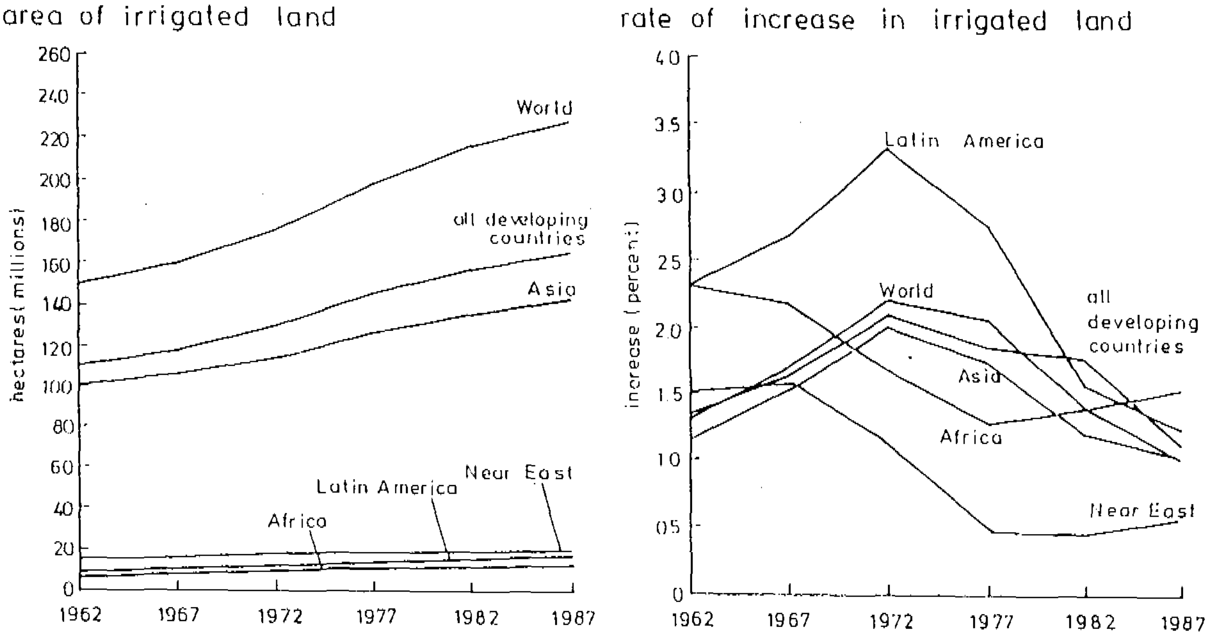


Source: ICWE, 1992 D.B. Gupta

Fig.2: Trends in water consumption of the world

Land use. - The need for land has reshaped large parts of the globe; tropical and other forests have been cleared to make room for agriculture, and in many places the removal of the plant cover has led to erosion of fertile top soil. Even countries blessed with large rainfall have become subject to drought after the rainy season. In other parts, in particular in the Sahel region of North Africa, once fertile lands, have become deserts.

Increases in deforestation and in the overuse of land are inextricably linked with the increases in occurrence of excessive floods and droughts. The resulting disasters affect many humans, and they make headlines almost daily. The masses of people moved by the droughts in Somalia and the flood disasters afflicting the people living in the delta of Brahmaputra and Ganges in Bangladesh are only two of the increasingly severe results of the combined effect of over-utilization of land, over-population, and social unrest.



Source: FAO, 1989

Fig.3: Trends in irrigation development

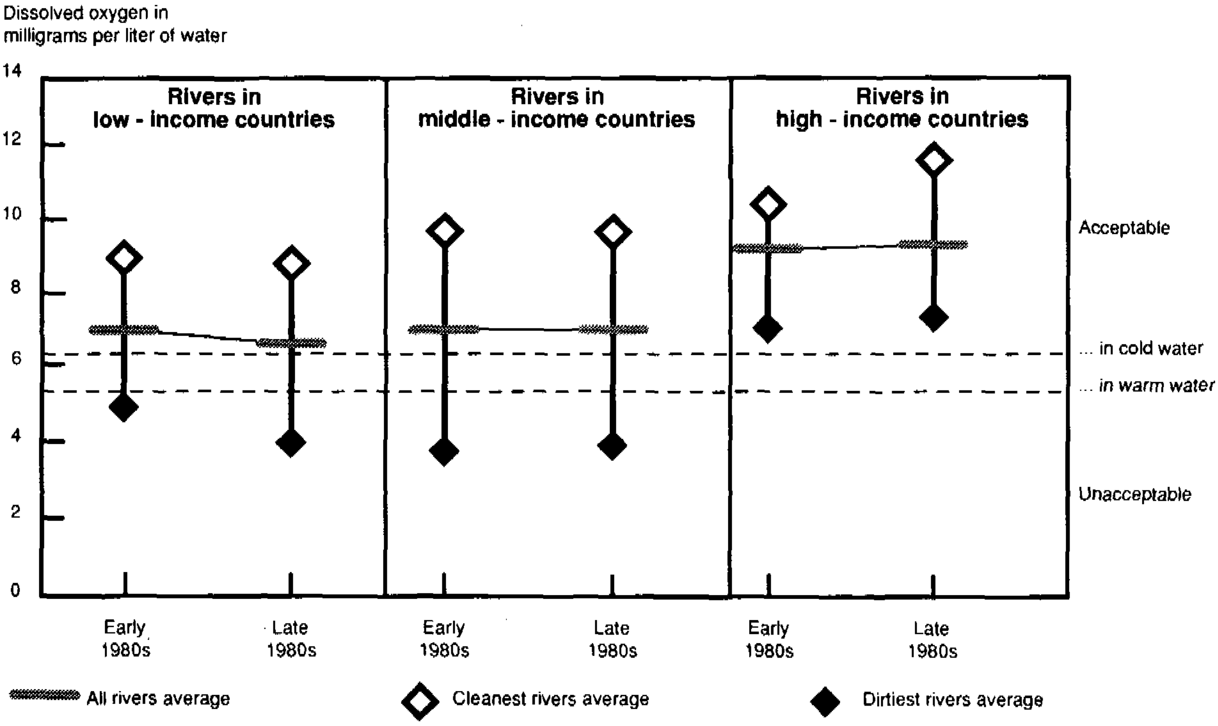
Water quality. - A great strain already acts on water supply systems for drinking water, and it will increase in the future, because the mega-cities are growing alarmingly. Historically, civilizations developed along major rivers, and most large cities today, are in such locations. However, the water from rivers or local groundwater sources no longer suffices, mostly because of its poor quality, and many new mega-cities are being created without consideration of the local availability of water. Hence, they will have to be supplied with water from reservoirs or aquifers and transported by aqueducts and tunnels often over great distances. By the year 2000, about 50% of the world's population is expected to live in large urban areas.

Water quality problems are not restricted to cities. In 1985, at the midpoint of the International Water Supply and Sanitation Decade, although 870 million people lived in urban areas of the developing world, roughly 1,6 billion were rural inhabitants. Approximately 22% of the urban group were without a water supply service, and 40% were without sanitation. The corresponding numbers for the rural population were 64% and almost 85%. The data show that for the urban populations the percentage of the people unserviced is roughly the same as it was in 1970, mostly due to population increases in urban areas of developing countries. In the same period, the situation improved in rural water supply. The decade, however, lost ground in rural sanitation. This is unfortunate, since the lack of sanitation facilities and the usually associated unsafe drinking water are still among the principal causes of disease and death in the developing world. The World Health Organisation (WHO) estimates that 25 000 people die per day from waterborne diseases in developing countries. Especially in the poorest countries, people fall sick and die from infected water supplies; the result can be outbreaks of typhoid, cholera, amoebic infections, bacillary dysentery and diarrhoea. Water-borne diseases account for 8% of all diseases in developing countries, and for 90% of the 13 million child deaths each year. Specific measures by national and international agencies to counter water related threats are imposed but difficult to control in full. Lack of money and inadequate local management lowers their effectiveness.

Water quality degradation is also an unpleasant side effect both of unchecked industrial development and of uncontrolled urban growth. Water is used in many industrial activities, for instance for food processing and for the production of metals, chemicals, textiles and paper. Today, in the developed world, industry uses between 40-80% of total water withdrawals; comparable figures for developing countries are 2-5%. The latter amounts are likely to grow as developing countries reach their development objectives. This will substantially increase demands on water and water quality. Unless a compensating link is established between environment and development, degradation of water quality is inevitable. As long as no balance is achieved between private pollution and public effect of resource degradation, there is no economic incentive to reduce private pollution. It is well known (for example, as stated in the World Development Report, 1992, da Cunha, 1987), that if environmental degradation is calculated as an economic factor, then protection of the environment is a viable economical option. Only countries with high income can at this time clean the water discharged from cities, industries, or heavily fertilized fields. For many developing countries, such a solution is not feasible. Many nations today depend on the long term degradation of their resources and their environment for the short term gain of having their populations fed and clothed. The absence of sewage treatment in many cities in the developing world, and in some cases in more developed countries, has resulted in severe pollution, as has the discharge of large quantities of waste water into rivers and lakes. A danger sign is the quality of the rivers: a comparison in Fig.4 shows that while the immense capital investments in urban infrastructure of the highly industrialized countries have gradually improved the quality of their rivers over the years, the water quality of the rivers in the less developed regions of the world is declining.

Bacteriological pollution of drinking wells is widespread in Africa. Industrial pollution is becoming a major problem in the newly industrializing countries of Eastern Asia and Latin America, as well, because short-term economic improvement is given high priority and enforcement of regulations is often weak. In recent decades, industrialization was pushed in these countries, while adequate but costly treatment was often neglected. Mining is the biggest source of water pollution in Latin America. In many countries, cities are growing too fast for sewage and waste water treatment systems to keep pace, and no arrangements are being made for the sustainable use of water resources. Legislation is needed in developing countries to stop pollution that is being caused in the process of industrial development.

Just as chemical pollution of near surface ground waters is a disaster of the rich, bacteriological and biological pollution is a tragedy of the poor. Significant scientific input will be required to obtain an adequate understanding of these ecological processes in order to develop effective counter measures.



Source: World Bank, 1992

Fig.4: Water quality of rivers of the world

Energy. - The transport of energy by water is a process that man has used since ancient times. The potential energy stored in the water is a direct conversion of solar energy through the hydrological cycle. Hydropower is the only feasible large scale source of solar energy. Not only does the sun provide the energy by evaporating water from the earth surface, but nature also provides the energy collection system through the system of rivers and streams. Of the approximately 15 million GWh/year of exploitable hydro energy, only about 14% is in operation; an additional 3.2% is under construction and another 7.4% is being planned. Such resources in the developed countries have been utilized to a level of more than 50%, whereas the level in Africa is only 4%. The largest potentials are in South America and USSR; most of the active planning is now going on in China, India and Russia, followed by Brazil and Canada. Unfortunately, hydropower can only provide a small fraction of the energy requirements of modern civilizations even if innovative approaches are followed; an example is tapping the tremendous energy set free in the melting and reforming of the polar ice caps.

Need for action. - The overall global picture is not encouraging. Humanity will need to exert extreme efforts to reverse the trend toward further degradation. A small but encouraging sign that this may yet be possible is given by the universal acceptance of the ban on sprays to prevent hydrofluorocarbons from further destroying the ozone layer of the upper atmosphere, and by the pledge of many countries to reduce CO_2 and motor vehicle exhaust. However, global resolutions such as the Earth Charter proposed by UNCED are no substitutes for global actions. These must be the sum of an infinity of personal efforts of engaged people at the local level. The chance of future generations depends on the success of this generation to attain truly sustainable development at local and regional scales everywhere.

Water Resources Development: sectorial projects on regional and local scales

On a local scale, experience and engineering have yielded solutions to most water needs; water supply and sanitation, agricultural needs, protection against floods, energy production, and to some extent, transportation. Conventionally, a sectorial approach to water resources development was and is used; in it the needs are approached individually. Depending on the value system of a nation, the political will, available resources and available infrastructure, sectorial systems have been developed that are capable of meeting the needs adequately. However, no water resources project is entirely without impact, and coping with the negative impacts of technical and other solutions for meeting these needs has become an important issue for water resources development. A few examples serve to illustrate the process.

Drinking water and sanitation

Most important among these uses is that of water for drinking purposes, and it is inextricably linked with issues of water quality. Drinking water and sanitation are two sides of the same coin. According to the UN (1991), water supply includes the traditional activities - to locate, develop and exploit new sources of water in a cost effective way, and demand management addresses the ways in which water is used and the various tools available to promote more desirable levels and patterns of use. In economic terms, water supply is the water delivered at the entry point to the distribution system (after treatment), and demand is what comes thereafter. Demand includes social demand as well as the distribution system to meet this demand. Water distribution systems exist that range from public wells or springs and street vendors of water to elaborate city distribution systems involving extensive networks of pipes, that are supplied through pumping stations, and temporary storage in water tanks.

Drinking water and its sources. - The traditional sources of water are the surface waters such as lakes and rivers, mainly because of easy accessibility. Groundwater used to come primarily from artesian wells, and it was used only if surface water sources were insufficient or unreliable. For domestic water supply, and in many cases also for agriculture, particularly, for high value cash crops, current tendencies are towards more extensive use of groundwater. Today, in many countries, most of the water for urban and domestic water supply is from groundwater. Surface waters are usually not pure enough to be used directly and the water has to be treated to remove pollutants and disease vectors and to filter out impurities. The use of ground- water has many advantages, one is its nearly constant temperature throughout the year (corresponding roughly to the average annual temperature of the region). In addition, a purifying action takes place as the surface water infiltrates into the soil.

Against these advantages one must weigh the disadvantages. Groundwater is increasingly threatened by pollution and encroachment of urban settlements, and extensive protective actions have to be taken to preserve its quality. Energy is required for pumping, a process that involves considerable investments and operating costs. Other disadvantages arise from the difficulty of locating and assessing the yield of groundwater resources. Poor assessment of groundwater resources, wrong analysis of the consequences of groundwater exploitation, or lack of technical understanding and inadequate institutional frameworks may lead to an irreversible loss of groundwater. However, current technology makes possible the reliable determiniation of the quantity of available groundwater, so that overly conservative assessments that would lead to not using a valuable resource in favor of more costly alternate solutions can be avoided .

Sometimes, conjunctive use allows us to combine the advantages of both groundwater and surface water. Typical management for drinking water in parts of Europe is based on the use of groundwater as the basic supply, and its augmentation in times of large demands by water from a reservoir. Also water from polluted rivers is cleaned by means of bank filtration, or artificial recharge of groundwater. In other parts of the world, where high evaporation rates make it prudent to use surface water as quickly as possible, groundwater is used as the emergency supply. Sophisticated management strategies are used, for example in Israel, to maximize the amount of water available through an efficient combination of infiltrating surface water and pumping groundwater.

Drinking water has been obtained by desalination of sea water and brackish groundwater. This technology is expensive, and in its high investment cost, can be overcome only if the requisite equipment can be produced in sufficiently large quantities, and if the high energy consumption of the desalination process can be reduced. The energy requirement with different technologies is summarized in Table 2, which shows that this technology is feasible only where energy is cheap and water extremely scarce, as on the Arabian Peninsula.

Table 2: Energy requirement for desalination

Method	Consumption of energy
Evaporation method	ca. 25
Reverse osmosis method	ca. 7
LNG heating and cooling method	ca. 3
Trans-evaporation method	ca. 12
- in using solar energy and waste heat	ca. 3
Electric dialysis method	ca. 18
Solar energy using method	
- direct method	ca. 1
- in combination with evaporation method	ca. 4
- in combination with electric dialysis method	ca. 7

Data: according to the investigation of Ministry of International Trade and Industry, Japan

Sanitation. - The disposal of sewage and other polluted waters has been a major challenge to science and engineering for more than a century. It is a major factor in the health care system of a country. In developed countries, sewage from domestic sources is collected in closed conduit sewer systems, and these need large quantities of water as waste carrier; in many developing countries, the sewers are open, either man-made or natural channels, or the sewage is not diluted by water and is collected instead as night soil. For locations where dilution of the sewage is not feasible, sewage disposal plants have been designed and operated according to principles based both on scientific principles and trial and error optimization.

Wherever possible, the prevention of pollution is preferable to the reduction or elimination of its consequences, e.g. by means of removing potentially polluting activities, eliminating pollution sources and integrating watershed management. This aspect is particularly important for the protection of groundwater which, once polluted, cannot be cleaned without great effort and large expense.

Irrigation and land management

Irrigation is one of the oldest methods that man has used to compensate for the variability of the natural rainfall. A tremendous amount of experience has been gained locally by trial and error, and by irrigation engineers who have worked in many different regions. Large differences exist in the irrigation practice of developed versus developing countries; these are mainly caused by differences in constraints set by climate, tradition and social structure. The percentage distribution among the use of water for irrigation and industry clearly indicates the degree of industrial development: in industrialized countries a high percentage of water is used for industries, and so a relatively low percentage is used for irrigation, whereas in less developed countries the water use for irrigation dominates and is often 80-90%.

Irrigation in developed countries. - In developed countries farming is a business with low labor and high technical inputs. Because of the relatively high income from his product, the farmer can invest in farm equipment and irrigation systems, and in some areas where energy is cheap (such as in the USA) he can use groundwater for irrigation, as described in Box 3. If groundwater is used only to the extent that it is replenished by rainfall, its use is clearly sustainable. If more water is used than recharged, so that water is mined like a mineral, it is not. A self-regulating mechanism against excessive withdrawal of groundwater arises from the cost involved in pumping from increasingly deeper groundwater resources. These expenses have led in some areas to the abandonment of farms that were irrigated with groundwater. An example is the use of the famous Ogallalla aquifer in the Middle West of the United States of America, described in Box 3. Only if groundwater reserves are vast, as seems to be the case in the Libyan Sahara (see Box 4), or if the use is only temporary, groundwater may be mined.

Box 3: Ogallalla Aquifer

The Ogallala Aquifer is situated in the mid-western United Sates between about 95^0 and 105^0 longitude and 32^0 to 42^0 latitude. It includes parts of the states of Nebraska, Colorado, Kansas, Oklahoma, New Mexico, and Texas. The region has highly productive soils, a relative level terrain, and a temperate climate. Although it is only about 6 percent of the land in the United Sates, it includes almost 13 million hectares of cropland and produces over 15 percent of the total value of wheat, corn, sorghum, and cotton and about 38 percent of the total value of the livestock produced in the country.

The Ogallala Aquifer area is dry and very windy. Normal annual precipitation is only about 46 centimetres per year. hence, over 40 percent of the cropland in the area is irrigated. The prevailing westerly winds induce high evaporation rates and wind-drift water losses for conventional sprinkler irrigation systems.

Over 90 percent of the irrigation water used in the area is pumped from the Ogallala Aquifer. The aquifer depends almost entirely on on-site precipitation for recharge. In the southern portion of the aquifer the recharge rate is estimated to average only about 1 centimetre per year, a mere 20 percent of what would be needed to replace the water currently being withdrawn for irrigation. Nevertheless, the aquifer, which stores approximately 3.6 trillion cubic meters, is a major source of high quality water.

Since the end of the Second World War, modern pumping technologies have made it possible to use water from this aquifer for irrigation. In 1950, the total irrigated area was about 1.4 million hectares. In 1980, it had reached close to 5.7 million hectares. However, the last decade has seen a 20 percent decline in areas under irrigation in the six states in the region. Several factors including increased pumping costs caused by declining groundwater elevations, rising fuel costs, and relatively low commodity prices, are responsible for the decline. In Texas the water table has dropped more than 15 meters over 25 percent of the area of the aquifer since 1940.

Box 4: Water from the Sahara in Lybia

For centuries the vast deserts of Southern Libya formed a barrier crossed only by caravan trade routes which followed established tracks from oasis to oasis. From 1953, these vast and largely unknown areas were progressively investigated in the search for new oilfields. This led not only to the discovery of large oil reservoirs but also great quantities of fresh water, as a consequence of the geology of Libya.

During the ice ages in northern Europe, the climate of North Africa became temperate and there was considerable rainfall. The excess rainfall infiltrated into the ground and was trapped in the porous rocks between impermeable layers, forming reservoirs of underground fresh water. The majority of this fresh water is between 38,000 and 14,000 years old.

Four major underground basins have been located. The Kufra basin of 20,000 km^3 storage capacity; depth over 2,000 m, with water of excellent quality (salts in sollution 250 mg/l); the Sirt basin (10,000 km^3, 600 m), the Murzak basin (4,800 km^3, 800 m) and the Hamadah/Jufrah aquifer.

The expanding economy and growing population along the fertile coastal strip of the Socialist People's Libyan Arab Jamahiriya is creating an increasing demand for water for irrigation, for industry and for domestic and municipal use. At the same time, the traditional water resources are becoming increasingly at risk through intensive use which is resulting in saline intrusion of the coastal aquifer. This phenomenon would, if unchecked, turn agricultural lands into infertile sabkha.

Extraction of the water known to lie below the desert has been contemplated for many years. In 1974, Libya took the first steps towards exploitation of this valuable resource when studies were commenced which were to develop into the implementation of the Great Man-made River Project. This will deliver large quantities of water over immense distances, from deep in the desert up to the agricultural coastal areas. It has been demonstrated that its utilisation in the desert areas overlying these water resources would be uneconomical, while conveying this underground water from the desert to the coastal region provides a source that is more economical than any other alternative.

Additionally, the Great Man-made River Project will provide water for industrial, domestic and municipal use.

The wellfields for the project are being constructed 400 to 700 kilometres inland to tap the better quality water available there. They are spread over large areas where the aquifers come close to the surface.

The project development is planned in five phases. The first phase, the largest, was inaugurated 28 August 1991, and consists of a system that will extract and carry two million m^3 of water daily (23m^3/s) to the coastal region where the majority of the population lives.

However, this system is designed to be expanded to carry 3.68 million m^3 of water daily in the future, utilising a total of about 1,900 kilometres of pre-stressed concrete cylinder pipe, ranging between 1.6 metres in diameter for wellfield networks and 4.0 metres in diameters for the main conveyance pipeline, laid and buried in a six to seven metre deep trench.

The wells are about 450 metres deep, and submersible pumps are used within the wells at a depth of about 145 metres.

The flow rate per well is 120 l/s which means that about 200 wells make up for the 2 million m^3 per day.

Source: The Great Man-made River Project, 1989, Management and Implementation Authorithy.

Recently, ways have been explored to augment the groundwater reserves by infiltration of excess surface waters from floods, or by infiltration of waste water. In some regions groundwater and surface water are used in conjunction. The energy required for pumping groundwater in one part of an irrigated area may be obtained during releases from a reservoir for irrigating other parts of the area.

The application of drip irrigation, water conveyance through pipe lines rather than through open and unlined canals, and other efficient water supply techniques are expected to lead to major changes in the design of agricultural projects. A revolution of irrigation has been the development of the center pivot irrigation system, in which a large rotating arm (about 160 m long) is mounted on wheels and rotates around a vertical pipe through which water is supplied to nozzles on the rotating arm. The original designs, in which the driving force came from the nozzles, have been generally replaced by designs with motor driven rotation, so as to reduce evaporation losses. With modern designs of nozzles, the losses of these systems due to evaporation can be kept to less than 5% of the applied water, but this design must be operated so as to prevent over- or under-irrigation.

The constraints on irrigation in developed countries stem primarily from competition for agricultural water with municipal and industrial water uses. If water is scarce, irrigation water must compete with other demands. Competitive and inefficient use of limited regional water supplies by irrigated agriculture and industry is a major threat to the sustainability of water supplies. The collective water use must be optimized for all of the local needs rather than for agricultural production alone. Because of the absolute priority for drinking water, the distribution of scarce water between domestic/municipal, industrial and agricultural sectors will usually shift to favor the first.

Irrigation in developing countries. - In developing countries irrigated agriculture primarily depends on surface water. These irrigation schemes were originally conceived as vehicles for development, self sufficiency in food, poverty alleviation, rural development, and reduction in urban migration. Although irrigation in Asia has helped to double agricultural yields, has increased double cropping intensity, and has generally reduced starvation (which was familiar as recently as the 1960's and early 1970's), irrigation has failed to deliver the anticipated benefits in developing countries. The reason is that the situation in developing countries is more complex. Social, political and policy issues result in low incomes for the farmers of somewhere around 150 to 200 US$ per hectare per year, and in small landholdings from 0.5 to 5 ha per farmer. This situation precludes the possibility of private capital investment. As a consequence, the efficiency of water use remains low, because lining of canals cannot be afforded; also crop yields are low - rice yield is about 1.5 tons/ha, even though cash intensive agriculture yields 5 tons/ha - because fertilizers and pesticides cannot be purchased.

The largest improvements in existing irrigation systems are expected to occur through diversification; which depends on adapting crops, like introducing drought or disease resistant plants. Crops should be optimally adapted to local climates and soil conditions. All will depend on good management and good engineering solutions. Engineering approaches are likely to consist of applications of known principles, and to involve transfers of technology to improve efficiency. For example, only about 30% of the water in a reservoir is actually transpired by plants, the rest is lost to seepage from leaky canals or to evaporation.

Environmental problems of irrigation. - It is vital that irrigation and drainage go together to avoid salinity problems in the irrigated areas. Also, it is vital that the structures associated with irrigation systems are properly maintained. If these concepts are respected, irrigation systems can be and have been sustained over long periods by present practices. Numerous examples of well functioning irrigation systems exist all around the world, in which operation and maintenance work hand in hand. On the contrary, the examples of irrigation systems destroyed by siltation of the reservoir supplying the system or by salinisation of the soil are usually results of faulty application of well known rules, of negligence, or of incomplete development. An example of improper practice is to leave out the drainage in order to save on capital investment.

Indirectly, irrigation has had a number of detrimental consequences, in particular, changes in water quality and water logging. Drainage water from irrigated fields and surface runoff are carriers of excess fertilizers and pesticides, and these can affect adversely the further, secondary use of the water in downstream regions. Another relevant issue is the quality of irrigation water which is impacted on by industrial and municipal water needs, and more importantly by highly intensive agricultural practices, such as the extensive application of fertilizers and pesticides, or by the influx of seepage from feed lots. And finally, the creation of habitats favorable to carriers of water borne diseases, such as snails and mosquitoes, should be avoided.

The pollution input from agricultural fields is increased by substances attached to the soil that are removed through surface erosion. This occurrence is another reason why loss of fertile soil due to erosion by wind, rain, or melting snow should be prevented. A world-wide exchange of experience on appropriate technologies for erosion reduction is desirable.

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

Groundwater is usually only a secondary issue in decisions regarding land use in highly populated and industrialized countries. Therefore groundwater protection has yet to find its place within the conflicting interests of infrastructure, industry and agriculture. Improved land use management, needed to increase recharge by reducing run-off and evaporation, is currently being studied especially for arid climates.

River training and flood protection

The training of rivers is one of the oldest tasks of the hydraulic engineer. He had to make rivers navigable for large ships by providing river training works, such as groynes and embankments, by dredging and by building navigation locks. Inland navigation is still one of the most advantageous solutions for carrying goods, the more so in that its reserve capacity is large, both for national and international exchanges. Among the conventional modes of transport (rail, road, and waterway), the waterway has the least impact on the environment. It is also the most economical means of transport over long distances, and it uses the least energy per ton of freight transported. In the simplest cases, the river works consisted of building a path beside a river along which ships could be towed. Later, the river banks were protected to avoid changes in the river course caused by bank erosion and by floods and to prevent damage of the shore by ship waves. These works usually had more than one purpose, and they included the task of protection against large floods from snow melt or heavy rainfall. These tasks are required for improving the infrastructure of many countries. However, one has learned to include the detrimental effects of these technical measures in design considerations; these include the effect of the river training on groundwater elevations and the induced changes of fauna and flora near rivers. Hydraulic engineers today no longer seek to "train" the river. Rather, they try to work with it: to constrain the river only as needed, and thereby to reduce environmental impacts as well as maintenance costs.

Interference of man with the behaviour of a river invariably brings about permanent changes of the river's course. In Europe, the training of the Rhine river and of the Danube has changed these rivers permanently by a staircase systems of locks. In 1992, the Rhine Main Danube canal was completed so as to connect the North and Black seas. The barrages needed for training the rivers are also used for hydropower generation. For the same purpose training of the Wisconsin river (the hardest working river in the US, for its modest size), the lower Mississippi, and the Tennessee river are examples of effective and almost wholly beneficial works carried out on major rivers.

Today, river training has become multi-objective; the needs of shore protection, protection against floods, hydropower generation, and navigation are combined with ecological considerations. Typical of modern approaches is that used in Germany, where comprehensive management plans are set up for the large rivers: there exists an "Integrated Rhine Program", for example, in which all the tasks required for use of the Rhine river as a major navigable river are combined with a comprehensive plan for flood protection of the cities in the Rhine valley between Basel and Mannheim and the protection of the remnants of the once abundant riparian forests. This course of action requires a detailed study of the river, the soil and the vegetation in the fluvial region, and the design of structures that not only impair the river flow as little as possible but also meet the combined objectives of esthetics, cost and maintainability.

Hydropower

Hydropower is a well established technology, and is one of the cleanest sources of energy available. It is a vast potential source in the developing countries. It can provide large, concentrated quantities of electricity needed to run factories and to light cities. Small scale and micro hydroelectric plants can provide power to isolated, sparsely populated communities and agricultural processing plants.

To reduce energy shortages, the most environmentally acceptable solutions are: conservation, improved efficiencies and expanded use of renewable resources. Hydropower is renewable because it is powered by the hydrological cycle. Hydropower is non-polluting and it is an asset with a long

life. Hydroelectric power plants operate at 85-90% efficiency.
Future opportunities for hydroelectric power development are great because it is a fully proven source with enormous untapped potential in developing countries, where less than 10% of the technically usable potential has been developed to date.

The number of pumped-storage plants is increasing rapidly. In 1990 the number of completed pumped-storage projects was 326. Many owners of power systems have found that pumped storage is the most economical way to store electricity for use in peak demand periods. In addition, pumped storage brings dynamic benefits to a utility system.

Many countries, particularly developing countries, are installing small plants (of 15 MW or less) at village level, to provide decentralised power on a sustainable basis. Apart from economic benefits, these installations have also improved the quality of rural life. Small scale hydropower generation is estimated to total 25 GW in 1991, that is about 4.5% of the total hydropower capacity. Small scale hydropower has the benefits of using indigenous labour and materials. China's experience in developing appropriate indigenous approaches with own capital and technology is unique. It resulted in tens of thousands of small hydro stations.
Because of its usefulness small hydropower generation is destined to receive wider attention and more funding in the future.

Reservoirs. - The pressure on water resources has increased considerably in the last several decades and will do so in the coming decades. Growth in world population, economic development; urbanisation and improved standards of living, vast expansion of irrigated agricultural and discharge of waste products are the main causes.
Water withdrawals for consumptive use, irrigation, industry and other purposes should rely on renewable water resources. To meet the demands for water, surface reservoirs are needed to modify the uneven distribution of precipitation in time, and together with aqueducts, to remedy the uneven distribution in space.
When storing water the dams create at the same time a head for hydroelectric power generation. The reservoirs can be operated to allow for space for flood waters and create safety. Dams can be projected in a sequence so that they provide adequate waterways for navigation.
A limiting factor on dam building occurs because of the environmental and social impacts they cause. It is necessary to study carefully, early in the project planning stage, the balance between beneficial and adverse environmental and social effects. It is necessary to quantify the impact of these, so that related costs can be incorporated as part of the economic evaluation of a project.

Water resources development: project planning on a regional scale

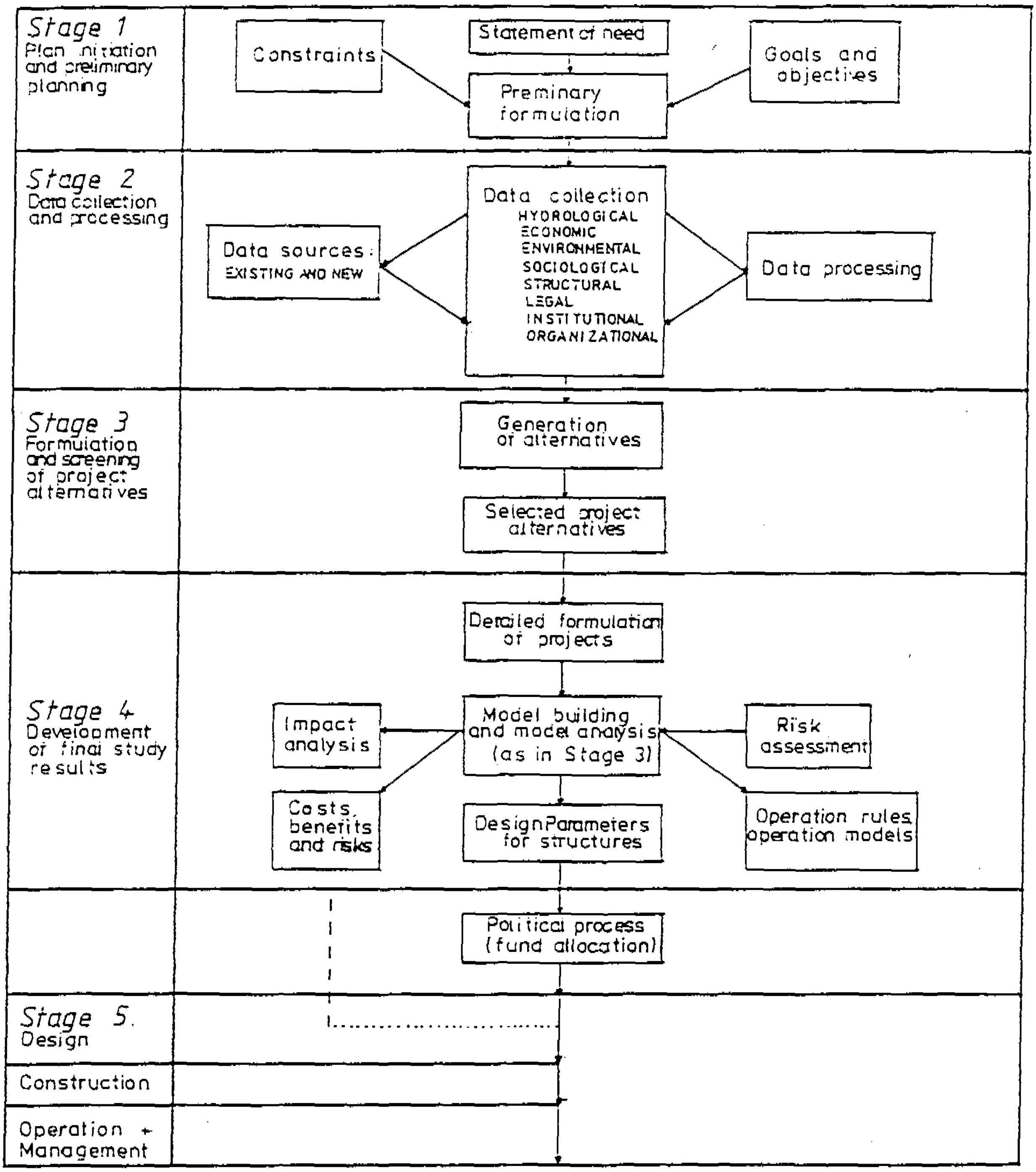
The central purpose of water resources development is to match demand and supply. Modern planning and management requires, however, that this be done in such a way that the life support system at all biological levels remains functional. This imposes constraints on every stage of a project, from the project planning stage to its final operation and management. The planner and the manager of a project can only operate effectively if the objectives of the project are clearly stated, and if demand and supply are clearly identified. The modern way of approaching problems of this kind is through the concept of a system, that includes an analysis of the interaction of the elements of water resources systems in space and time.

Water resources planning

The natural unit of water resources development is the river basin. Water resources systems are created for the task of matching supply of and demand for water, in basins or in their sub-units. Their traditional form is a group of structures connected through information links; these connect all aspects of water supply with all aspects of water demand. The system for water resources utilization 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. The task of water resources engineers is to meet optimally the requirements set by demand and supply in the planning, design, construction, and operation of the system.

The process of planning water resources systems is outlined in Fig. 5. (UNESCO, 1987). It consists of four stages, ranging from plan initiation to design. Fig. 5 suggests a structure for water resources management, and it includes not only planning and design, but also operation and maintenance of the completed system. Water resources systems have been around as long as man has tried to harness water for his own purposes. The irrigation systems of ancient Egypt and Mesopotamia were already quite sophisticated, and they had all the ingredients of modern systems: a structural system developed from a need that was sized to meet the needs economically, and an operation rule by which water was withdrawn at various times and places.

In general, every water resources system is created and operated by the schematic sequence of Fig. 5. In response to a political demand, a need is quantified for a projected planning horizon. Meeting that need is the objective of the system. The need is described in terms of sectorial objectives: meeting demands for water supply, irrigation, energy generation, navigation. Only under favorable conditions can the objectives be met outright: a village near a large river can meet its water supply by a simple structure that feeds water from the river to the village. Usually, a water resources system must be planned under restrictions imposed by nature or by other users - such as limitations on the quantity of available water. These and other restrictions form the constraints on the system. Obviously, no development is possible without the financial resources for construction, and many projects never reached their objectives because insufficient funds prevented full implementation of the planned project. By far the most important constraints, apart from financial restrictions, are imposed by environmental issues: and these emerge as factors that limit, development in many regions of the world.



Source: UNESCO, 1987

Fig. 5: The process of water resources systems planning

After demand and supply have been quantified and other sectors of development have been duly considered, the plan is developed in an orderly fashion. It proceeds from an inventory of resources, augmented as feasible by an extensive program of collecting and measuring relevant data, through the formulation and quantification of project alternatives.

The demand for water in a region is generally quite well defined. The empirical data for water quantities needed for various uses and the criteria for water quality are fairly well established. Less certain factors are whether the water sources are adequate and can be manipulated to guarantee a supply that satisfies the required demand at all times. Many sources of water fluctuate widely with time, and availability can be quantified only on a statistical basis; the accuracy of the information depends on the quality of the measurements and on the length of available records. To improve the reliability of supply, buffering is required; it is obtained through storage. Natural storage is provided by lakes and groundwater aquifers. Artificial storage through reservoirs and man made lakes and ponds has provided engineering solutions for decreasing the variability of the water supply. However, demands cannot be met in all circumstances, and managers of water resources must always be conscious of the element of uncertainty under which they operate.

Methods and tools for analysis of water resources systems

The difference between the traditional approach to matching supply and demand - which is still commonly used - and the most sophisticated modern approach to water resources development, such as is used for the Israeli Water Plan, is twofold: the planning and operation of the latter is optimized by means of modern techniques from operations research, and the breadth of the issues considered as objectives and constraints is much wider.

Extensive research has made the tools available for solving the problems associated with the traditional development of water resources. Planning used to be the domain of the hydraulic or agricultural engineer, and he developed the methods needed for his designs from hydrology, hydraulics and structural engineering. Now, the number of the fields of science included in the planning and design processes has increased, and the planning process as outlined in Fig. 5 must be handled by teams. Furthermore, in the course of adapting to new demands, the basic sciences have made available important analytical tools that are necessary for generating modern water resources systems. Some of the developments in science and engineering that have made modern planning possible are mentioned briefly in the following paragraphs.

Operations Research Techniques. - For the modern approach, the physical system, the processes linking supply and demand, and the planning methods are quantified during the planning phase by means of a systems model. The majority of the methods and techniques necessary for planning water resources systems for sustainable development of a region are available. Planning and operation of water resources systems are possible with tools developed for the operation of industrial plants and economic systems. Optimization techniques such as linear and dynamic programming, and mathematical optimization methods ranging from simple gradients to neural systems are available; and they are widely applied to water resources studies. For example, the local interactions of water resources systems with the environment can be described by comparatively simple conceptual and mathematical models; also, engineers have been successful in creating sectorial systems serving a single dominant purpose, such as water supply, hydropower, or irrigation. Traditional knowledge is readily accessible in textbooks and it forms the basis for all branches of water resources engineering.

Hydraulics. - Modern hydraulics has greatly increased the scope of its traditional approaches through the possibilities offered by the computer. The traditional approach based on hydraulic model studies and formulas that are one-dimensional approximations with empirical coefficients has been gradually extended by methods based on the partial differential equations of fluid mechanics. Applications include important areas of man's activities - constructed and natural water systems, including estuarine regions 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. The techniques for solving water quality problems were summarized in a recent publication of the International Association for Hydraulic Research (1991).

Hydrology. - Hydrology has emerged as one of the fundamental natural sciences and its applications extend into all geosciences and into many engineering fields, as shown in a recent publication of the National Research Council of the USA (1991). Its traditional role, that of supplying data for hydraulic systems design, is still one of the main tasks. However, the data needed for design include not only point data of distributions and extreme values, but also the dynamics of the rainfall-runoff process; these are contained in event based models such as the unit-hydrograph method or long-term simulation models. Data aquisition by means of stream gages, networks of raingages, and groundwater monitoring form the subject of operational hydrology. Special 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, analytical and numerical models for groundwater flow, and contaminant transport and watershed models. Current technology makes possible the reliable quantification of surface and groundwater resources, provided that a data basis of sufficient extent is available for verification and calibration.

Water chemistry and biology. - Water chemistry and biology have provided the means of identifying and analysing toxic and harmful substances in natural waters and in effluents from industrial production. Refined methods of analysis, even for very small concentrations, have been developed to guarantee a continuous supervision of water quality both from surface and underground sources. Water chemistry has been used to trace the chemical reactions of nutrient cycles and of effluent substances with natural and other substances. Water biologists and limnologists have developed bio-indicators for water quality, and they have determined the linkages between pollution and biological activity.

Hydraulic structures. - The technology for structures of all kinds, including hydraulic structures, is well developed. For example, the enormous hydro-electrical potential in the world can be developed according to well known principles of hydraulics and structural analysis and with existing technology. For most applications, the types of structures and their design have evolved over many decades, and only for extremely large structures, such as high dams or navigation locks with high lifts, or in unusual circumstances (such as high discharge spillways - with unit design discharges of 150 to 250 m^2/s, - or diversion structures in geologically young rivers with sediment discharges that contain large boulders) do engineers face problems which require new solutions for conventional situations. New fields such as value engineering and probabilistic design help to provide economically balanced developments.

Hydraulic structures, including dams and canals, have been built for use in conveying water to the location of demand. The technology exists to transport water over long distances. For the pumping and collection of ground- and surface water, lifting devices ranging from old fashioned buckets on ropes to sophisticated multistage pumps have been employed, and wells have been developed ranging from hand-dug water holes to modern wells that are drilled and cased.

The structures most frequently discussed are dams for water storage. A variety of water uses and re-uses is being accomplished with multipurpose dams for the following uses: water supply for domestic, irrigation and industrial uses; protection of lives and property from flooding; hydroelectric energy generation; improved navigation by increasing water depth and by creating lakes that are also used for recreation and fisheries. Over 200 dams higher than 15 m are being 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 oriented so as to make these structures compatible with local conditions; to design them so as to cause as little disruption of the social and natural conditions as feasible. Environmental, social, safety, and cultural aspects of dams and reservoirs are being addressed in the early planning stages. The negative consequences of dam construction and hydropower generation are strictly local, and in most cases they can be overcome by sound planning, adequate design and appropriate measures to control adverse effects.

Technology for treating water. - Water technologies have been developed in the industrialized countries both for processing drinking water and for sewage disposal. The quality of drinking water is routinely controlled to eliminate harmful substances, such as disease vectors. Significant advances have been made in sewage treatment, water re-use, and solid waste disposal. Vast amounts of funds are invested in sewage disposal plants, and wherever possible, the oceans and the rivers are used as effluent carriers to provide sufficient dilution of the treated sewage. In most industrialized countries, sewage of inland cities is treated in disposal plants, whereas in cities located on sea shores, ocean outfalls - pipelines extending a few 100 m or a few kilometers into the ocean with a diffuser at the end - provide for the needed dilution. Any diluted sewage that returns to the shores then has a less than critical concentration.

New technologies have been developed for cleaning up contaminated sites. This process is particularly difficult; because the contaminated water may be deeply infiltrated into the ground, extend over large regions, and not have been observed for many years, it may have formed a plume reaching long distances. A whole industry has evolved that uses various techniques ranging from soil removal and cleaning of the soil on the surface to ingenious applications of pumping stations for in situ soil cleaning or reduction of toxicity.

Conclusion

Engineering tools and the requisite research results are available to solve most of the technical aspects of most water resources problems. A water resources project can therefore be engineered. However, technical skills alone are not sufficient to make a system sustainable. Sustainability involves other aspects that deserve intensive discussion, and it requires a willingness to go beyond the scope of standard technical solutions.

Some of the properties of sustainable water resources systems are presented in the next chapter, and it shows that many of the questions concerning sustainability cannot be answered within the current state of the art. Research and development needs are described in detail in chapter 4.

Chapter 3: SUSTAINABLE WATER USE

"Scarcity and misuse of freshwater pose a serious and growing threat to sustainable development and protection of the environment. Human health and welfare, food security, industrial development and ecosystems on which they depend, all are at risk, unless water and land resources are managed more effectively in the present decade and beyond than they have been in the past". (The Dublin Statement, ICWE 1992)

Sustainable development of water resources is an essential feature of 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 sectors. Sustainable development of water resources implies extended criteria for planning, designing, operating and maintaining water resources systems. Although the full extent of what sustainability means is not yet clear, it is possible to formulate some important criteria for structural and non-structural projects which are likely hallmarks of sustainable systems.

Prerequisites for the various aspects of a sustainable water resources development project are:

1. The political will to plan, construct, and operate the water resources development project in a sustainable way

2. Finances and time to gather the data necessary for planning

3. Finances to continuously operate the project

Sustainability must be the concern of the project planners, engineers and scientists involved in a water resources project. The planning must meet the following criteria:

1. Planning of sustainable water resources development projects is based on a view of the project as an integral part of the societal system, and takes into account all interactions of the project with society and environment, i.e. projects are designed for multi-objectives, multi-structures, and multi-users.

2. It includes optimally adapted structures designed by experienced engineers. Structures controlling natural waters should be designed to "work with nature".

3. It should include consideration of non-structural solutions as a first alternative.

4. It involves due consideration of ways to alleviate any water quality problems the system may cause during operation.

5. It includes a full assessment of beneficial and adverse environmental impacts, and of means to alleviate the adverse ones. A sustainable system interferes as little as possible with the natural environment.

6. It includes an assessment of risks, and precautionary measures for preventing disasters. Risk assessment comprises possible failure states of the structures (such as failure of an embankment), as well as possible failure states of the system (such as not being able to meet a demand during times of drought).

7. It results in resilient structures, which after failure can be replaced or repaired without undue disruption of services.

8. It includes due regard for uncertainties of both supply and demand.

9. It includes considerations of social impacts caused by dislocations of people, and stress during system failure (such as water shortage).

10. It includes provisions to cope with changes: changes in demand, land use, and climate.

11. It involves the people that are affected by the plan in the planning process, so that projects can become optimally adapted to local living conditions and to local environments.

12. It eliminates, to the extent possible, all potentials for future international conflicts.

Such criteria must be applied to all kinds of water resources systems ranging from local systems, like the water supply of a village, from a local well or spring to vast multi-structure and multi-purpose systems of large dams built to control floods, generate power, and irrigate thousands of hectares of land; sometimes projects are so large that more than one nation is affected. Society as represented by its political bodies is challenged to demand that such criteria be met, and to establish the legal and political frameworks required to enforce them. In setting such criteria, society broadens the demands on water resources planners and engineers beyond traditional techniques and skills.

A well planned project is no guarantee of a sustainable system. Sustainability implies that the system is operated to perform as planned for all foreseeable future. A prerequisite for appropriate operation and maintenance is good management, which among others is guided by the following principles:

1. A sustainable water resources development project is managed by a competent staff of managers, technicians, and workers for operation and maintenance.

2. Management has to insure that a continuous supply of water is available at all times for all needs.

3. Management is continuously improving the performance of the system to achieve maximum efficiency.

4. Management is cost conscious and considers and promotes means of covering the cost of operation and maintenance in an equitable and efficient way.

5. Management continuously monitors the performance of the system.

These conditions are discussed in detail in the following sections.

General aspects of sustainable systems

The most important conditions that must be met for achieving sustainable development of water resources are political will, adequate financing, and sound management practices. Political will to develop water resources of the future so that they become sustainable is more important than new technology for solving water problems. On a national scale, an institutional framework is required that provides for proper construction, use, and maintenance of all water resources development systems of a country. The political will to generate and uphold this framework must exist at national, regional, and local scales, and must be translated into sustainable projects.

Basic planning for development projects is usually undertaken by central governments. Issues to be considered by national bodies are ways to create the basis for planning and construction of projects, and to create an enabling legal environment by setting standards and laws that are binding on local and regional development projects; these include provisions for protecting the areas for the collection of surface and groundwater against pollution, and for integrating them into other laws that regulate land use. The process usually involves developing vulnerability maps, delineating protection zones around sources, and keeping waste dumps apart from potable water sources: tasks that are best handled by centralized agencies.

Implementation and operation, maintenance and management of a water development project are likely to be better handled if decentralized and delegated to regional or local entities. They understand better the local situation, such as regional demands on flows in rivers controlled by dams and reservoirs, and they recognize local constraints on water distribution and can better adapt projects to local needs. Also, if regional entities are involved in the project from its beginning, they are more likely to accept it as their own, and to give it their full support.

Financial basis of water resources projects

Major constraints on the development of sustainable water resources projects are financial. Obviously, a large scale development project cannot be effective if the financing is insufficient. Financing is required not only for construction, but also for planning and operation. For planning, both time and finances have to be available to produce a properly designed plan based on a sufficiently large set of data on all aspects of the plan. Unfortunately, many remote regions of the world have poor data bases on hydrology and climatology, so that extrapolations have to be made from records that are too short and lead to large uncertainties. If the urgency of the project allows it, much of the planning uncertainty can be eliminated if the time for planning is sufficiently long for improving the data base. Generally speaking, any project planning should, from the earliest stage onward, be supported by a data collection program.

In many cases one finds that the cost of structures and the system are not much higher than the cost for the measures necessary to alleviate undesired impacts. To save on the latter may jeopardize the success of the whole project. In many irrigation projects drainage was not provided to save costs and the results were unsatisfactory.

Operation also requires financial support. From the beginning of a project, a plan how to finance the management should be available. The sustainable operation of the system depends on functioning infrastructures and adequately paid management. The way in which water is priced by governments usually has little to do with actual costs. Many economists recommend that private enterprise should be allowed to manage water development projects both in developed and in developing countries. The involvement of the private sector may lead to more efficient operation and services by providing appropriate financial incentives to improve the performance of personnel in the water supply and sanitation sectors. One way of obtaining the necessary funds is through water pricing. If socially feasible, one-time capital costs and recurring operation and maintenance expenses should be introduced on a "user pays his fair share" principle. Many different cost distribution methods, like staggered price controls, exist. Similar considerations based on the "user pays" principle must be applied also to other dealings with natural resources, an example is the solving of the problem of contaminated soils.

For keeping the price of water low, or in order to not divert funds from other infrastructure uses, water should be conserved and used efficiently, even in water rich regions. A water development project is inefficient if it emphasizes meeting demands at all times by constructing supply facilities, rather than by improving the efficiency of existing supplies, conserving water and pricing it in accordance with cost. Important steps towards more efficient water use are made through water saving activities, such as reducing water use in industry, in households, and in public facilities like swimming pools. Also, much water can be saved in agricultureal projects if efficient irrigation methods are used for delivering water, and if water applied to the crops is adjusted to the actual water demands of the plants.

Planning requirements

Water resources planners today see water resources systems as a set of structures integrated into a network of interwoven relations between man and nature. Instead of viewing them as closed, they are seen to be open, i.e. they interact with numerous other activities. In order for such a system to be sustainable, it has to interact smoothly with other subsystems involved in shaping the fabric of society, and it must adapt to changing needs and uncertainties in demands with as little disturbance of the other parts as feasible.

In contrast to the water resources engineers of old, modern managers of water resources systems have to consider a large number of often conflicting demands on the available water, and they have to develop and operate their systems under binding constraints. The various different interests require a decision process involving multiple objectives, and multiple decision makers, multiple users and multiple constituencies. Ultimately, water-management strategy for sustained growth and development has to be optimized by strategic planning. The demands on water for irrigation, drinking water, sanitation, urban and rural development, hydropower, and other uses must be involved with trade offs among the water users, and furthermore, the planning process for the water system must be matched with planning objectives from other sectors, like transportation and energy production. Often, other needs of society as well as the preferences of the people involved in the planning process act as constraints, that are in addition to those constraints set by natural limitations.

Such constraints stem from environmental, social and cultural considerations and should be included in the planning, design, construction, and in the operation and maintenance of water projects.

Engineering for sustainable water resources development. - The engineer's role in sustainable development is that of a broad based, concerned person who is willing to use a multi-disciplinary approach. His work includes impact assessment of projects and their operation, and the evaluation of their effects on human activities. The duty of administrators and engineers is to draw attention to the issues and to inform the political bodies of the options, of the benefits and threats, and of the opportunities for water use, and to search for a continuing dialogue between engineers and decision makers in the socio-political arena to assure that water resources are used for the optimum benefit of the people. He will have to answer important questions: Will the foreseen development of the country as, perhaps, it develops from a rural society to a more industrial one, require the water resources system as originally planned, or might not new requirements change it? Are the structures of the system such that they can be repaired easily in case of damage? Does the plan incorporate maintenance into its operation rules? Are the structures so planned as to maintain their function indefinitely, and at an acceptable cost?

The engineer is challenged to use all technical and non-technical means in finding optimum solutions for the water resources development system. Structures are necessary only if other means cannot be employed, particularly if the structures interfere with natural conditions. Non-structural solutions include demand management to reduce peak consumption; optimum operation of existing systems through rehabilitation of inefficient structures and control elements, and through use of optimized operation rules and computer control; and management of land use in flood plains.

A modern view is no longer to attempt to "train" rivers but to work with them, so that the negative impacts, for example from forcing rivers into unnatural beds, are minimized. Many of the detrimental effects of river training, such as lowering of groundwater levels, erosion of formerly stable channels, and the resulting effects on the fauna and flora of the wetlands adjacent to the river, have been experienced in the upper Rhine Valley. In the lower Mississippi, natural course relocations due to meandering, cutoffs and sedimentation have interfered with preventive actions (Old River, Atchafalaya diversion), and in some areas their effects involve huge maintenance efforts for generations to come.

The emphasis given to sustainability of new structures does not imply that sustainable structures are to exist only for the future. On the contrary, the designs of some large structures built a century or more ago have stood the test of time with only minor modifications. Hartung and Scheuerlein (1992) have pointed to the excellent performance of the old Nile barrages constructed long before the building of the High Aswan Dam. These are models of sound engineering and design. The successes of our forefathers on this and other large projects were based on extensive studies of rivers over long periods of time. Some of the structures they developed were extremely well adapted to natural conditions. River training was accomplished by working with the river, not against it. One of the most controversial aspects of foreign aid is that projects are too often pushed through with insufficient time for planning and for assessing the full consequences of a project. 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 be made only once, and it results in a process that is nearly irreversible. The conclusion is that the design of a sustainable structure must be the result of long time observations, and thorough analysis of the hydrological and soil conditions, and by finding a structure that satisfies its purpose with a minimum of interference with natural conditions.

Demands on water quantity. - The Mar del Plata United Nations Conference on Drinking Water and Sanitation in 1977 proclaimed the right for drinking water in sufficient quantity and quality to meet basic needs as a human right. These goals have been reached in most developed countries. However, in spite of great efforts by governmental and non-governmental agencies and organizations, they have not been provided to many people in developing countries. The provision of clean, safe, potable water in a sustainable and economical way requires investments that are often too high for poor countries, in particular in arid and semi-arid areas of the world. Donor countries have been challenged to provide the necessary financial resources.

Demands on water quality. - Most projects have been primarily concerned with providing needed quantities of water. Today, the supply of water is threatened, in many regions of the world, not so much by insufficient quantity, but by inadequate 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. Air pollution, man made or due to natural causes, may lead to acid or nuclear precipitation. Lake eutrophication due to acid rain, well known through its effect on otherwise pristine lakes, has been observed in particular in the Nordic countries. Chemical and biological pollutants from diffuse sources, such as fertilizers and pesticides from agricultural areas, or stormwater runoff from urban catchments, appear with increasing frequency and concentrations in drinking water, and they are found in many surface and groundwater sources. For many lakes they are the major cause of eutrophication. Some of the substances introduced by human actions are non-biodegradeable and may accumulate in their passage through the food chain; some are highly toxic and contaminate aquatic and terrestial ecosystems.

Water quality and environmental issues cause growing concerns to water resources management. Their impacts are best resolved on a local scale. "The river basin is the most practical hydrogeographic unit within which the quality of rivers, lakes, reservoirs and aquifers can be effectively controlled" (United Nations, 1992). An inseparable part of water resources management on the local scale is environmental protection against pollutants that threaten surface and underground water supplies. Quality standards must be met for all water supplies. The quality of river and groundwater near most cities can be controlled through sewage disposal facilities. Vast funds are needed to treat water and to dispose of the end products of the cleaning process in an orderly manner. However, this effort is not sufficient. In many developed countries, pollution due to rural sources is the major factor in water pollution. The great benefits from modern irrigated agriculture and industrial processes are offset in part by serious water contamination. Irrigation of heavily fertilized land has resulted in runoff from agricultural fields that is rich in nutrients, and it reduces, through algae growth and other biological process, the oxygen in rivers and lakes. Eutrophication due to this cause 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) from discharges of industrial sewage in rivers are life threatening. Some 3000 to 4000 chemical substances are found in the rivers of industrialized countries. Some of them may affect human health, either alone or in combination with other substances. Also, the sediments of the rivers are repositories of toxic waste, which result in long term effects through mobilization of pollutants and release of nutrients from bottom muds. The toxicity levels of these are often unknown, and other interests may prevent the application of the "precautionary principle", that a substance whose effect on human health is not known should not be put into public waters at all.

To protect the quality of groundwater, the recharge areas in many countries are declared protected regions, and thus are kept free from further development. The enforcement of strict regulations to prevent pollution from point and diffuse sources is, however, not a simple matter. One reason is that in many countries the right of using groundwater belongs to the owner of the land below which the groundwater is found. Protective zoning interferes with other uses, such as urban development. Placing groundwater in the public domain as for surface water may help to implement better management, but it needs competent man-power, financial means to operate the system, and awareness of "co-ownership" in order to keep people from polluting. In particular, the farmers of the region want to be compensated for the losses that they suffer from reducing the use of fertilizers and pesticides. Such compensations are paid in parts of Germany and elsewhere.

Water quality in the downstream reaches of a large river is a summation of all the inputs along the course of the river. The cleaning up of a polluted river, bay, or part of an ocean is a major task that involves large numbers of people and many communities, and it can only be accomplished if most of the pollution along the river can be stopped. The best approach is to prevent pollution from the start; later on, the costs may be prohibitive. However, it can be done, as exemplified by the results for the mouth of the Rhine river: large efforts by communities both in Germany and in the Netherlands based on a series of actions outlined in Box 5 are responsible for the success of the effort. The decrease of the pollution load for the Rhine at the Netherlands border is shown in Fig.6 (from the Country report of the Federal Republic of Germany to the ICWE, 1992).

Box 5: The 1987 Rhine Action Program

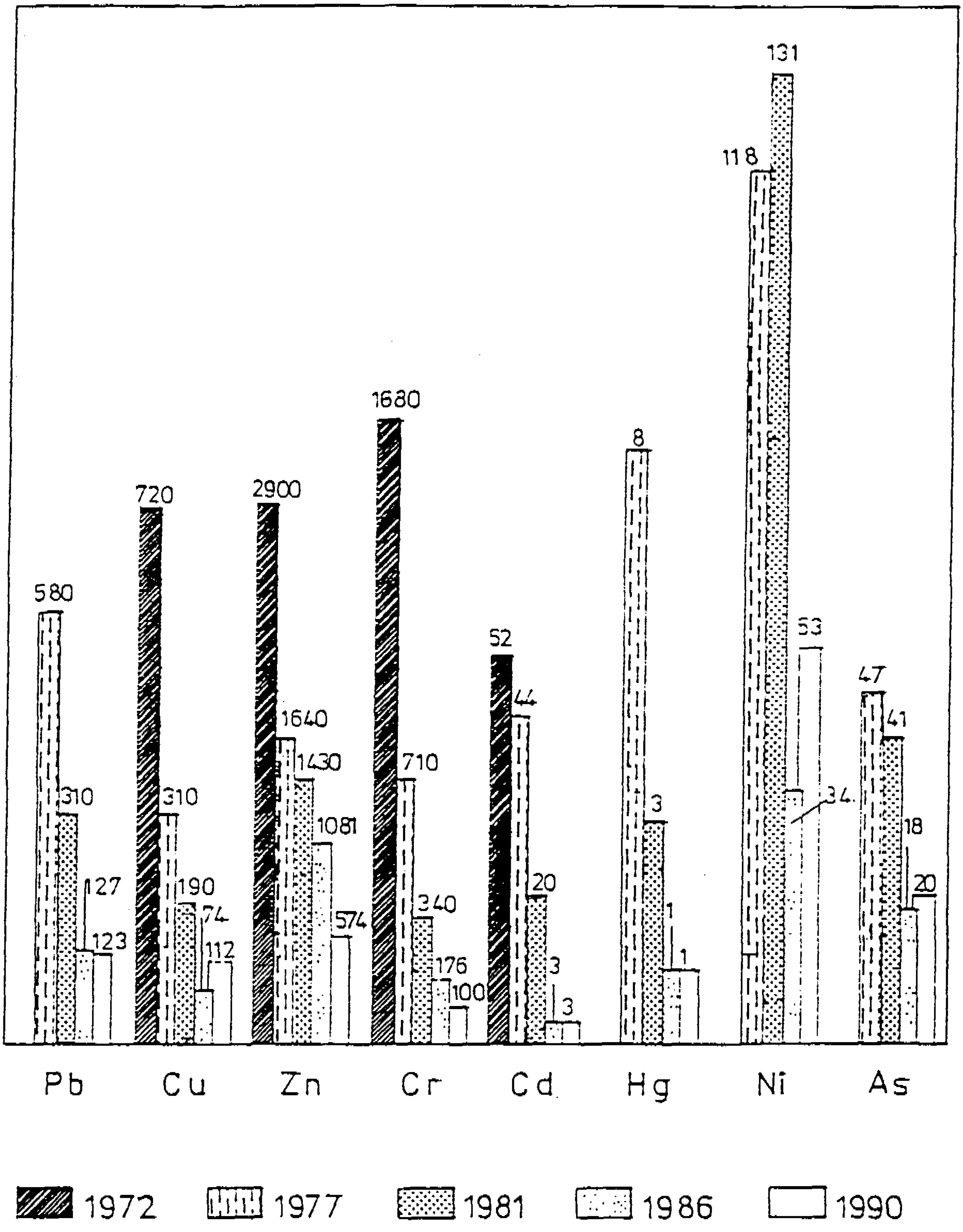
Dutch policy is to set broad targets and to design action programs by means of which these targets are to be reached, in the case of the Rhine by international agreements and consultations on the highest political level.

Objectives are:

1. The Rhine must become a suitable habitat to allow the return of higher species (e.g. salmon) once found here.
2. The use of the Rhine water for drinking water supplies must continue to be possible in the future.
3. The river sediments must not be polluted by toxic substances.
4. The North Sea environment must be protected.

The objectives must be achieved by means of the measures included in the joint action program. They involve:
- accelerated reduction of permanent pollution caused by direct and diffuse emissions (e.g. reduction target of 50%)
- protection against hazardous accidental emissions by companies situated along the river
- improvement of the hydrological and morphological conditions.

Water supplies from groundwater sources are becoming increasingly important, but they are threatened by unplanned exploitation and by contamination from many sources. Pollutant inputs are produced by wastes from intensive feedlot operations, from contaminated sites of industrial complexes, and from city dumps and repositories of toxic wastes. In the past, these have been inadequately protected from contact with the groundwater, and they often have created what are in effect "time-bombs" of groundwater pollution. In fact, for many developed countries, one of the costliest and most urgent tasks for environmental protection is that of reclaiming contaminated sites. Such sites might be left from old mining or industrial activities, or they might be the result of excessive salinity in irrigated areas. The most important concern for such sites is that the transport of the polluted groundwater be known, and extensive monitoring systems must be set up around them. In addition, careful monitoring of aquifers, including estimates of discharges in groundwater flows and volumes of storage, can allow early recognition of chemical spills and biological activities and enhance timely countermeasures.



Source: ICWE 1992

Fig.6: Rhine water pollution

The funds needed for having clean water are large, and especially in comparison with the benefits from industrialization. If possible, remedial measures against polluted water should be charged to the polluter ("polluter pays" principle), but in many cases the polluter is no longer around, or is not financially in a position to pay for cleaning up the site. Some countries, notably the USA (with its "Superfund"), have set up special funds, supported by potential polluters, to make available financial resources for remedial actions. Developing countries can learn from such measures. In order to attract industry, they may permit relatively liberal effluent and emission standards; however, the cost of cleaning up water, once it has been polluted, is high; hence the need is for water quality standards that include taking into account the cumulative consequences of industrialization.

On the other hand, excessive water quality demands may conflict with and slow down needed local development. While there is an urgent need to preserve our planet in as unspoilt a state as possible, the needs of the people must be given due priority. Not every environmental concern can receive remedial action. By heeding the advice of experts, the politicians must protect the public from unneccessary investments for overly conservative environmental protection measures. The public should be provided with the information necessary to resist public pressures which are based on unfounded conclusions. For example, people frequently oppose water supplies possessing detectable contaminants, even though they meet local public health standards.

Water technology development needs. - In a sustainable context, a freshwater basin must be considered as a single aquatic ecosystem, not only in protected natural areas such as nature parks, but also in intertidal zones, lakes, reservoirs, riverbanks, wetlands, flood plains, and estuaries. Waste discharge and biological activity are interconnected in the land-water ecosystems. To maintain these waters at an acceptable level of purity, existing water treatment technology is usually sufficient.

Furthermore, for the efficient use of available resources, nature should be allowed to participate in the processing of sewage. There is an unfortunate tendency to regard water pollution control as the skillful design and operation of sewage treatment plants regardless of the receiving water's absorption capacity. In some countries, treatment standards call for a reduction of the BOD (biological oxygen demand) level in sewage water by a certain percentage, regardless of the size of the sewage disposal plant or of the discharge of the receiving river. A better way is to have river quality standards and to control the sewage inflow in accordance with the self-purifying power of the river; direct linkages must be established between pollution-control and resource-management.

The technology for treating some industrial effluents is limited and managers of industrial products should be motivated to change their methods and facilities to ones that are more friendly to the environment. Deficits exist in controlling micro-pollutants, and many problems must be solved in order to find means to decontaminate or to safely store contaminated dredged materials. Controlling the cost may also affect the water distribution system; for example, separate systems for supplying potable water and for water for industrial and agricultural applications may have to be provided.

A wider application of re-used water can be foreseen, in particular in large cities with inadequate supplies; an example is the local re-use in individual buildings and small areas of communities. Some examples of possible re-uses of water are summarized in Box 6. Noteworthy is the use of waste water for fish production, as is done in many parts of Asia. Fishponds near Calcutta receive sewage from the city, and the harvested fish are sold back to the city. Latrines are built over fishponds in China and Vietnam, fish are raised in cages submerged in faecal-contaminated streams in Indonesia, and vegetables (such as water spinach) are grown in canals fed with sewage in Thailand, (Than and Biswas, 1992). However, in most countries the quality of water that has been used is hardly ever acceptable for other uses, and special considerations are involved in deriving an appropriate chain of actions if water is used more than once. The supply system for re-used water presents some problems, and separate distribution systems for re-used and fresh water have been suggested to prevent the mixing of the two kinds of water. Agriculture and landscape irrigation are, for the present and the foreseeable future, the largest users of reclaimed wastewater.

Box 6: Water reuse

With increasing demand for water, reuse of treated wastewater effluent is becoming increasingly important in the water resources strategy of a number of countries. This will be particularly the case in more arid regions. In the drier parts of USA total water reuse has now reached 2.6 million m^3/day making it the world leader in total amount used. However, this amounts to only 0.2% of the USA's total water needs. Israel by comparison meets 5.4% of its total water needs from reused water. In Bahrain, by the year 2000, the available supply of treated wastewater will nearly equal the entire natural supply of fresh water.

Reclaimed water is a water resource which is available right on the doorstep of an urban environment. It can be a reliable source, even during times of drought, and is thus able to replace potable water for non-potable and sub-potable uses.

There is a wide range of options for reused water and the table below lists the main ones used in industrialised countries. These may also be applicable in developing countries as appropriate to local conditions.

Landscape Irrigation
- Parks
- Cemeteries
- Golf Courses
- Thoroughfare Rights-of-Way
- School Grounds
- Greenbelts
- Residential Lawns

Impoundments
- Ornamental
- Recreational

Agricultural Irrigation
- Fodder, Fibre & Seed Crops
- Nurseries
- Frost Protection

Environmental
- Streamflow Augmentation
- Marshes
- Wetlands
- Fisheries

Industrial
- Cooling
- Boiler Feed
- Stack Scrubbing
- Process Water

Groundwater Recharge
- Potable Aquifer
- Irrigation source
- Intrusion Control
- Subsidence Control

Non-potable Urban
- Landscape Irrigation
- Garden Watering
- Fire Protection
- Toilet Flushing
- Air Conditioning
- Vehicle Washing
- Street Washing

Miscellaneous
- Aquaculture
- Snow-making
- Construction
- Dust Control
- Livestock Watering
- Ballast
- Pumped Storage

Environmental Concerns. - Water resources systems at all scales affect the environment and complicate modern water resources engineering. The projects associated with them are hardly ever wholly beneficial. 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 causes a variety of impacts on the environment. One can distinguish three types of environmental impacts that have to be considered.

First, one of the most critical issues of environmental impact assessments is the occurrence of water borne diseases. Water is the carrier of many microbial diseases, and polluted water is the cause of major diseases. The linking of water pollution and cholera, by J. Snow in 1854, was a major reason for the construction of the first systems for treating drinking water. Water borne diseases , such as schistosomiasis, malaria, filiariasis and river fluke infections continue to be major health problems in many developing countries. Such consequences have arisen especially with certain irrigation projects, in tropical and subtropical regions. Replacement of simple traditional practices with perennial irrigation schemes can cause adverse health effects because the long shorelines of reservoirs and irrigation canals and ditches create breeding grounds for such disease vectors as snails and malaria mosquitos. A case in point is the infiltration of blood fluke in Sudan as a result of the Gezirra irrigation scheme.

Second, land use changes and changes in the surface and groundwater regimes may alter the chemical and biological balance of the water. Soil salination and water logging are classical examples of such environmental problems. In the Euphrates valley in Syria and the lower Rafadain plain of Iraq, over 50% of the total area of the country suffers from these effects. In Iran, some 15% of the country is affected, and in Pakistan, more than 13 million ha out of about 15 million ha of irrigated land are seriously affected (El-Gabaly, 1977).

Finally, a third impact is the effect of water resources projects on the fauna and flora of a region. In parts of the world, aquatic weeds have substantially impaired the efficiency of water resources systems by using up large quantities of water for their transpiration, and by clogging turbines and outlets. Some reservoirs have been covered by water hyacinths after only a few years of operation. The remedial measures, such as herbicides, may be more damaging in the long run than weed infestation. Other impacts are the changing of wildlife habitats, in particular, those of rare animals and rare plants.

Water resources planners and engineers have learned to adapt their techniques so as to minimize negative impacts, and are thus responding to the growing concern of people in the region of adverse environmental impacts. Modern state-of-the-art collection, treatment, recovering, recycling, and dilution techniques include considerations to avoid such negative effects as eutrophication, salination and pollution, and their consequences on populations. The identification and application of existing knowledge of these processes is an important task for those working in the area of water resources. They have learned to look to the natural sciences for an understanding of the connection between water and biological and chemical processes. These connections are studied and quantified by specialists, who in turn have learned to present their results in a form that can be applied by practicing engineers in the field without in depth study of the fundamentals. Strategies have been developed for environmental impact assessment, and in many developed countries they are required by law. For developing countries, impact reduction is an increasingly important part of development aid.

The requirements for environmental impact assessment and pollution control have affected source-selection as well as structural, regulatory and legal aspects of water control. Introduction of the necessary policies should receive wide public support and should result in functional infrastructures and institutions. Officials in many countries are trying to develop effective legal and administrative procedures for constructing environmentally sound public works. They enable experts and administrators to plan for the true need of the people and to evaluate all of the important environmental issues that may concern them. Such studies should be done in cooperation with environmental groups, who should be made aware of all issues involved in local development so that they can work with the engineers in creating an optimum environment.

A guiding principle for the planning of locally sustainable systems is the concept that a system should interfere as little as feasible with the proper functioning of natural life cycles. Environmental impact assessment today is directed at finding out what impacts a project has on the environment and then applying a set of more or less subjective value criteria to the impacts. This procedure will probably no longer suffice at some time in the future: instead, we will need to consider alternative environments that can coexist with the water resources system and decide on the one that is most acceptable to the environmental sensibilities of the people who are affected. A typical example is the creation of an environment for irrigated agriculture downstream of a reservoir, one that profoundly changes the natural conditions that existed before the system was built. Another environmental aspect of sustainability is the conservation of nature and preservation of species, and these have led to the demand for reestablishing appropriate environments. In many cases the result is also esthetically more pleasing than an overutilized countryside. A good example is river renaturalization as practiced in some European countries. Before the middle of this century many small rivers were straightened in order to gain land for agricultural production. With agriculture no longer a primary concern, many of these rivers are being changed back to more natural conditions. Many such projects have been initiated recently, and the results have usually been well accepted by the population.

Giving due regard to hazards and risk. - Man is subjected to a multitude of natural water hazards, like floods, rain-induced land slides, and droughts. A hazard is defined as the potential for the occurrence of an extreme adverse event. When such an event actually happens, its consequences may range, depending on its severity, from small property damages to the loss of human lives. When these damages are extensive, the event is a disaster. The most frequent water related disasters are those caused by extreme floods, and they develop rapidly. In contrast, some disasters, such as those caused by droughts or water contamination, may develop over long periods of time.

Floods not only bring the obvious effects of flooding but also carry health hazards. Water supplies become polluted from the overflowing of wastewater basins and septic tanks, sanitation becomes non-functional, and all water becomes suspect and has to be boiled for drinking purposes. Obstruction and subsequent damming of water courses by debris from land slides, by log-jams, and by volcanic ejecta can be major issues in mountaineous areas, and in highly sediment-yielding and erosive canyon-like terrain. A number of projects have been doomed by such obstructions that occurred in the lifespan of a project. Any geologically unstable feature should be accounted for in the realizations of plans and designs before embarking on a large scale project. A good example is the Ganges Project in India, in which water resources development for energy is severely handicapped by the sediments injected into the river by land-slides.

Man has also discovered that his water supplies can be threatened by disasters of his own making, those caused by human error in the operation, by long-term negligence of the system elements of plants in industrial production complexes, or during transport of hazardous substances. Such non-natural disasters are occurring more and more frequently. Consequences of such disasters, for example those due to chemical spills or nuclear accidents, may be far reaching. Sustainability implies a condition of stability in which the threats to society, as well as the threats to water, are managed in such a way that man is prepared to cope with them.

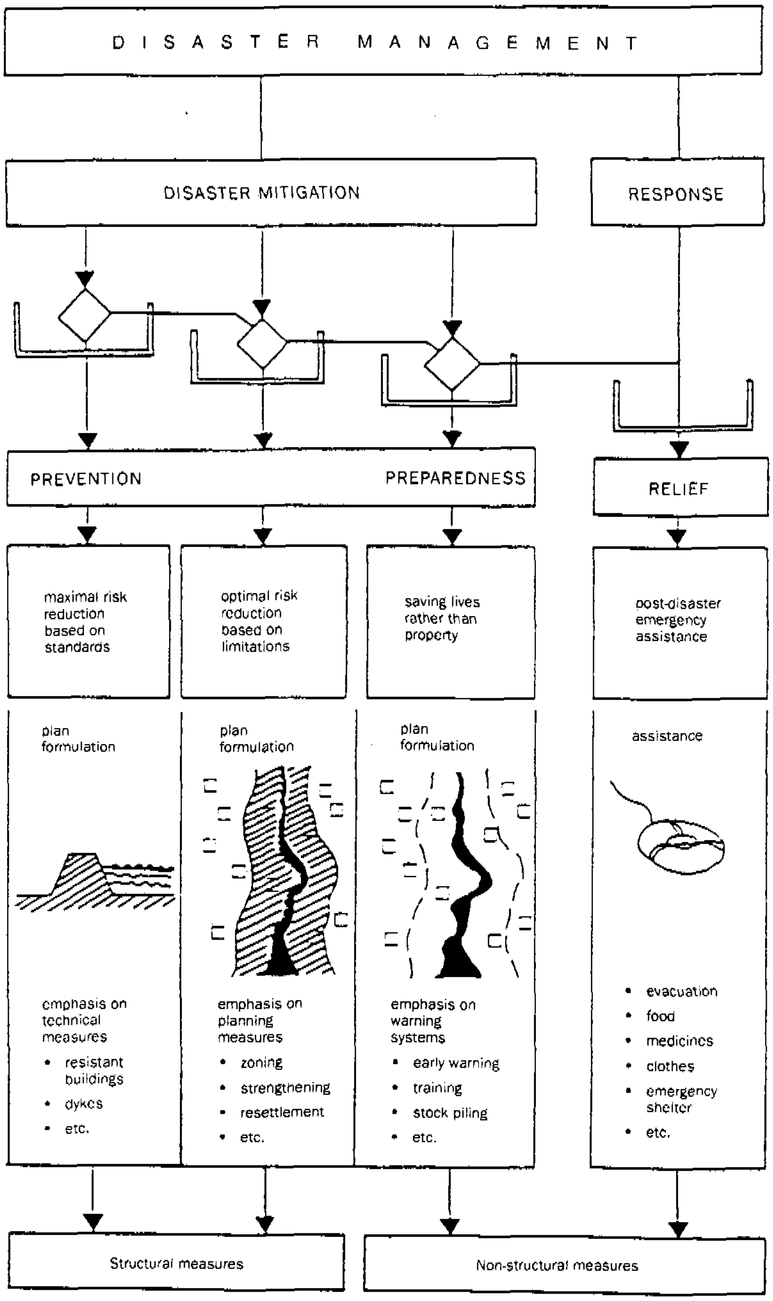
The beneficial role of a dam in a water resources development scheme is easily taken for granted. The reservoir behind the dam equalizes water supplies, except possibly in the case of a major drought. In such the manager tries to provide a reliable back-up system; for example, a groundwater supply is often an essential component of a water supply system. However, breaks of dams cannot be entirely ruled out, and apart from the disaster caused by the dam break event itself, they can cause major disruptions in a water supply system; many years are required to replace the structure and for the reservoir to fill again to the level required for a sustainable operation. Well known examples of loss of continuity, or complete failure of supply due to dam failures are the breaks of the Vajont dam, Italy (reservoir filled by a major landslide), Teton dam, USA (loss of dam), Vega de Tera, Spain (loss of dam), and Malpasset, France (loss of dam). As part of flood contingency action, dam legislation in many countries nowadays requires flood inundation maps, that are based on dam break models. Public awareness programs are implemented to ensure adequate evacuation drills and other procedures to be followed. Both sunny day dam breaks caused by foundation failures, and failures due to excessive floods during strong rainstorms must be envisaged.

The issues implicit in the prevention, management and control of disasters have a high priority in the attainment of sustainability. However, it is not economically possible to eliminate all potential hazards or to design all water resources systems to withstand any conceivable extreme event. Not only must the severity of a disaster be taken into account, but also its frequency of occurrence. One must compare the cost per year of a disaster with the cost of preventing it. An event with extreme consequences that is also extremely rare may not be worse than a less consequential event that occurs frequently. The consequences are quantified through the risk, which is defined as the average potential consequence of a disaster per unit time. It weights the consequences of a disaster, such as loss of lives or monetary losses, according to their probabilities of occurrence.

The purpose of risk management is to make efficient and economical planning decisions that mitigate the effect of potential disasters. The primary purpose of disaster management is to prevent both natural and man-caused disasters. Risk management includes provisions to cope with a disaster in the unlikely event that it does occur, for a poorly managed disaster can disrupt the social structure of a region for many years: in fact, natural disasters and wars are the two events that are the most disruptive of life.

Risk management has been formalized in recent years. An example is the approach to risk management for flood prone areas along a river as outlined in Box 7. The first step in coping with disasters is identifying the hazards existing in a region, and evaluating their probability of occurrence. Other steps are outlined in Box 7, a procedure that also applies in principle to other hazards. Further developments in the methods include uncertainty and risk in the design process, and the development of rules to operate a water resources system in such a way that it is resilient, so that, after an extreme adverse event has materialized and caused the system to fail, the system reverts back to a stable state in a sufficiently short time and at an acceptable cost, and so that the consequences of the failure do not disrupt society. Within risk management, a large number of methods is available for disaster mitigation; these range from forecasting and warning systems to disaster resistant construction and disaster zoning; in the latter, people are prevented from inhabiting regions of high potential disasters - like flood plains.

Box 7: Risk management of a flood situation



Source: *UNDRO: Mitigating natural disasters: UN, New York 1991*

The social impact of water resources projects. - A major aspect of sustainable planning is that people in the area in which the project is being realized are not disadvantaged by a project. Already in the initiation stage of a project they may need to be resettled. Thus they must move from their ancestral homes and traditional living conditions to areas with which they are unfamiliar. Resettlement programs have become part of large scale water resources projects; 75 000 Tonga tribesmen were dislocated by the construction of the Kariba dam on the Zambezi river, and more than 100 000 people had to be resettled because of the Aswan high dam in Egypt and lake Nubia in Sudan.

Impacts of water resources development projects on local people can also be severe after the project has been completed and is in operation. In many cases, the development of a water resource has been of greater benefit to far away users than to the local people. Even worse is the case, in which the project has not yielded the desired effect, or in which the project functions only for a limited time.

An example is a dam built to supply water for irrigation in an arid country where siltation may cause the reservoir to fill with sediment. What happens, if the reservoir becomes so full that the system can no longer operate? Perhaps a better choice is to improve existing methods of agriculte rather than to introduce, through a system that depends on the dam, an agriculture that can last for a limited time only. A silted up reservoir not only becomes a useless capital investment, it also has disrupted the society of the people whom it is supposed to serve. During the lifetime of the dam, local farmers adjust to irrigation depending on the reservoir, and they change their life styles and working habits accordingly. While the dam is still in operation, the traditional approaches may be forgotten and experiences in sustainable and adapted agricultural practices be lost. Once the reservoir is filled with sediment, the old approaches are needed again but may no longer be available. Such a disruption in life style and in supply can affect the stability of whole nations. For an orderly and peaceful development, a project must perform reliably. Continuity and confidence in the system are prerequisites for proper respect for operation rules and for maintenance of the physical plant.

The poor, particularly the poor women, suffer from projects that are not sustainable. An eloquent plea for these people was made during the Dublin Water Conference (Traore, 1992):

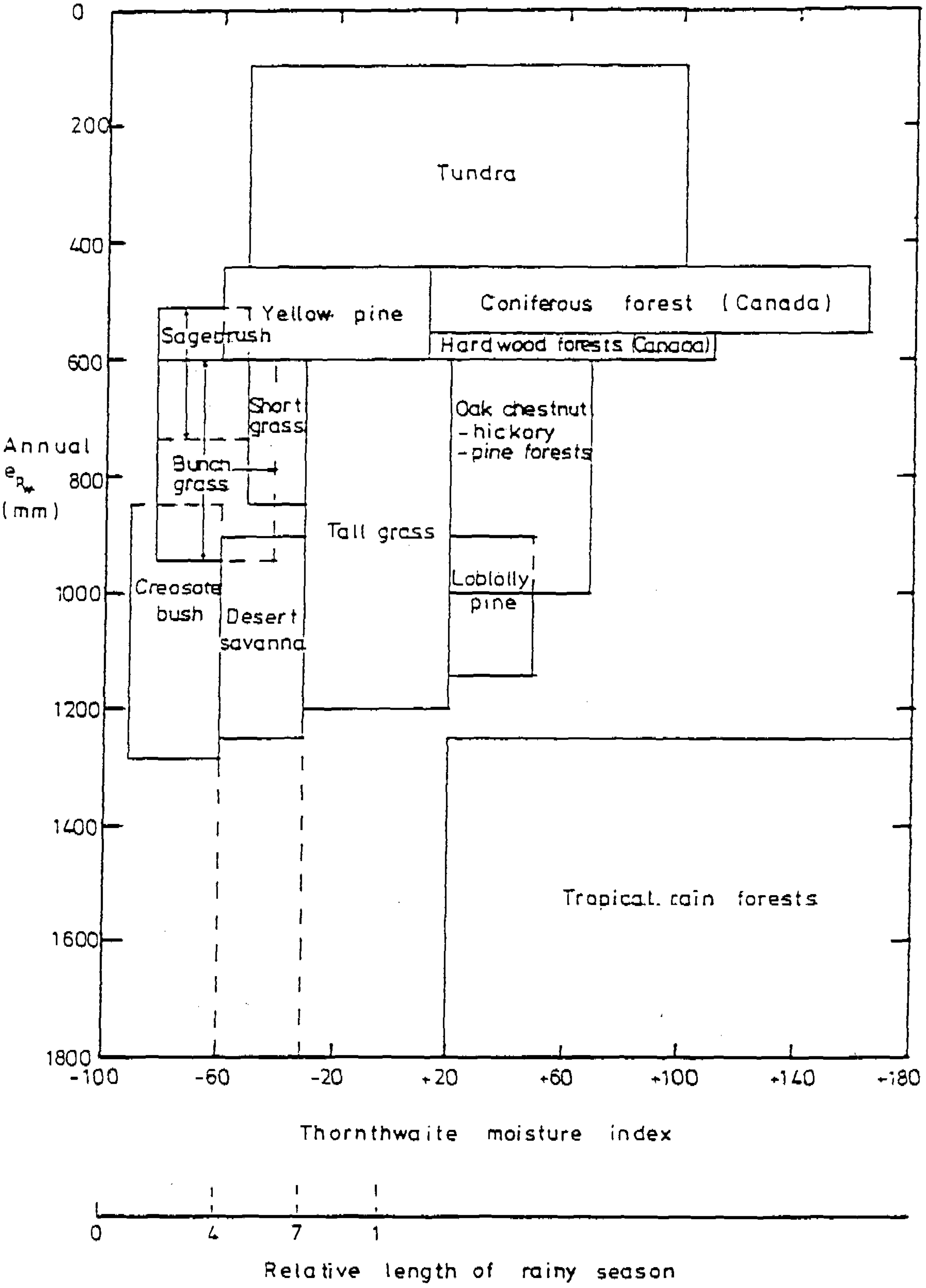
> *"Because of their involvement in development projects and programmes which have actually often failed, the women in the third world - especially in rural communities -, must turn to their natural environment for the food, water and firewood which their families need. They have to procure them directly in the ecosystem undergoing degradation. Women in the impoverished areas of Asia, Africa Middle East and Latin America have seen springs dry up and the distances to sources of drinking water lengthened well before most of us were aware of these phenomena. They continue to bear and care for millions of children each year who suffer from diarrhoeic diseases, watch over adults and children suffering from malaria, typhoid, cholera, yellow fever and other diseases which are linked to the lack of drinking water and poor sanitation and which of course do not spare them themselves.*
>
> *Efforts made over the last twenty years to improve the situation of this silent half of the population have been remarkable, but quite inadequate. As regards drinking water, we note the poorest women must consume the amount of water available to them, whether drinking water or not, increasingly sparingly or, for example, sell wood to buy water, as certain women in Mali have reported.*

> *Water resources, like forests, will not be protected, and the socio- medical situation and productivity will not be improved until we adjust our strategies to the real needs of the economically deprived social strata, giving special attention to women. What steps can this conference (the Water Conference) take to strengthen the efforts already being made in this respect?*
>
> *This existing situation is a vicious circle which we should try to break as soon as possible if we consider that all of us, including the poorest, have a right to our share of drinking water to survive.*
>
> *Who is to ensure that we do, since, according to the financiers, "someone must pay". Some even dare, and sometimes regret to say that the poor community cannot have everything and should set priorities between expenditure on food, children's schooling, medical costs, and drinking water and sanitation."*

Planning for changes. - The development of sustainable systems includes planning for potential changes: changes both in demands and in supplies. Water resources planners must ensure that they function even if the data base changes, and even if the original data base was insufficient - field data are rarely sufficient. Or changes may occur in land use or climate, that alter the purpose or the performance of a system. The use of the land may change in the catchment area from which water is obtained. A formerly forested catchment may be changed into agricultural land, and its hydrological characteristics may then also change: interception by the trees and the temporal storage of water in the root zone may cease, and more water may run off than did before. Or a deforested catchment is converted, in the course of an improvement of land use, into a forested area, and the water resources system must adjust to the resulting changes in runoff. Sustainability implies that adjustments of a system to foreseeable changes in land use can be made without expensive construction; provisions must be made for accommodating potential changes.

Sustainable water resources systems must also be resilient to potential changes in climate. Long term changes have been observed, for example, in Africa, where some of the large lakes are drying up: Lake Chad, which is systematically drying up and or the four large lakes in the African Rift Valley, which have experienced spectacular declines of the water levels over the last 30 to 40 years.

Many indicators point to a recent rise in global temperature, and past records of climatic effects on regions of the earth as well as calculations of climate scenarios by means of general circulation models (GCMs) point toward an increase in local and regional climate changes. These are accompanied by changes in growth rates of the plant cover and other biological factors. A change in temperature may push the local climate into a different climate zone, with other equilibrium plant covers and ecosystems. Different plant communities make different demands on the water, both on its distribution in time and on its quantity. Examples of climatic bands for different plant covers are presented in Fig. 7 as a function of the Thornthwaite moisture index and of the duration of the rainy season (Falkenmark, 1992). Should one use the predictions of the GCMs for the planning of a water resources system? This question is difficult to answer. Generally speaking, the main issue of climate change is not the equilibrium state, but how soon the effect of climate change on local water resources requires action. Can GCM's really predict the time scale of change? Numerical results published on the prediction of temperature developments cast doubt on their ability to do so. They, like all models, never represent the entire physical world. They are abstractions of some aspects of a physical problem, and they must be combined with many other aspects to represent physical reality. Even if one does not go as far as Casti (1991), who claimed that "Models are tools for ordering experience rather than a description of reality", one should be reluctant to base long-term decisions on the uncertain predictions of the present

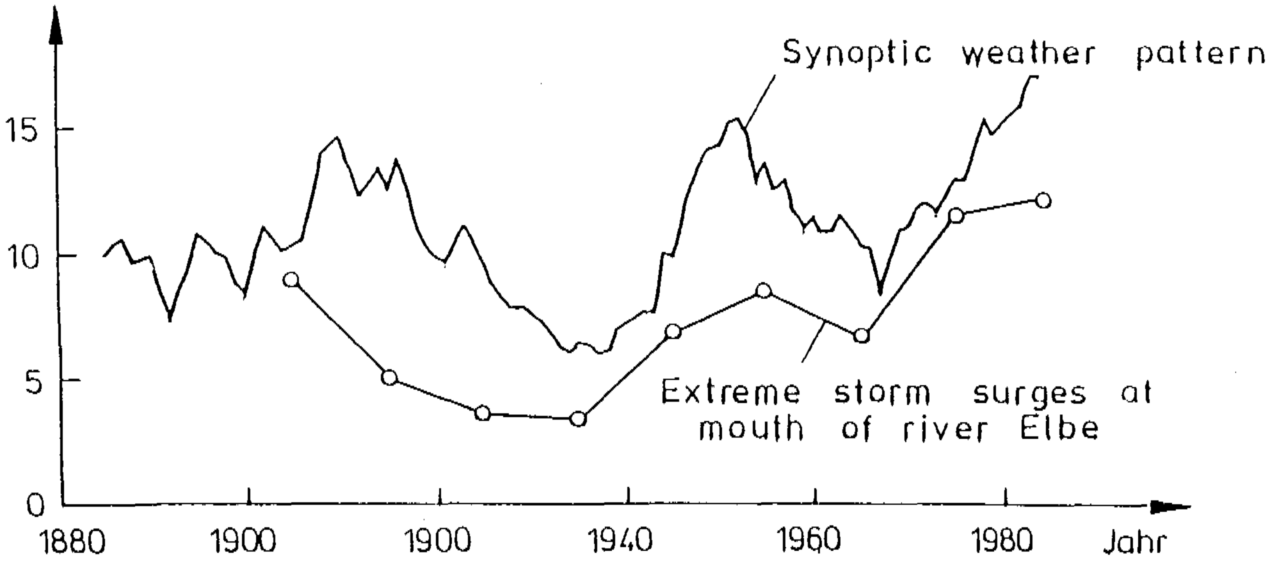


Source: Falkenmark, 1992

Fig. 7: Plant communities as function of the Thornthwaite Climate Index

generation of models. It is certainly premature to prepare for a Mediterranean climate in Central Europe, or to take measures against desertification in Mediterranean Europe.

Yet indications are already observable, for example in records of the German Weather Service, that changes have occurred in recent times. Weather patterns that dominate the climate of Central Europe have changed their frequencies (Bardossy and Caspary, 1990) and produce milder winters and hotter and dryer summers. They also affect other phenomena. For example, they apparently cause more storm surges coming from the North Sea into the German Bight. Plate and Ihringer (1991) have calculated that the probability of floods for the city of Hamburg from storm surges has increased by 45% over the last two decades. This change has three causes: human intervention (in this case the dredging of the lower Elbe river); also the sea level has risen (about 4 mm/year), and the frequency of storms over the North Sea has increased. This change is illustrated in Fig.8, where both the trend in the frequency of storm weather pattern and the accompagnying number of extreme tides is shown. Although storms alone do not cause extremely high tides, the correlation is significant. The sea level rise of the North Sea has led the low countries bordering it, in particular the Netherlands, to plan and design protection works against extreme tides that may be needed in the future.



Source: Plate & Ihringer, 1991

Fig. 8: Frequencies of extreme tides at the mouth of the Elbe river and of storm weather patterns over the North Sea

In such conditions, the "precautionary principle" is promoted. It is stated in the executive summary to the ASCEND 21 Conference: "any disturbance of an inadequately understood system as complex as the Earth system should be avoided" - and it implies that all human actions that may contribute to a future climate change should be kept to a minimum; at the same time planners should be alert to possible global changes and take measures commensurate with the time scale of climate change and the time scale of planning, design, and construction. A project started today that may take decades for its realisation must take climate changes into account, whereas projects with a short time scale must still be designed to be readily adaptable to possible changes in environmental conditions.

People involvement in the planning process. - The tasks of political decision makers are to weigh benefits against negative consequences and to set priorities. They have a special responsibility for water resources projects. A project planning process based on sustainability concepts must be a part of a hierarchical development plan, one that embeds the water resources planning process in the general development strategy of a country. Such a general plan should not be developed by experts and administrators alone. Rather, the public should be involved in this process as much as feasible, so that decisions are supported by consensus. To quote from the keynote address of Charles, Prince of Wales, to the World Commission on Environment and Development in London, in April 1992:

> *"Starting with people, analysing their needs, taking account of their culture and traditional practices, making certain that the roles of all sectors of the community are understood, and above all, to ask people to frame their own, local, environmental goals are all prerequisites to satisfactory solutions (of development and environmental problems)"*

By involving every person who has an interest, a fair and orderly procedure should lead to mutual problem solving. Most developed countries have the legal framework for conflict resolution among different water users through a continuous process of problem recognition, political legislation and legal and administrative actions. For developing countries, the non-government organizations concerned with environmental and social issues can have an important part in helping to provide such frameworks. They speak for the people, and they help to provide a balance between governments and the citizens affected by development projects.

In many of the poorest countries of the Third World, water ranks low in national priorities. Hence, they do not have balanced water management at standards comparable to those of countries with greater resources. Traditional ways of helping such countries by providing assistance for setting up water resources development projects in the European tradition, as for water supply and sanitation, may not be appropriate. More important is to develop techniques based on local skills and traditional techniques. Engineers and managers alike have the challenge to look for local ways in which the development goals can be reached in an efficient manner that is also adapted to local conditions. Standards or techniques from other countries should not be imposed. Instead, local engineers and technicians should learn to identify the requirements in these areas from consultations with the local people, and to find ingenious and adapted ways to meet them. To quote from the statement made by Mrs. Traore during the Dublin Water Conference:

> *"Despite the economic and financial difficulties confronting them, third world countries, particular rural communities and women, can play a decisive role in protecting the environment and in managing the natural resources, including water. The questionning currently taking place at international level and within individual countries is creating the necessary conditions for a new partnership with populations who need training and information on the mechanism of development, including funding. In the meantime, it is premature to ask them suddenly to cover their own cost in all fields, at the risk of aggravatimg poverty and causing further severe social and political conflict.*
>
> *Humanity has the means of avoiding such a situation, but it will only be able to do so if the development theoreticians drop some of their set ideas, particularly as regards human development, and give the communities, particular women and young people, the freedom to express their own points of view and take their own decisions."*

There are encouraging signs that people in many parts of the world are approaching their water supply problems in an adaptive way, and that these are based on the wishes and the financial and manual capabilities of the people themselves. A good example is the Oranji Pilot Project developed in the city of Karachi (see Box 8). Other examples are the construction of small dams in rural areas by self-help organisations, or the establishment of simple pumps for tapping the groundwater elsewhere. Dedicated engineers from developed countries are helping people to understand natural water flows and to harness them for their purposes; with only a little financing they can affect attitudes towards much larger engineering projects, which may not be used effectively by the people for whom they were constructed because they were misunderstood. These examples serve to illustrate that imaginative approaches to the utilization of water resources are possible; one needs to find and introduce new ways of interdisciplinary education and of transfer of basic knowledge to developing countries. The traditional approaches used in developed countries may not be the right solutions for the developing countries (UNDP, 1991).

Box 8: Oranji Pilot Project of Karachi

In the early 1980s Akhter Hameed Khan, a world-renowned community organizer, began working in the slums of Karachi. He asked what problem he could help resolve and was told that "the streets were filled with excreta and waste-water, making movement difficult and creating enormous health hazards". "What did the people want, and how did they intend to get it?" he asked. What they wanted was clear - 'people aspired to a traditional sewerage system....it would be difficult to get them to finance anything else". And how they would get it, too, was clear - they would have Dr. Khan persuade the Karachi Development Authority (KDA) to provide it free, as did (or so the poor perceived) to the richer areas of the city.

Dr. Khan spent months going with representatives of the community to petition the KDA to provide the service. When it was clear that this would never happen Dr. Khan was ready to work with the community to find alternatives. (He would later describe this first step as the most important thing de did in Orangi - liberating, as he put is, the people from the immobilizing myths of government promises.)

With a small amount of core external funding, the Orangi Pilot Project (OPP) was started. It was clear what services the people wanted; the task was to reduce the costs to affordable levels and to develop organizations that could provide and operate the systems. On the technical side, the achievements of the OPP architects and engineers were remarkable and innovative. Thanks partly to the elimination of corruption and the provision of labour by community members, the costs (for an in-house sanitary latrine and house sewer on the plot and underground sewers in the lanes and streets) were less than $50 per household.

The related organizational achievements are equally impressive. OPP staff members have played a catalytic role: they explained the benefits of sanitation and the technical possibilities to residents, conduct research, and provide technical assistance. The OPP staff never handle the community's money. (The total costs of the OPP's operations amounted, even in the project's early years, to less than 15 percent of the amount invested by the community.) The households' responsibilities include financing their share of the costs, participating in construction, and electing a "lane manager" who typically represents about fifteen households. Lane committees, in turn, elect members of neighbourhood committees (typically representing about 600 houses), which manage the secondary sewers.

The early successes achieved by the project created a "snowball" effect, in part because of the increased value of properties with sewerage systems. As the power of the OPP-related organizations increased,they were able to put pressure on the municipality to provide funds for the construction of trunk sewers.

The Orangi Pilot Project has led to the provision in Karachi and to recent initiatives by several municipalities in Pakistan to follow the OPP method and,according to OPP leader Arif Hasan, have government behave like an NGO." Even in Karachi the mayor now formally accepts the principle of "internal" development by the residents and "external" development (including trunk sewers and treatment) by the municipality.

Source: World Development Report 92

Involvement of people is also important for the impact assessment of large structures that involve changes in many parts of society. Design and construction of dams and other hydraulic structures used to be the exclusive prerogative of engineers, but nowadays engineering works are increasingly affected by non-engineering considerations because of their potential impact on environmental, social, cultural and aesthetic values. Whether a project is beneficial is a question of "beneficial for whom". For example, planning of a hydro-project should not only involve the beneficiaries of the project, but it also requires informing and involving all those directly affected. A mechanism to look after the interest of those indirectly affected has to be incorporated.

International aspects. - Although water-related problems are usually local or regional, where rivers or lakes cross international boundaries, or where seas separate countries, the problems of water consumption and pollution take on an international character, and they require joint approaches towards finding acceptable and effective solutions. Sustainability should not only guide conflict resolution within countries but should also apply to international water related disputes. Most of all the major river systems of the world, many are shared by two or more nations. The interests of these countries in the waters of the river are usually quite different: the lower country wants to have clean and unlimited amounts of water for its own development purposes, whereas the upper country wants to use the water of the river to its own full benefit. Important sources of conflicts are water supply, river pollution and contamination of groundwater on international river basins. Such conflicts must be resolved through treaties, such as the ones which regulates the use of the Nile water between Egypt and Sudan and the pollutant level in the Rhine river at the border between Germany and the Netherlands.

International conflicts are perhaps the greatest risk for the proper functioning of water resources systems. The water supply of the cities, of a region, or of a country is the most vulnerable part of a country's defence system. Bi-national or multi-national agreements can be specially sensitive issues for future generations to maintain or resolve. The Ruacana project between Namibia and Angola is a case in point, sabotage and terrorist activities here destroyed much of a burgeoning bi-national project. Another case is the ill-fated Cabora-Bassa scheme, for Mozambique and South Africa. It also succumbed to terrorism, although the major structures of dam and powerhouse remain intact for future use, the power lines (1000 km) were sabotaged.

The growing body of national and international legislation on water, pollution, and the environment presents an opportunity and a challenge for future water managers; it requires broad training and exchanges of professional information. A worldwide exchange of experience with local, regional, national and international problems of water supply and pollution control would be useful. The principle of sustainability must be translated into legal requirements that overrule special national interests. Integrated management of river basins and estuaries, inland seas and lakes should be promoted within national and across international boundaries to share common resources, and an universal code of ethics and standard operating procedures should be established.

Management requirements

Once a water development project exists, management has to translate the demands into an operational system that will provide a continuous flow of water to meet the needs of the people. For providing water from large projects, a staff of technicians and layers of management ranging from plant supervisor to revenue collectors are needed. Most of the supply for urban water users is provided by public service institutions. The managers of these institutes have the responsibility for meeting the quality standards that they themselves have to set and will have to enforce. Such institutions must also have the regulatory powers to enforce needed safety and quality standards. A high level of responsibility is required, which is not always present.

Assistance in building the managerial capacity should be given to countries where such abilities do not exist, so as to ensure appropriate human resources development, financial viability, operational skill and maintenance. The more a country has achieved stability and set on a course of peaceful evolution, the greater are its needs for competent water management and institutions for the effective and professional utilization of scientific knowledge and engineering expertise. Hence, capacity building of staff is an essential part of foreign aid programs, and interdisciplinary training of water experts is the most important factor in making a large scale project sustainable.

During the International Decade of Water Supply and Sanitation from 1980 to 1990, large scale investments were made in new facilities; these resulted in expansions of service in many countries. For making such investments sustainable, three conditions must be met, and they are as important as the technical know how: good operation and maintenance of the elements of the system, a favorable institutional framework based on good management practice, and the requisite staff of qualified people.

Inefficient operation and poor maintenance of systems continue to present serious problems in many less developed countries, and they call 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. If these problems are not solved, systems will continue to deteriorate, with a decline in levels of service and wastage of investments.

Efficiency and Conservation. - Conservation and efficient use are essential to the reaching of a balance between growing demands and finite supplies, and their incorporation should precede the construction of alternative supply systems. This approach does not require new techniques, but only more effective use of existing technology, better management, and effective transfers of knowledge and experience. Reductions of water withdrawal, consumption, and waste will also reduce the negative effects of excessive use of water, e.g. decreased wastage in agricultural applications has the important side effect of reducing salination and waterlogging. Professional governmental and non-governmental organizations have much to contribute to the processes of "finding more efficient ways of doing things".

In any water system, only a small part of the water is consumed; the rest is often contaminated by the users and is then returned to rivers and other water bodies. Therefore, development plans for water supply should include an integrated strategy for water supply management and re-use, as well as comprehensive management of all aspects that affect the human environment. Such management of water quality and quantity cannot be handled effectively without an integrated multi-disciplinary approach, a process that in turn requires a suitable infrastructure.

Water pricing as management tool. - Participants in the Copenhagen Informal Consultation on Integrated Water Resources Development and Management (prepared and supported by the Nordic Countries, Nov 11 - 14 1991) discussed the issue of water pricing, and they concluded that water resources should be developed from the "bottom-up" - i.e. by the communities that need the water. They decided that the past sectorial and "top-down" approaches to water and land management have proved unsuitable in ensuring the sustainability of water resources. Their conclusions for management of water resources for rural communities summarized in the "Copenhagen Statement" were:

1. Water and land resources should be managed at the lowest appropriate cost
2. Water should be considered as an economic good, with a value reflecting its potential use.

Among the management methods for controlling the consumption of water in a region, water pricing is one of the most effective. Water may be provided free to all, as part of a communal service, on one end of the scale, or it may be charged at a price that covers all costs involved for collection and distribution. For agriculture, most countries prefer a pricing policy somewhere between these extremes. For drinking water, however, in many countries, water prices include the cost of treating the same quantity of water both prior to use, and afterwards as sewage ("user pays" principle). If water is delivered at cost, drinking water is likely to have to compete with water for other uses. For example, if high quality drinking water becomes a scarce comodity, either because of a general water shortage or because of the poor quality of the available water, its price is likely to go up, not only that for high quality drinking water but for other uses as well.

A pricing policy must be found that assures a balanced economic development. Joint planning of water use for agricultural, industrial and domestic purposes is needed, and the plan should include environmental needs for maintaining and satisfying the water demands of sound ecosystems. As an incentive for private involvement in the treatment of water, the "user pays" principle may be reversed; the user of water can be paid for improving the quality of water, as for filtering surface waters in the ground, or cleaning the water used for industrial production before it is returned to the water carrier.

Water pricing is also an effective way for saving water. Economists have made studies that show the role of water prices in resource protection and water saving, and politicians are challenged to use their results in plans to preserve the water resources of regions. Some of these studies show that private financial mechanisms may be used with advantage for drinking water distribution and treatment of waste water, for both urban and rural areas.

Monitoring and evaluation

As soon as the project or development plan becomes operational, an important step is an analysis of performance aimed at determining the extent to which the objectives of the project or development plan are being achieved. Such an analysis may, for example, ascertain how much water from an irrigation project is actually used, what the originally unanticipated responses of project users are, what the impact of the project on the downstream users is and what the impact of the project on the downstream groundwater regime is. Such performance analyses are indispensable for assessing the effectiveness of the project or development plan, and it may help prevent mistakes in the future. This ex post facto evaluation is included under the heading of monitoring and evaluation.

If water development projects are to be sustainable, monitoring and evaluation have to be an integral part of the management process. There are many reasons for carrying out systematic monitoring and evaluation of water projects, the principal ones being the following (Biswas, 1990):

to determine the extent of achievement of the goals of a project by assessing actual impacts and comparing them with anticipated impacts, to obtain information on why a project may not have had anticipated impacts by identifying the magnitude, extent, and location of the problems in order that corrective actions may be taken to maximize the beneficial project impacts;

to increase the understanding of the management of the various interlinked processes and issues involved so that the resulting enhanced management understanding can be translated into actions in terms of immediate, observable, concrete decisions;

to improve the planning, implementation and management of similar projects elsewhere through the lessons learned;

to verify the relevant project assumptions;

to plan later phases of the project more effectively based on the evaluation of the performance of the present phase;

to provide facts and success stories at the ministry or department level which can not only defend existing policies and programs but may also assist in getting additional financial support;

to provide national policy makers with objective information in order that they can decide to what extent such activities should be continued in other parts of the country.

These reasons are in part self-evident, nevertheless, there exists a reluctance in many countries to do these ex post facto evaluations. They take a long time to do, require painstaking collections of data that yield information only after many years, and are done by people who were not involved in the planning phases, and who therefore do not know the exact planning objectives. In addition the operation rules usually changed somewhat to better accomodate the actual or perceived situation. And final arguments against such costly steps are that one does not know exactly what to evaluate, and issues of secondary concern may bias the evaluation procedure. The former President of IWRA, P.J. Reynolds, quotes the example of the funding of a monitoring and evaluation scheme of Nigerian water projects by the World Bank through the Agricultural Monitoring Evaluation and Planning Unit in Kaduna; in spite of rather high costs it did not yield much useful information - in part, because evaluators concentrated more on data evaluation methods than on true performance criteria. However, in spite of such disappointing experiences, project evaluations and performance monitoring is needed. One cannot expect a system to perform exactly as planned, and for it to become sustainable it has to be adapted so as to suit the actual conditions. In the process, a performance evaluation is indispensable.

Conclusion

Sustainable water resources development is based mainly on the application of sound and well developed principles of systems engineering and management. A systematic and well balanced application of these principles and concepts is important to assure the sustainability of a water resources system. Unfortunately, all systems are constrained by financial limitations. Investments in developed countries are dictated mainly by needs for replacement of deteriorated parts and for expansion of existing facilities. In developing countries, new investments are difficult, and they can only be provided by giving high priorities to basic needs like disaster reduction and disease prevention. Shortage of funds affects not only the implementation of projects, but also the required training and education of the management and the operating personnel. Financial support on a large scale is required from international donor organizations to promote the transfer of

technology for efficient practices for water supply, pollution control and waste management.
Future research should be directed towards finding better answers to questions that have been answered before. These answers should provide cheaper, more efficient and better adapted solutions. Many of the solutions to problems in sustainable development can be improved by more efficient methods, or from deeper insights into the physical, biological and chemical processes involved.

To indicate some of the research needs associated with obtaining better projects, the next chapter identifies research areas that are under consideration by the professional Associations represented by COWAR.

Chapter 4: CHALLENGES FOR FUTURE RESEARCH AND ENGINEERING

"...avenues for solving problems and seizing opportunities exist. A major avenue is identifiable in the realization that knowledge is the driving force of human progress. It is knowledge about the world we inhabit and our place in that world that has brought us to this societal juncture. It is progress in the understanding of matter, energy, life processes and information, and their interaction that has empowered individuals to transform the natural resources in the environment into the goods and services that satisfy basic needs and aspirations. The research community has been eminently successful in generating knowledge. Knowledge generation by individuals must continue; the need for new knowledge will only increase as societies advance. But greater emphasis, I believe, must now be given to integrating, disseminating and applying that knowledge." (T.F.Malone: "The world after Rio", American Scientist, 1992)

T.F.Malone has stated aptly the challenge that exists to science and engineering in the water field. Water science and engineering must develop further through intensive research in many areas, as outlined in this chapter. However, one cannot look forward to spectacular new findings which could vastly increase the basis of sustainable development. Progress in research in the water field is made in small steps. The major contribution of water scientists and engineers will consist of transferring existing knowledge, patiently working out details of basically understood concepts, using careful observations of applications and hard thinking. However, the concept of sustainability has imposed new constraints on engineering, and new designs and the application of other than traditional concepts have to be applied to traditional engineering tasks. It gives a new perspective to old problems, and can lead to finding new answers, dictated by the constraints, and made possible by new materials and new theoretical concepts.

In developing the holistic perspective that is needed for planning sustainable water resources systems, one finds that development work and research are required on many topics to improve existing techniques, particularly at the intersection of different traditional disciplines, and much local benefit can be derived from such research. The research aspects of the water resources development process outlined in Fig.5, are restricted to the first two stages, - planning and design.

Research problems in water resources planning

The planning of sustainable water resources development projects must be an integral part of national development programs. The success of the program will depend on how well the water problems are solved. They range from plans for the utilization of water as a resource to the use of the rivers for navigation and transportation of goods. The possibilities inherent in the water resource are to be formulated at the beginning of all planning for future development. For example before an extensive network of highways is being developed, the possibilities of navigation should first be explored. The transport of bulk cargoes is particularly economical in terms of energy, and it should therefore be a part of sustainable development. An inventory of waterways should be prepared for the year 2025 to assess global navigation requirements on which future decisions can be oriented. Research is needed on the evaluation of alternatives and their effects on the human and natural environment; an example is determining the environmental advantages and disadvantages of sea and waterway transportation, including the means to combat oil spills.

Although many books have been written on the planning of water resources projects, there is still room for much research in this area. Planning as described in most of these books leads to models of the project which are based on many simplifying assumptions, and these need be removed by future research. The main reason for inadequate models is inadequate data for model fitting. More and more of these data will become available in the future. The experiences with previous models will guide the data taking for new projects, and if properly monitored projects become more common, then the basis for improved models will also be laid. It is quite evident, however, that even the best models will not truly represent the reality. The deviation of the model from reality, regardless of its source, must ultimately be delegated to stochastic noise, and thus the model leads to predictions which are subject to uncertainty - uncertainty, for example because the demand of water for the planning horizon cannot be predicted with certainty, or because the model parameters for the process models change with time such as for the hydrological characteristics of a catchment that is subjected to changes in land use. The methods that will have to be developed for water resources planning are to be based on decision theory, with risk and uncertainty included - a theory that relies heavily on methods of operations research and stochastic process analysis.

Operations research techniques are needed to combine water resources systems with other components of the societal system. The modern tool that needs development for such studies is systems engineering, which uses information systems and decision support systems, based on information theory and systems analysis. It involves refined methods of planning and design, and includes development of operation rules, which involves forecasting and assessment of the impacts of possible actions, and which developes criteria for design and operation of the systems. In its most developed form, in such a system the functioning of the societal system as a whole has to be modelled, and usually simulation techniques are needed to evaluate its performance under normal as well as extreme conditions. Ideally, such planning should be used to find efficient and cost effective optimum solutions that yield a sum of all costs, such as the cost of its operation, as a random variable. Its probability distribution and that of the economic consequences of failures have then to be analysed by methods which yield design criteria, and which are simple and clear enough to be operationally useful. The necessary research crosses the boundaries of hydrology, water resources engineering, and economics, and since not every consequence of decisions can be evaluated in monetary terms only, it involves the incorporation of social values as well.

Research needs in assessing the natural water supply

Water resources development requires a water supply that draws on the science of hydrology, but that is not identical to it. It is operational hydrology, which encompasses all activities that are required for assessing the quantity and quality of the natural water supply in its distribution in time and space, and it is required for the efficient and scientifically based planning and operation of water resources development projects. The difference between operational hydrology for water resources planning, and scientific hydrology is that the former is method oriented and is used to generate numbers for the planning process, whereas the latter is oriented towards an understanding of the natural processes that affect the motion of water above, on, and below the surface of the solid earth. Without question the most reliable concepts to be used in operational hydrology are those that are based on a solid scientific foundation, in which the processes of water motion are explained by means of the fundamental laws of physics, and in the case of water quality hydrology, also on chemistry and biology. We therefore see a convergent evolution, in which operational hydrologists improve operational models by improving their basis in the natural sciences, and in which the analytical tools of the operational hydrologist are applied by natural scientists to help explain the physical processes that they observe. Furthermore, integrated research on the components of the water cycle crosses barriers between disciplines, so that the water cycle from rainfall and rainfall origin to runoff into oceans and its influence on local ocean regions are considered in an integral manner. From considerations of the interdisciplinarity of water research, agendas for research needs have been derived, for example by Ayibotele and Falkenmark, (1992). COWAR, widens the list of important issues, by first of all insisting that the research needs must be associated with hydrological scales, and that research must be performed so as to provide better understanding of hydrological processes at all scales, the point scale, the regional scale, and the global scale.

The point scale of hydrology is the scale to which physical models can be applied. Conceptually, it refers to a vertical column with a unit cross-sectional area through the earth surface from the atmosphere down to an impermeable sublayer. The regional scale is the scale of a catchment or a river basin that the hydrologist describes by means of conceptual models. The global scale corresponds to Global Circulation Models (GCMs), or to similar large scale forecasting models. In the context of sustainable development, the primary research objective is the quantitative description of the components of the cycle of water and matter at the scale of a water resources development system, and it is usually the catchment or basin scale. Unfortunately, basic knowledge about the processes that govern the transport of water and matter is available only incompletely, and mainly on the point scale.

Research needs for water motion at the point-scale of hydrology. - The physics of the process by which rainfall is separated into surface runoff and infiltration, and further into evaporation and groundwater recharge - i.e. the basic processes of the hydrological cycle - is best understood on the point scale. The input into the area element is rainfall, the output is the runoff, the difference between the two is caused by infiltration and evapotranspiration; these are the key processes governing the water balance on the point scale. Understanding infiltration is fundamental for understanding surface runoff during strong rainfalls, and is important for the process of surface erosion. Also, much of the infiltrated water ultimately will reach the groundwater, and infiltration therefore is the basic process for groundwater renewal, which needs to be known for assessing the sustainability of using a groundwater aquifer.

The other key process is the process of evaporation, both from bare soil and from soil covered by different crops. Evapotranspiration is the demand function for plant water, and thus it is the basis of assessing the irrigation water demand. It is also the component that needs to be evaluated for modelling long term water balances in soils.

These processes have been studied and verified in laboratory experiments. The information from the laboratory can rarely be directly used on a field scale: too many secondary processes are obscuring the basic process and contribute to the randomness of the model parameters. Even the simplest case of infiltration from a ponded water body over a column of saturated soil in a laboratory is not amenable to mathematical description without an empirical soil conductivity factor, a factor that varies randomly among different columns from the same soil. The uncertainty increases if one attempts to go from the laboratory to the field point scale. It is well known that in the field infiltration and water flow in the unsaturated soil zones are determined by macropores, which usually can be found only in undisturbed soil layers. On the natural point scale rain water finds many different ways of getting into the soil - directly by infiltration into macropores, or indirectly by first collecting in rills and depressions and then infiltrating after local ponding or after being conducted for a few meters or centimeters. Not all infiltrated water remains in the soil; some of the infiltrated water finds strange paths back to the surface to exfiltrate. If this process repeats a few times, the apparent surface runoff cannot be described by an equation based on sheet flow, because it is much more delayed. Alternatively, the runoff that collects in rills may be concentrated and runs off faster than sheet flow. These processes are difficult to quantify and can only be evaluated from observations in the field.

Added complications arise from the fact that the processes in the unsaturated zone of the soil are highly nonstationary. The soil is drying and wetting depending on rainfall and other climate conditions, and this nonstationarity affects both the motion in the unsaturated zone and the recharge of groundwater. The groundwater table may be isolated from the unsaturated soil by a layer of vapor, that inhibits motion or connected by a capillary seam that enhances it - processes that need to be better understood if artificial recharge, as from excess storm runoff, is to be used as a means of improving water supplies for irrigation or drinking water.

The transport processes for water in the saturated zone are handled by mathematical groundwater models based on Darcy's law. Numerical calculations are essential to gain an insight into an aquifer, which is accessible to observation only at single points. Stochastic approaches are needed to describe the heterogeneity of the aquifers and to develop methods of parameter estimation, that allow the models to be calibrated against field observations. These stochastic methods provide a description either of asymptotic behaviour or of the initial stage of ensemble averages, and these may differ considerably from the actual behaviour of the medium of interest. Both geophysical methods for determining relevant parameters in the field and predictive modelling of transport processes have to be improved to cope adequately with the management of water and the environment.

Better understanding is needed of the local and regional structure of the hydrological cycle by obtaining inventories not only of water quantity but also of water quality, and by studying the fate of contaminants in surface and groundwaters. These travel along paths that are different from mean trajectories determined from irrotational flow models, and they must include dispersive effects caused by soil inhomogenety, and by inhomogeneties of the application processes for the contaminants. An issue for further study is colloidal transport in porous media. Not only do colloids affect the motion of water and substances, they also carry some of the contaminants, which makes it important to know about the patterns of their migration. Much speculation goes on on the fate of substances such as nitrates, herbicides and other pesticides in the soil. Some assume that polluted water is conducted through the channels provided by the pores of the soil, others assume that pollutants are adsorbed by the stationary pore water and gradually released from it, either through diffusion processes or through mass exchanges of pore water with percolating water. Practically unknown is the role played by the macropores, and much needs to be found out about chemical reactions of pollutants with biological matter in the soil.

Detailed study of the unsaturated zone is needed, and it must be supported by field experiments. In this zone where the groundwater table fluctuates, conditions frequently change between saturated and unsaturated. Of particular significance are areas such as flood plains or wetlands. Within the unsaturated zone, air is a third phase. Although models of transport and reaction in the upper soil layer have been developed, they are not sophisticated enough to allow one to predict with confidence the impacts of local inputs of substances, for example, those due to new agricultural practices on the watershed.

Microorganisms are the significant form of life in groundwater. Yet, aquifers as bacterial ecosystems are poorly described. More effort is needed to understand the dependence of the nature and abundance of bacteria on temperature, water movement, distribution of organic matter, chemical composition and physical properties of the aquifer. The interaction of these microorganisms with the chemistry of the groundwater has to be studied. This understanding of the microscopic reactions occurring in the underground is needed to introduce the coupling of hydrodynamics and bio-geo-chemistry into transport models for predicting non-conservative contaminant transport. The kinetics of the reactions can be controlled either by the actual thermodynamic reaction or by the transport mechanisms in the porous media which bring the reactants into contact with one another. It is therefore essential to understand how the coupling of transport and bio-chemistry occurs.

Water scientists and engineers must learn to transfer such process information across scales, by using the knowledge of the physics of point processes as a basis for extrapolations to the larger scales of fields and basins. Each transfer from smaller to larger scales adds uncertainty, at the same time it permits simplifications through averaging over larger areas. Methods must be developed by means of which this kind of transfer can be handled, since no model is useful that cannot be handled in practical situations, and that cannot be used as a tool for operational water resources management - no matter how well it describes all physical aspects of reality.

Research needs in assessing the natural water supply on the basin-scale. - The basis for operational hydrology is the catchment, or river basin, or urban area. The average of the parameters observed on a point scale is not necessarily representative of the conditions of a catchment. Hydrologists are keenly aware that what they observe on a point scale cannot be integrated directly into area averages useable for operational hydrology, and that the spatial redistribution of the water cycle components must be considered. Edge effects occur, for example, between one soil type and another, or between areas covered by grass and by forests, and the geology of the basin causes layering effects - factors of importance for determininination of groundwater availability, depletion and renewal.

Detailed study of the interface between surface water and groundwater, the benthos, is needed as groundwaters are related to the terrestrial and aquatic ecosystems in many ways. The directions of the fluxes of water and the pollutants they carry vary with the levels of surface water and groundwater, and these depend on hydrological conditions. The fluxes are controlled by the state of the river bed or lake bottom, which can be clogged by filtering, biological growth or previous chemical reactions. Alternatively these areas can be cleared by river sediment transport and release pollutants stored in the sediment. The interface proves to be a crucial zone where processes like absorption and decay of pollutants determine the ultimate condition of the water quality.

The many inhomogeneities complicate transfer from point processes to area information, complications that are aggravated if the basin is not horizontal, or uniformly sloping , but has a more or less structured topography of mountains valleys, with ridges and rills in which water can collect. The methods required are regionalization methods, in which the transfer from the point scale to a catchment is achieved, or by which results from one area of a region are transferred to another subarea. One also needs methods through which hydrological parameters from one region are transferred to other, similar regions - and the term "similar" needs to be made more precise through scaling laws that are at present only vaguely understood.

The conventional way to handle surface runoff problems from extreme events is the method of the unit hydrograph, or its modifications and extensions to systems of catchments, each being described by a unit hydrograph, and all of them then being combined by means of a flow chart in which time displacements are calculated through an appropriate flood routing model. The unit hydrograph was originally conceived as a linear transfer function, but in the course of time, non-linear aspects have been included, the most significant feature being the inclusion of event dependent parameters, i.e. parameters that depend on the depth of rainfall. In the original or modified form it has been used extensively, and much research has been done to regionalize the unit hydrograph by correlating its parameters with geographical information like area size, area topography, network of rivers, and the like. Interest exists in the modelling of the infiltration rate, usually also through a linear model, and for long term simulations, simple extensions of loss functions accounting for evaporation or evapotranspiration are available. Needed is research to make these parameters transferable to other regions, and to associate them with the geology or the properties of the soil and the plant cover. Research is directed at extending the point models to regional scales by aggregation, and then to simplify the results by casting them into the shape of a unit hydrograph with parameters that are obtained from extended point scale models.

The need for field studies and extended capabilities for data analysis. - The conclusion to be drawn is that progress in understanding and quantifying basic processes, such as infiltration, can only be obtained if measurements are taken on a field scale for innumerable soil and climate combinations; from these general relationships are to be inferred that yield parameters, for given soil and crop and climate conditions, of infiltration, water storage, and evapotranspiration. One of the most important tasks of hydrologists is therefore to draw maps for the spatial distribution of local parameters of the water cycle. In this task, the hydrologist needs help. He cannot hope to cover a significant area with a reasonable effort in time and money, unless methods are made available to shorten his efforts. Much hope rests in the possibilities of remote sensing, either through satellite images or through areal photos taken at different ranges of the electromagnetic spectrum. Hydrologists today are asking whether these methods can be used for the assessment of water resources, including information on rates of evaporation and evapotranspiration of different plant covers, the depth of the phreatic surface below the soil surface, the thickness of the groundwater aquifer, and perhaps information on the recharge processes in semi-arid areas. They want to use them to assess the potential, or to monitor the actual success of regional water schemes; an example is to improve the quantification of groundwater where it is the predominant resource. Groundwater availability maps should be prepared world wide on a regional basis.

Methods are needed not only to correlate what is observed by these techniques with parameters of interest to the hydrologist, but also for computer aided information collection and evaluation. The latter range from data quality evaluation - finding outlyers, errors, inconsistencies, as well as calibration and routine evaluation of measuring instrument performance - to data storage and analysis. The data have to be stored in data banks, and have to be correlated automatically to other data, such as for soil moisture, soil type, soil composition, area exposition, area geometry and other parameters which can be obtained from digital topographical maps. Finally, results of the evaluation have to be presented in the form of coded maps. For all these tasks, tools have to be developed and applied, such as Geographical Information Systems (GIS), and areal interpolation methods such as kriging, have to be adapted. And finally, the reliability of these maps needs to be determined and evaluated through extensive field studies especially set up (a.) to verify the data base, and (b.) to asses their adequacy for use in reaching important environmental conclusions which can only be obtained from rigorous scientific studies based on complete sets of field data.

Data-acquisition that is operable and accessible in developing countries has to be developed, and there is a need for inexpensive and user-friendly data banks and geographical information systems for the acquisition of field data. In this regard it is essential to develop and maintain national hydrological services.

The need for inclusion of local information and demands. - In the developing of water resources for a region, one must realize that no model will ever fully describe the motion of the water on or below the surface. Models for water resources development involve more than the application of known mathematical models to a mathematical description of the physics of the hydrological cycle. They obtain their unique and challenging character through two essentially non-mathematical aspects.

The first aspect is that local features have to be incorporated into hydrological models in the simplified form of boundary and initial conditions. To do this properly, one must have a thorough knowledge of the natural conditions of a particular area: a knowledge of geographic features, which should not be limited to the information available from maps and geodetic surveys, but must include details of the agriculture and the climate. One must have a good knowledge of the soil and bedrock hydrogeologic characteristics; these include the infiltration capacity of soils, and geometry, permeability, and storage of the main aquifer systems. And one needs to know the human inputs into the region, such as the structures and highways.

The second aspect is the need to see such hydrological investigations as a part of a well conceived regional development. This approach is of paramount importance for those developing countries that stand at the beginning of a comprehensive use of their water resources. For no matter how well the transfer of information and how intensive the involvement of local scientists are in this process, not much is accomplished if an enabling environment does not exist. Such an environment is particularly difficult to establish if water-related problems are not exclusively local or regional, but where rivers or lakes cross international boundaries, or where seas separate countries. In these situations, the problems of water consumption and pollution require a common approach towards finding acceptable and effective solutions. In such situations much can be learned from conflict resolution techniques, including megagames.

Research needs for water supply assessment for studies of global change. - Great advances have been made in recent years in determining the variability of important climate variables, such as temperature or CO_2 content, over very long periods. This information has found its way into climate models: models that attempt to include the global transfer processes of atmospheric motions and water flows to obtain a scenario for the climate conditions of the future under the forcing of CO_2 and other greenhouse gases. However, these models are still in a process of development because many of the physical processes that affect climate have not yet been fully parameterized for useful inclusion in the prediction models. The scientists involved in modelling long term global changes are looking back to historical and prehistorical information to identify a behavior pattern for the earth's climate. Examples of information to be hoped for are listed as questions in Box 9.

Box 9: Questions on behaviour pattern of the earth's climate

In the framework of IGBP (International Geosphere-Biosphere Programme) the project PAGES (Past global changes, including Peleogeology and Paleohydrology), investigations of long term hydrological trends (paleo hydrological investigations) are made to answer the questions:

1. In what sequence, in episodes of glaciation and deglaciation, do changes in greenhouse gases and surface temperature occur?
2. How has the surface temperature of the earth changed, regionally and globally, through the last 1000 years?
3. To what extent do natural feedbacks in the Earth system contribute to greenhouse gas forcing?
4. To what extent have activities of man modified climate and the global environment in the past?

The understanding of the natural variability of climatic processes can yield important information on the variability that must be expected to occur in geological time scales. Climate change is thought to take place at very slow paces, perhaps enhanced by human interference with the global water cycle through air pollution. However, the possibility exists that the earth system has a variety of unstable equilibrium states, and the transition from one equilibrium state to the next may take place in times that are short enough to be observed in current data. This can be analysed by looking at the geological development of sediment layers, ice formations of glaciers, and deposits in lakes. A time history of the climate of the last few thousand years can be found from an examination of tree-ring data, it can give information of the relative magnitude of wet and dry periods in the life history of trees, and thus lead to valuable information on the climate variability of a region. Also of interest is the question of the absolute magnitude of extreme events, which is one of the practical questions investigated in the field of paleo-hydrology; for example, information on large floods is found from the debris that was deposited in remote places (such as caves in canyon walls) by the extreme floods of the past.

The detection of different types of trends and the identification of significant factors causing or influencing them, i.e., climate change, soil fertility deterioration, and deforestation, are of vital importance. Their basis will have to be carefully observed data, obtained at significant locations all over the world. A world wide observation network is required, perhaps through the Global Climate Observing System (GCOS).

As inputs in climate models, the partial information now available about the regional hydrological conditions must be expanded to global scale interactions of hydrological processes with the biosphere, i.e. to extend the local-level studies on the hydrological cycle to world meteorological scales in order to supply hydrological information, for example on evaporation rates, to Global Circulation Models. Such information is particularly needed for humid regions, which determine to a large extent the water performance of Global Circulation Models (GCMs). Through these models, one should be able to better predict changes ranging from climate to simultaneous rainfalls for large areas. Land surface phenomena need to be better integrated into Global Circulation Models at the temporal and spatial scales used by meteorologists.

A scientific challenge is posed by the inclusion of climate variability into hydrological models, and into decision models for design and planning of water resources systems. Hydrologists must use the results of the GCM's to make local short term and long term predictions for the interactions of hydro-sphere, atmosphere and biosphere. Any potential 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. The key problem for the water resources engineer is the handling and designing with non-stationary data. 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 of climate change through human interference with natural processes must also be considered, and this change may 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.

Research needs for demand prediction and control

Research on water demand is largely dictated by sectorial needs: needs that arise from the different uses of water. Many of the problems that have to be approached result from the process of transferring existing knowledge, or they are aspects of technology development that are not specific to water research. Therefore, these aspects are embedded in the demands of sustainable systems as summarized in Chapter 3. However, some aspects must be handled in a more fundamental way. Some of these issues are addressed in the following sections.

In all systems, public health must be an overriding concern, and the local factors that influence the habitats of disease carriers need careful study in order to control them. Management procedures and operation rules for reservoirs, for example, can control the water levels of the reservoirs and thus profoundly influence the habitats of carriers that are affected by them. Equally important is the assessment of the threats to health that come from water pollution through domestic and industrial waste water. Health risk factors associated with chemical pollutants are not well understood, and much needs to be done to assess their true potential for causing cancer or other diseases. Only with scientifically sound maximum permissible values can extreme precautionary strategies be avoided. In the interest of economic development, improved standards are important contributions to be made by epidemiologists, chemists and biologists. In view of the large number of chemicals that are used in modern societies and discharged into the rivers, such research will have to focus on identifying representative substances and their effects on human health for classes of chemicals and to correlate the effects of other, chemically related substances to them. Bio-indicators, such as certain fish or water plants, have to be developed for studying synergetic effects.

More epidemiological information and a greater understanding of the factors causing disease in marine organisms (including fish), birds and mammals has to be generated to predict the reaction of the marine environment to the discharge of specific pollutants.

Research needed for assessing and controlling drinking water supply. - The availablitity of drinking water of sufficient quality is a fundamental condition to enable the populations in cities and rural areas to live a healthy life. Research is needed wherever natural conditions are disturbed by contamination or do not suffice to meet the needs of the people. This is required both for water quantity and quality. For water quantity, the demand first must be quantified by means of reliable predictions of present and future consumption. Techniques must be improved for local water exploration. Forecasting methods, taking cognizance of the local development potential and the local population dynamic are needed to properly size water supply systems.

For water quality, needed research includes the following:

> Non-point or diffuse source pollution needs more accurate identification of causes, amounts and control strategies.
>
> Groundwater is greatly affected by the nature of the surrounding soils. Soil research is crucial to controlling contamination. Organic pollution of groundwater from point and diffuse sources needs further investigation.
>
> Health effects and ecological risk research is needed to develop better science for good decision making. Many current water quality standards are based on incomplete evaluation of risks.
>
> Viral contaminations of waters need more investigation - transmission routes, types, threats, prevention, and the effects on drinking water.
>
> Improved biomonitoring techniques for water quality (and treatment plant) process monitoring.

This is a short list only of the many water quality aspects that need be considered in future use of scarcer, and more contaminated water resources. The ability of chemical analysis equipment is thoroughly taxed by the many potentially harmful chemical and biological compounds that might be found in water supply sources, and techniques are needed which permit the evaluation of the water quality by simple and fast methods based on significant indicator substances.

Research needed for assessing and controlling irrigation water. - The demand for water of an irrigation system is dictated first by the water need of the crops that are irrigated. In order to increase utilization of irrigation water, the relative water demand expressed either as tons of produce per ton of water, or as net monetary income per hectare per ton of water. Two tasks exist for which research is needed. First, the water demand of existing crops must be determined as a function of seasonal demand by climate or by state of growth of the plants. Such demand functions depend on the soil type, the water quality, and the depth to groundwater table. In order to avoid excessive irrigation, the demands should be matched, in the simplest case, by a fixed delivery schedule, in the most sophisticated systems by dosages of water that exactly meet the plant requirements and that are controlled by sensors of soil moisture or even of plant water content; a computer programmed supply schedule can adaptively activate remote control valves. Second, to improve the performance or the yield, research is needed on different crops, and on crop combinations: some advantages may be gained by investigating crop rotation schemes. It is necessary to find the crops, or crop combinations, that are most suitable for a particular area, and for the water supply available.

However, the demand of water for the crops is only a part of the demand of the irrigation system, much of it is determined by conveyance losses, due to leaky canals and faulty distributions, and by evaporation. 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. An important area of research is to find appropriate conveyance structures based on local material and local construction skills. Indeed, one of the foremost tasks for irrigation research is the development of methods for evaluation of the performance of existing systems. The functioning of future systems, as well as the upgrading of existing systems, can be improved if the reasons are known, why a system performs well whereas systems created under apparently identical conditions do not. For assessing the performance, performance indicators are needed based on day to day information. Results of this performance monitoring then must be translated into management decisions: on the day to day operation, or to assist policy formulation and investment decisions.

With these informations, research can not only help in planning future irrigation systems, but can also assist in the upgrading and modernisation of existing systems. Of high priority is the improvement of the efficiency of irrigation systems. A sustainable irrigation system is likely to be controlled and monitored by a computer that sets the times and quantities of seeding and supplying water to the crops based on soil moisture and soil conditions, and it will use all techniques adapted for income optimization, including crop diversification based on market research.

Research needs for assessing environmental issues

For incorporation of ecological effects, the interaction of water and the biosphere need to be studied at scales ranging from point to local. On the point scale one will have to incorporate aspects of vegetation into the hydrological and hydrogeological processes to extend the understanding of the feedback loops between the atmosphere and the soil. On the point scale one has to determine the plant-soil and water interactions needed for assessing environmental impacts of pollutants, such as stormwater or sewage, or of chemicals, such as fertilizers or pesticides, on the plant cover. They can also effect on the microfauna existing in the soil, in both the unsaturated and saturated regions.

Research needs for assessing environmental effects on the catchment scale. - The regional scale of ecological studies is the watershed or its subareas. The eco-systems of many watersheds are imperfectly understood in the relationships that exist between different kinds of plants, types of soil, and groundwater levels and fluctuations. Detailed studies of such plant communities are required for many different and typical areas, in which the plants and their locations are mapped. Biological studies of the interaction of the plant communities as they develop with time give valuable indications of their vulnerability and resilience. Acceptable discontinuities in the eco-system 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 eco-systems and water quality. For example, such studies are valuable aids in assessing the impact of a dam: after completion of a dam the past ecological condition has to shift to a new condition, and it must be made acceptable to the people of the area; it must also maintain itself in a stable form and change with the annual cycle and the biological development stages of the plant community.

The research efforts in the evaluation of environmental effects on the regional scale are predominantly concerned with problems of impact of human actions on natural environments; an example is the chain effect of pollutant transport from diffuse sources. Nutrients and non-degradable pollutants of surface waters find their way into receiving fresh water bodies and ultimately into the oceans, and these are slowly accumulating pollutants. It is not yet fully established which substances are deposited harmlessly in the ocean environment, and which are harmful to fauna and flora of the sea. The capacity of oceans, seas, lakes and rivers to receive effluent should be assessed, distinguishing between local and regional effects. Models are needed to follow critical substances on their path from emission to final deposition. Micro, meso and macro mixing phenomena and effects on the physical, chemical and biological status should be included. The assessment of these effects requires different research activities for rural and urban areas.

Research needs to assess and control environmental impacts in rural areas. - Sustainable irrigation and land use projects interfere with the natural environment, as described in chapter 3. Due to an increased environmental awareness and the mounting pressure exerted by conservationist groups, the design of structural interventions in rivers must now consider environmental problems. In some cases, even existing works, decades and centuries old, are under scrutiny for possible "re-naturalization". Not all effects can be compensated for by means of available technology, and research is needed for improving methods of impact assessment as well as of impact alleviation. A typical example is river re-naturalization.

In a number of European countries, hydraulics and hydrology are used to restore the country to a more natural environment by reshaping small rivers. These had been straightened and narrowed to serve the needs of agriculture and are being returned to a more natural shape that is in basic agreement with the natural ecological condition that had existed in earlier times. For doing this, not only the static hydrological conditions which exist on the river have to be known, but also the response of the plants comprising the eco-system to the dynamics of the rainfall runoff process. Engineers must learn to create, through hydraulic methods, the desired nature-like conditions. As a "natural" configuration will generally correspond to more severe hydraulic conditions, research is needed to improve the compatibility between biological and engineering requirements, as well as to define new standards for the design of trained rivers. Natural vegetative bank protection is defined as being both esthetically acceptable and also sustainable; the benefit is the reduction of maintenance work, especially in navigated rivers or in navigation canals, that are subject not only to the forces of flowing water, but also to the forces exerted by ships' bow waves.

For such projects the question must be answered: what is a natural condition? One must define "Leitbilder" or model images for what a river should be like, images based on reaches of rivers that are in ecological equilibrium. The "ideal landscape" conceived in this way may not be fully achievable; it represents an idealistic goal, one on which planning is oriented (Larsen, 1992). In such work, one must find out what sustainable and self preserving natural conditions can exist under the given hydrological and environmental constraints. Then one can strive to obtain the most acceptable conditions and define criteria based on knowledge about stable ecological systems.

Research needs to assess and control environmental effects in urban areas. - The environmental effects of urbanization are only gradually being addressed by city planners. The urban environment offers quite different conditions to fauna and flora than does the open country, and the transfer of ecological impact knowledge from rural experiences to urban environments is not ussually possible. What are the natural eco-systems that can coexist with urban demands? According to Kreimer and Munasinghe, (1992) the integration of ecological concepts in metropolitan development has emerged as an important topic for research. An approach to resolving environmental problems in urban areas is required that would integrate the principles of ecology with the realities of urban regional development. A need exists for research into the causes and explanations of behaviour in the various sectors, in order to understand and control the contributing factors.

Environmental impacts in urban areas are also seen in the impact of the environment on the stability of cities; these areas are endangered by natural disasters, such as floods, slope instabilities, wind- and snow storms, strong frost, earthquakes, volcano eruptions, and, in coastal areas storm surges and tsunamis. Strong rainfalls are involved directly in floods, and indirectly in many landslide induced disasters. All disasters threaten the infrastructure of a city by disrupting supply lines for water, electricity and gas. The pivotal point at which a natural phenomenon becomes a disaster is that at which the city's ability to cope is exceeded. Many cities, in particular in developing countries are insufficiently prepared and are located in areas where they are vulnerable to natural extreme events. The factors that make them vulnerable should be studied at various levels:

level of internal processes of a city;
level of relationship of the city to its surroundings;
level of hierarchy and relationship of the city to other cities in the nation;
level of international economic and political relationship.

To assess the degree of vulnerability, and thus to plan for disaster prevention or mitigation, the impacts of the natural phenomenon on the following urban elements must be combined into a suitable "index of vulnerability". This must include:

impact on natural conditions: from soil and topography to climatology;
impact on the material base: infrastructure, services;
impact on the environment: contamination of air, soil and water
impact on the socio-economic environment: from income and life expectancy to nutrition and education;
biopsychic impact, as manifested in perception, tension, and anxiety.

Scientists have only recently become aware that such problems offer many opportunities for interdisciplinary research and for transfers of technology from developed countries to countries that have no protection against natural disasters. The purposes of the International Decade of Natural Disaster Reduction (IDNDR) of the United Nations are to foster these objectives, and to draw attention to the important role that disaster prevention plays for sustainable development.

Research needs for designing for sustainable development of water resources

The engineering profession has to contribute its share to sustainable development by inventing new designs which are more cost efficient and use fewer natural resources than conventional solutions. Most adjustments of demand and supply in water resources development require technical solutions, i.e. structures designed to be sustainable in the sense described in the previous chapter. For these tasks, existing technology must be used optimally in those areas where sufficient experience is available and codified in design codes. In places where this is not the case, knowledge must be transferred from the scientific to the engineering community and amplified by scientific research which closes important gaps. Some of the topics that need research activities are presented in the following sections.

Advancements in technology

Equipment is to be improved for water distribution and water technology, which in developed countries must have the objective of saving energy, increasing efficiency. For all types of hydraulic structures, methods must be developed for evaluating environmental impacts, and decision models for drawing conclusions from environment impact assessments must be found. For other countries, adapted technologies are to be developed. Primitive tools are not to be resurrected; instead, with the methods of "high tech", the techniques that have been developed from long local experience are to be improved.

Indeed, 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: energy-efficient desalination; environmentally beneficient dam design; low-water-use sanitation; more economical (e.g. drip) irrigation; erosion-sedimentation-flood control measures; and techniques of more economical water extraction, storage, transport, and pumping (e.g. groundwater recovery and artificial recharge in catchments using wind and water power, and extraction of deep groundwater).

An example of unconventional technology is the construction of underground dams. Because groundwater is shielded from the direct impact of the sun's radiation, it is an excellent long-term source of water in semi-arid countries. Near the equator evaporation from open water surfaces may be as high as 4000 mm/year, the loss to be expected for water stored in a reservoir. This high loss has made the idea of underground storage of water quite attractive, and prospecting for aquifers that are suitable for storing excess water from rainfall is in progress in some regions. From the underground storage, water is pumped out again in the dry season. To prevent water from seeping into neighboring regions, underground dams are being developed, as shown in Fig.9. Such dams can also help keep fresh water from mixing with sea water in coastal regions.

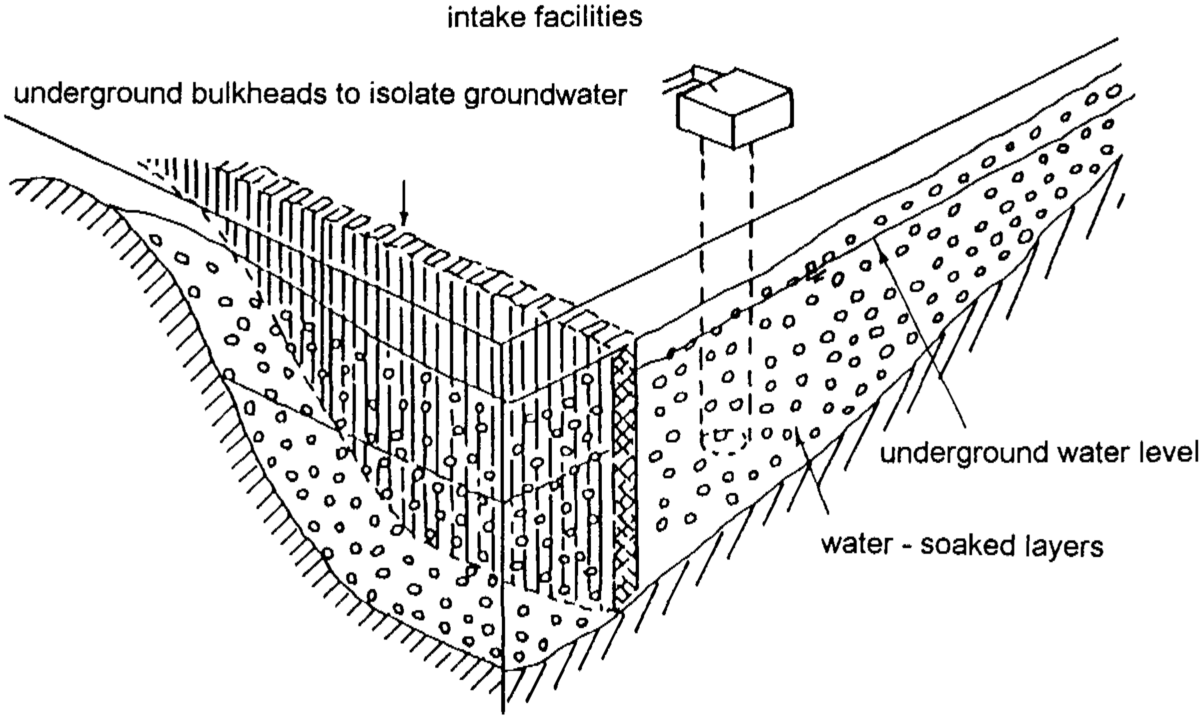


Fig.9: Example of an underground dam for confining groundwater

When, as expected, water becomes more and more a limiting factor in the development process, then innovative ideas should be pursued for increasing supplies in regions that are short of water, perhaps including exploration of exotic sources (i.e. trans-watershed diversion, rainfall and run-off augmentation, importation of water and even of icebergs). This area needs much development to find such solutions that are economically feasible.

Water supply systems. - Structures for water supply systems include those of the distribution system: the wells or pumping station at the source, the pipe network for water distribution in the area served, and the water treatment system, in which the drinking water is purified to meet accepted quality standards. Treatment methods adapted to local conditions are to be developed where they do not exist, and basic research requirements for treatment methods are derived from local requirements. Water quality is as important to monitor as is water quantity, and analysis techniques, probe taking, remote controls and information transfer all are parts of a well designed system. To do this efficiently, and to make the information known to the people that need them, in a form understandable to them is a major challenge for local research and development.

Research needs for hydropower installations. - Sustainable design for hydro-electric power projects requires the familiar research and development, but should also include:

Upgrading, refurbishing and rehabilitating existing hydropower complexes is increasingly important to make more efficient use of energy transfer. In some cases existing dams can be raised to increase power output.
Increase peaking capabilities of utilities by means of pumped-storage projects.
Small scale hydro sites need to be exploited, especially, in isolated communities in developing countries. More economical equipment needs to be developed. Drop sites in irrigation canals should be utilized.
Design more efficient turbines for variable discharges.

Hydraulic research needs

The design of hydraulic structures is based on well known principles of fluid mechanics and long design experience. Conventional design needs to be done in new ways, for example by means of computer graphics, which permit interactive design and decision making and the study of the effects of parameter changes for the structures. Fundamental research needs exist in special cases, in particular for mathematical modelling.

Mathematical models. - Active areas of research exist in mathematical modelling: generating models that are capable of handling ever more difficult boundary conditions and that include more and more details about the turbulence structures that, makes use of modern techniques of turbulence calculations such as k-epsilon models and large eddy simulation models. Since all turbulence models of practical usefulness are based on approximations, research needs exist for expanding their applicability through experiments in the laboratory for model verification. These capabilities need to be used extensively in river hydraulics to represent complex processes of the fluvial system, including secondary flow and secondary sediment transport in geometrically complex configurations, formation and development of the three-dimensional micro- and macroform of the bed, vertical and horizontal distribution in the bottom layer of non-uniform grain sizes, and dynamics of hyperconcentrated flows, called mud or debris flows.

Mathematical models that allow the calculation of pollutant transport in soil and water are available, but most of them are based on classical hydraulic and diffusion models which yield only crude approximations to values in natural environments. Pollution transport must be studied extensively. Although the goal of sustainable water quality management is to avoid pollution wherever possible, many situations exist for which a quantification of pollution transport is necessary; accidental spills and chemical pollution from industry are obvious examples. 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 environmental pollution and of biogenetic and toxic materials should be developed to restrict or eliminate local distribution.

The rules and laws for water transport have to be expanded to include the transport of matter: in particular, transport experiments conducted on a laboratory scale are not readily scaled to natural conditions if the underlying processes are non-linear. Even small non-linearities may cause large deviations between experiment and nature. In particular, spatial variability of transport mechanisms and geochemical properties in natural media can be large. The scaling laws that can be used for up-scaling non-conservative transport still need to be developed, both in terms of the constituent equations and the relevant parameters which have to be measured in the field. Major interdisciplinary field experiments should be organized for studying this up-scaling.

Improved models are needed also for water flows in which changes of the state of the water are important, such as ice covers of rivers; these should be viewed not only as stationary conditions but as conditions affected by the flow and by temperature and other variables. Water is usually considered as a neutral fluid, its thermodynamic properties have not been emphasised. Much still needs to be found out about the thermodynamic processes involved in heat transport in water: how slow will ice form under typical flow conditions, what are the stages for the ice formation to be processed from frazil to solid ice? How is the ice sheet on rivers forming, how does ice accumulate, and what are the conditions for it to break up and into what forms? The understanding of these processes is a challenge not only to scientists, but it is also a prerequisite for designing better structures or for devising non-structural measures to control unwanted ice-effects.

The great variety of complex phenomena that depend on thermodynamic processes and need to be understood are: thermal regime; climate changes; diffusion and dispersion of pollutants; ice modelling; related numerical methods and instrumentation.

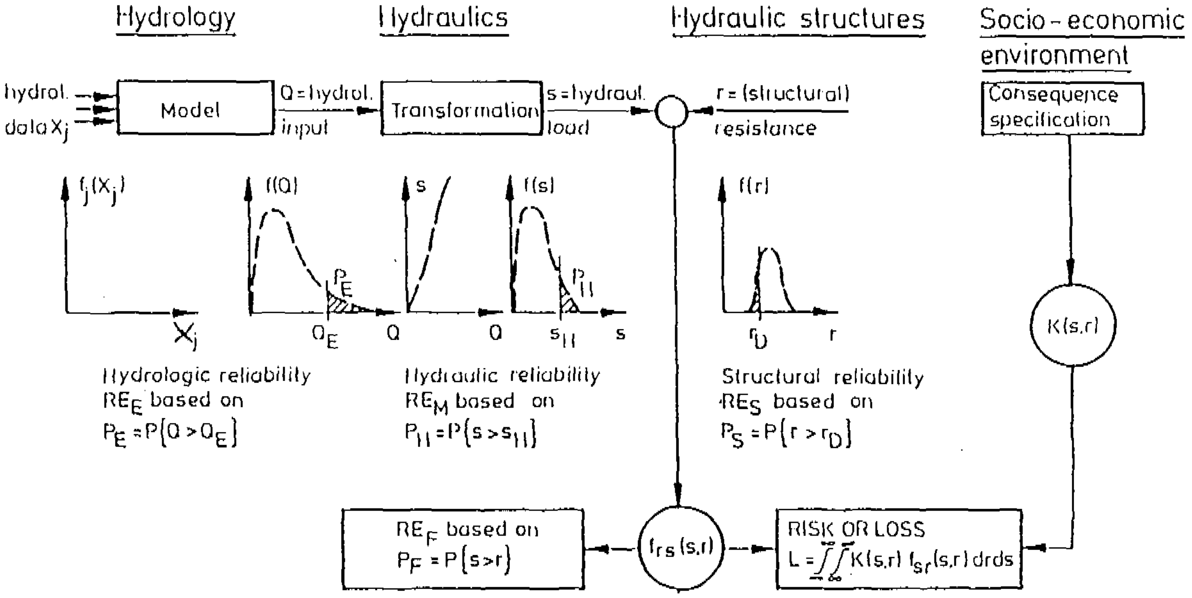
Research needs for dam design. - Topical research on dam design should include studies of the non-linear behaviour of materials under static and seismic loadings and the determination of seismotectonic features for dams. Design of instruments for monitoring the structural behavior of new and existing dams is needed. Time-dependent changes of structural properties should be determined and procedures developed for the detection and assessment of aging of dams, foundation and other materials, and structural and material solutions are needed for, for example, the repair of cracked concrete structures. For the design of new dams, a probabilistic approach should be incorporated from the beginning.

Research needs for structures related to uncertainty. - Continuing analysis of dam failures and near-failures (including tailing dams) is necessary to enhance dam safety. Too little use is made of the potential of the methods of risk analysis, in which all components of the chain leading from extreme loads are included. Hydrologists and meteorologists are still challenged to provide the vexing maximum probable flood. The consequences of a dam break must be assessed including hydraulic considerations on new ways of energy dissipation and the improvement of dam break analyses. For new dams, environmental impact assessments will have to include a detailed risk analysis, as outlined in Box 7, and emergency plans for a dam break.

The task of reviewing the safety of older dams requires simplified methods, which should, be based on scientific principles. Engineers will have to assure the safety of older dams, especially by upgrading them to handle larger floods and resist seismic events.

A modern theory for hydraulic design must allow one to account for the uncertainties of all variables that enter into the design process, starting from the input uncertainties and including the uncertainties in the criteria to be satisfied. The method for this is stochastic design, which applies to any engineering design. The transfer of the method to the specific case of hydraulic or water resources design provides a scheme of the design process as shown in Fig.10 (from Plate and Duckstein, 1988). However, much research is needed before this methods can be applied routinely, because of the difficulty of specifying and quantifying the uncertainties.

Fig. 10 indicates the sequence of calculation steps, along with the effects of uncertainty of the design variables. They are based on the design condition $P_F < P_{Fd}$, where P_{Fd} is specified a priori, and P_F is the probability that a load s exceeds a resistance r, which is determined by a technique of reliability analysis appropriate to the problem at hand, such as second moment analysis (see Ang and Tang, 1984). The permissible failure probability P_{Fd} is chosen so that it accounts for the natural variability of resistances and loads.



Source: Plate & Duckstein, 1987

Fig.10: Stochastic design scheme

Stochastic design is based on the concept that a perfectly safe structure can never be built. Although it is a logical method, it has the handicap that it is difficult to convince engineers of the need to incorporate failure into their design considerations: they usually feel that any structure that is properly designed, constructed, and maintained should not fail. However, a structure or a system with zero probability of failure is much too expensive and cannot be the objective of an economic design. In fact, it may be argued (Lind et al., 1991) that an important objective of economically sound development is the proper evaluation of the economic consequences of saving lives by risk reduction - which is by no means considered in an economically appropriate way by modern political decision makers. The research needs in stochastic design are, apart from mathematical problems, associated with integrating this approach into concepts that include economic as well as environmental considerations, as well as structural design and systems planning.

Sedimentation and erosion. - Sedimentation and erosion problems continue to challenge scientists and engineers who do not yet understand the basic process of sediment transport, and who still must handle the large natural variability of sediment transport phenomena. The study of sediments has acquired a new urgency because they are depositories of substances carried by rivers or ocean currents; the remobilisation of such substances by floods often causes large scale environmental disturbances that are not yet predictable. Intensive studies by many scientists have yielded no more than empirical formulas with widely scattering results: for example for erosion from watersheds where the purely empirical Universal Soil Loss Equation of Wischmeier is still by far the best engineering and agronomical tool for predicting erosion rates. Or for sediment transport in rivers for which in spite of generations of researchers the practicioners still use mostly equations developed by observation, dimensional analysis and curve fitting - such as the old Meyer-Peter formula, or the regime formulas developed by Blench and his predecessors. Such formulas may be useful for balance estimations, but they are usually not sufficiently specific to be applied in numerical models of two-dimensional flow systems, such as braided rivers, or for detailed studies of estuarine and coastal morphological and dynamical processes. These applications require further understanding of the motion of sediment grains in sheets or in sediment dunes and ripples, and of depositional and erosive processes, which are known to be highly dependent on local flow conditions and sediment properties.

Studies of consequences of sea level trends and on coastal and estuarine management are also needed. These should encompass in particular research to understand the morphological processes occurring in estuarine and coastal regions, together with their numerical and mathematical modelling. Extensive field data are also needed in support of the calibration of numerical models.

Design requirements for structures in urban areas

A vast industry exists that is involved with waste water control, and much of the needed research for local waste water management is done by them. Sewage disposal is viewed from many different perspectives. Even in developed countries, sewage disposal systems do not always function as planned, in particular with effluents from industries. Also, the solutions for developed countries are not necessarily the most suited for developing countries, where tropical conditions or other climatic differences may exist. There, it is particularly necessary to find new and innovative solutions. Niemczynowicz (1991) has pointed to interesting experiments that have been made in sewage control through source control, zoning, and in particular through use of ecologically sound solutions, whereby sewage is cleaned through biological actions in natural water courses. Experiments have shown, for example that basins covered with water hyacinths are effective sewage removers, and many other natural environments are useful in disposing of different kinds of effluents.

Research needs in urban drainage. - An important area for research is the urban drainage system; recently such design has turned to use hydrological inputs on storm development to calculate the sewer networks both for new systems and for upgrading existing systems. Research on urban drainage in cold climates is important. The combined population of cities with a mean January temperature of 1^0C or lower exceeds one billion. The research topics include urban snow hydrology, drainage hydraulics and stormwater management in cold climates and these are characterized by problems caused by ice formation, urban snow removal and disposal, and associated water quality issues.

Hydraulics of drainage systems is the basis for design to accommodate urban floods and assure transportation of pollutants during the periods of low flows typical for dry weather. Stormwater management options include source controls, combined sewer overflow structures, and storage in sewers, detention ponds and tanks. Solid separation is needed for proper diversion and removal of sediments. Drainage and groundwater interactions, e.g. sewer exfiltration, must be controlled to prevent groundwater pollution. Real-Time Control (RTC) of urban drainage systems, comprising sewer networks, sewage treatment plant and the receiving waters, uses favourable manipulations of flows and pollutant discharges to improve water pollution control and reduce the associated costs. Essential components of the RTC system include control and data gathering hardware, computer models of drainage systems, and a decision support system.

Research regarding sewer sediment transport has a high priority. Sewer sediment is a major vector for transport of pollutants through sewer systems, and a cause of many operational problems. Sewer sediments differ substantially from those considered in classical hydraulics. They are a mixture of cohesive particles with widely ranging physical and chemical properties. The ongoing experimental programs in several countries need to be coordinated.

In some cities storm water runoff is conducted into city parks, forest preserves and other natural areas in order that it can infiltrate and be cleaned in the soil before it recharges the groundwater. This method is based on the separation of rainwater and sewage: sewage during dry days is conducted to sewage disposal plants and stormwater runoff is infiltrated. In other cities sewage is conducted onto infiltration fields partly used for agriculture under the assumptions that biological processes in the soil decompose the sewage, and that valuable fertilizers contained in sewage are used by agricultural products.

Need for developing maintenance procedures and operationally efficient designs

New technology for sustainable water supply and sanitation aims at "operation and maintenance friendly design" - not only in new designs, but also in the important task of rehabilitation and retrofitting existing systems. Most infrastructures of the Western countries have reached advanced ages: sewage systems were introduced in many cities 100 to 150 years ago, some water supply networks are even older, and city development, as well as deterioration with time, make it necessary to upgrade or replace existing systems, often at enormous cost. Management methods as well as technological solutions in the form of machines and systems are being developed that make repair and retrofitting tasks more efficient; these can be used to repair continuously and efficiently. Managament is asked to provide schemes for supervision and replacing system parts in a cost effective and technically efficient manner. Maintenance also is one of the key issues in obtaining sustainable irrigation systems, which fail at an alarmingly high rate, due to technical problems associated with poor maintenance, or with poor water delivery strategies, or because of salination. Research and development on more effective water-use practices in irrigation must address local conditions, including the attitudes and opinions of water users (especially of the farmers). Human attitudes and tradition are often major impediments towards changing established practices. For example, communication between engineers and farmers is essential to assure that water scheduling for irrigation be carried out effectively. Human, institutional and political constraints often have to be overcome before existing technologies can be applied, adjusted or improved. This approach is expected to lead to a major change in the design of agricultural projects, so that collective water use is optimized in accordance with local needs rather than with agricultural production only. The criterium of increased efficiency for optimizing cost and yield also applies to hydropower projects, where research is necessary to optimize the cost of new dams and hydroelectric projects in the context of overall regional development.

Conclusion

Many research needs have been listed, not only those that are specific for sustainability. New concepts are expected to lead to improved designs and improved planning for water resources development projects. Undoubtedly more topics, some more important than those listed, need to be considered. The conclusion to be drawn from this is that the development of sustainable water projects requires an active research community that is involved with the issues of water quantity and quality. This is possible only if ways are found to finance not only ongoing research, but also to disseminate the information gained from research to engineers and to managers.

COWAR sees the most direct path for knowledge transfer in the cooperation of engineers and scientists in scientific and practical projects, and in active endeavours of knowledge transfer from developed to developing countries. What the member associations of COWAR are doing in this respect is the subject of the concluding chapter.

Chapter 5: TRANSFER OF SCIENTIFIC INFORMATION AND PROFESSIONAL EXPERTISE

"With regard to a strategy for water resources capacity building, it must first of all be recognised that each country and region has its specific characteristics and requirements with respect to its water resources situation and its institutional framework. Therefore operational startegies must be tailor-made."
"Developing countries and ESA's (External Support Agencies) are encouraged to use local and international institutes, professional associations, water and sewerage utilities, twinning arrangements and consulting firms as additional ways of obtaining expertise and of sharing information." ("The Delft Declaration" on a Strategy for Water Resources Capacity Building, UNDP, June 1991.)

The challenge of implementing water resources projects for sustainable development calls for unprecedented cooperation from national governments and the international development community. Great commitment is required by the nations to improve national water resources management: the political will for sustainable exploitattion of water resources is prerequisite for appropriate actions. To be effective this commitment must be based on public understanding and support. Governments, voluntary organizations and the media have to see the duty to inform the population of the critical issues, especially about the links between environment, population and development. In this **information transfer** from the planners to the public, the engineers engaged in the water resources projects must be very active, and they must contribute, through their **professional expertise**, to an impassioned discussion of the positive and negative aspects of a development project.

But commitment alone is not sufficient: countries must have both the manpower and the know-how to cope with the problems involved in water resources development, and they must have, or develop, the capabilities of local technicians to operate and maintain the system. A necessary condition is that appropriate institutions must exist through which to carry out planning, operation, and maintenance of a water resources system. An appropriate management system satisfies local administrative requirements, and its managers are trained to optimize the system management by taking customs and legal structure of the country into account so that the demands on the infrastructure are commensurate with the available talent. For this, information is needed for finding the right methods, and professionals and engineers from many different specialties have to cooperate for reaching all water resources development objectives. Perhapse not all of these specialties may be available in every country. In countries whithout adequate high-level manpower, international help must be provided: a help that is based on the concept of training for enabling local professionals to solve local problems. Here, the international community of scientists and engineers is challenged to give the needed help unselfishly, and, where information is not available to coordinate and support national and international research. Past experience has shown that the exchange of information and the interaction within countries and among international scientists may be best served through professional societies. In this chapter, the main emphasis will be on the important role which national and international associations of the scientists and engineers who work in the water related fields play in the information transfer. It is based on information supplied by the member associations of COWAR.

The role of technical associations in technology transfer

The need for national or regional professional societies - The key to a successful development of local water resources by local engineers is the existence of sufficiently well trained manpower in all of the fields that are involved in the development process. Where such a capacity does not exist, it has to be built up. It is the responsibility of engineers and scientists working in the water field to assure that the water resources of their country are utilized efficiently and optimally. This responsibility requires that these engineers and scientists are working together and find a common voice for convincing the political leadership of their country to allocate the necessary resources. They create national awareness - that disasters and water shortages do not have to be taken for granted - and assist in national capacity building for service improvement and sustained maintenance of assets. Wherever such organisations existed and had strong backing by professionals they have had great influence on the development of a country. Unfortunately, in many countries, in particular in the developing world, a suitable information network to bring these engineers and scientists together does not exist. A means of remedying this is through the creation of national engineering societies - the important role which associations like the Institute of Civil Engineers in England, or the American Society of Civil Engineers has played in the development of their country provide examples. Well functioning engineering societies can help in the development process by providing the following services:

> They offer a mechanism for the continuous updating, through journals, seminars and training courses in all aspects of water development, of the professional knowledge and skills of their members, and thus they prevent professional isolation.
>
> They produce manuals of practice for operation and maintenance, as well as for planning and design.
>
> They act as a link between institutions, such as public water and sanitation agencies, irrigation districts, and private manufacturers, consulting and other companies active in the sector.
>
> By working in close collaboration with national decision makers in defining national policies in their sector, they help set realistic targets and standards, both for engineering practice and for equipment and material, and codify good practices in utilities, government departments, consultants, manufacturers, universities etc.
>
> They promote national and international exchange and co-operation in the areas of research, training, technology and overall strategy, by transferring experiences of experts from one country to another.

Therefore, we feel that one of the most effective ways in which technology and knowledge transfer can be accomplished for developing countries is by helping them set up national professional societies, if possible in such a way that they cover wider areas than the traditional associations in developed countries. For this, COWAR's member associations are prepared to help.

For many years, international professional Non-Governmental Organizations (NGOs) as well as the relevant UN bodies have served as the link between professionals in developed and developing countries. Numerous cooperative projects and activities testify to the success of this approach. For example, the International Association for Water Quality (IAWQ) has given moral and other support to national professional societies in Thailand, Malaysia and South Korea. The International Water Supply Association (IWSA), in partnership with IAWQ and the International Solid Waste Association (ISWA), has formulated a project for improving professional societies in selected developing countries. By a systematic program of organisation and management they seek to improve the competence of the selected societies to better serve the professionals in their countries. Associated with this there will be programs of technology transfer in water supply, sanitation and solid waste disposal which will be provided by the members of the three associations. In this way local members are integrated through their professional society into the international community.

The role of international professional societies. - A significant role can be played by the international associations working in the water related fields described briefly in Chapter 1. The cumulative experience of all engineers and scientists participating in the activities of these associations forms the solid basis on which water resources development rests. The dissemination of this knowledge to colleagues around the world has been and is one of the most important tasks of the international associations in the water field. Foremost in this process are scientific meetings of various kinds. However, most associations also provide other services, many of them specially intended for their members in developing countries. Some have even made service to these members a prime responsibility. Many years ago PIANC established a special committee for finding ways of helping scientists and engineers in developing countries. An indication of this growing concern is that other associations are following this lead. IAHR, for example, has two committees that are directly involved with such questions: a Committee on Continuing Education and Training, which has explored imaginatively different methods of knowledge transfer and made its findings available to all members, and a Consultative Panel, which has the function of finding ways and means of intensifying, for the benefit of its membership, interactions between the association, national professional societies, the UN Organizations, and the large funding agencies, such as the World Bank. IAH has its "Burdon Commission" on developing countries with comparable objectives. And IWSA, has followed the recommendation of its Committee on Cooperation and Development and has established a Foundation for the Transfer of Knowledge, which provides speakers to regional or national conferences.

An important service is provided through the dissemination of information material for technology transfer and for application of the advances in the field, such as hydraulic structures design and water resources planning, in particular on safety aspects of hydraulic structures design and construction, and on environmental and related socio-economic aspects. Also, recent research results are being disseminated. IAHS has a special Task Force for Developing Countries, which disseminates, free of charge copies of its journals and conference proceedings to libraries and institutions in developing countries.

As result of deliberations in committees and councils, the associations have incorporated a variety of activities for developing countries, with the following objectives:

to improve the professional competence of its members

to encourage members from developing countries to participate
in the process of exchanging scientific information

to diversify their membership.

For improving the professional basis of their members, the associations have produced monographs or guide books on special subjects, as examples, PIANC is preparing a "Handbook on Port Maintenance" of which a number of chapters have been published, IAHR is producing a series of design manuals for hydraulic structures, and IAH prepares monographs on urban water and small scale groundwater irrigation especially directed to developing countries.

Other activities include the following:

> the associations hold special seminars or workshops on engineering or scientific topics in developing countries. These workshops are conducted as separate events, or in conjunction with a conference. The series of seminars which are conducted preceding regional IAHR congresses, or during the World Congresses of IWSA are examples.
>
> the associations provide (and cover the expenses of) high level lecturers, who present lectures on topics of special interest to a region, such as the IAHR/UNESCO lecturer of IAHR, or the IWRA lecturer.

Other ways of being of service are being explored. Recently IAHR created a series of Seminars for directors of hydraulic research institutes, which are convened parallel to the scientific congresses and during which information is exchanged on efficient institute operation, and on the improvement of coordination among the institutes.

For helping scientists of developing countries share in the process of scientific information exchange, the associations are engaged in the following activities:

> Some of them operate Third World Membership Funds, which allow them to sponsor colleagues and institutes in third world countries. Membership is granted free of charge for a number of years, and the membership fees are paid from the fund that is supplied by donations from more affluent members. Other organisations, such as IUPAC subsidize outright members (or affiliate members) from developing countries.
>
> They provide travel funds so that students and scientists from developing countries can submit papers and attend international conferences; for example, IAHS sponsors the participation of experts from these countries in its national and regional conferences.
>
> They include topics especially tuned to the needs of developing countries into their conferences. For example, PIANC included in its Edinburgh Congress 1981 the topic: "The exchange of planning and engineering technologies with developing countries and its relationship to improve maritime ports and inland terminals", and in its Brussels Congress 1985: "Commercial and fishing ports in developing countries".
>
> They organize and conduct some of their major congresses in developing countries: the IWRA World Congresses in Mexico City 1979, New Delhi 1985 and Rabat, 1991; and IAHR Congresses in Sao Paolo 1975, New Delhi 1981, an IAH Congress, in 1988, in Guilin (Peoples Republic of China,PRC), and IWSA Congresses in Tunisia, 1984, and in Rio, 1988. Also, IAHS has organized a series of international meetings in developing countries: on Water Resources Management in Beijing (PRC), 1990, on the Soil Moisture Balance in the Sudano - Sahelian Zone, in Nyamey, Niger, 1991, and on Erosion and Debris Flow, in Chengdu, PRC, in 1991.

> They cooperate with international agencies of various types in joint activities, such as the conference on droughts in Khartoum in 1988 which was organized by IAHR and UNESCO, or the conferences which have been offered as contributions to the fourth phase of the IHP.
>
> They support the COWAR initiative WASNA (Water Sciences Network for Africa), which is aimed at involving African scientists and engineers in the associations' activities, by providing association generated journals and proceedings through the existing networks of the associations.

These services are only the organized part of the contributions by the International Associations to their colleagues in developing countries. The non-organized part is the contribution through contacts among members. The hydrologist or engineer working in a developing country is often quite isolated as he has few opportunities to meet professional colleagues in his own country. Through contacts with persons from other countries who are his professional colleagues, he can not only improve his professional knowledge, but he can also gain confidence and self assurance from being part of an international community of men and women who share his interests and pride in his profession, and who understand and value the work he is doing.

International associations also provide services on national levels for contacts among professionals. One of them is the encouragement of local professional groups. Some international associations, such as ICID, IAHS, and ICOLD, have created National Committees. These committees work most effectively if initiated by individual scientists and guided by able chairmen. In some countries National Committees are set up by the national Ministry in charge of water resources, a process that ensures continued interest in the committee by the top officials of a Ministry.

Very successful has been the strategy of IAHR to set up regional divisions (in Latin America, the Asian - Pacific region, and Africa). The meetings of the regional divisions (for example, the 8th Congress of the Asian-Pacific Division in Pune, India, and the 15th Congress of the South-American Division in Cartagena, Colombia, of IAHR in 1992) addressed problems of particular concern to the scientists of the region, which often differ from the research interests of the largely academic international research community. These meetings have been effective in fostering regional cooperation, and have helped the regions gain a certain scientific independence. The example of IAHR has been followed by the IAWQ, which has regional divisions in the Asian-Pacific region, East Africa, and in the Middle East, and these also hold biennial conferences. Furthermore, ISWA has successful organisations in Asian Pacific, Africa, and Central Asia.

The need for cooperation

As pointed out in previous chapters, the most important task of the scientific and engineering community is not the generation of new knowledge, but the organization of the existing knowledge into a form that is readily accessible. The increased knowledge of the profession has resulted in many specialized fields with little contact among them; consequently, a sectorial approach to water-related problems is prevalent. Some scientists feel that a more comprehensive approach can be restored by means of knowledge-based decision support systems or expert systems; in these the computer assumes the role of the collective memory, stores all necessary knowledge and provides the answers to suitably formulated design questions. Others feel that the answer lies in learning to work in teams of experts, who provide their respective expertise to handle partial problems, e.g. a water resources planning scheme that is part of a comprehensive systems analysis.

Integration through the systems approach. - A common ground for the cooperation of scientists from many different disciplines is the systems approach. It provides order by subdividing a water resources system 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. The planners provide final systems configurations and prepare decisions for further actions, in the sense of the model description of Fig.5. This approach has been used extensively in policy studies, and many valuable results have been obtained. These approaches should not be applied indiscriminantly, but by carefully only evaluating the issues that need to be covered by a model: details of the less important issues should be omitted in order to concentrate on the critical aspects and their interrelationships. Because of the mistakes that can be made by an indiscriminate application of models and model components, more than for any other reason, cooperation of scientists and engineers is required. As a third aspect, this approach can be successful only if the decision makers are willing to accept both the engineer and the scientist as their partner; also, the scientist must be willing to work on the practical aspects of the project for which he is a partner.

Cooperation in international programs. - One of the foremost tasks for scientists all over the world is to cooperate on international programs that are set up to create mechanisms for international knowledge transfer; in these the scientists of developed countries learn to work with their colleagues from less developed countries. Such programs have been shown to be very effective. Examples are the Operational Hydrology Programme (OHP) of the World Meteorological Organisation (WMO), the International Hydrological Programme (IHP) conducted by UNESCO, or the International Geosphere-Biosphere Programme (IGBP), with its strong emphasis on "Global change", organized by ICSU. These programmes are designed to support international activities deemed most important by the countries represented in the UN system. A significant focussing event was the Mar del Plata Water Conference in 1977, which led to the International Decade on Drinking Water and Sanitation, from 1980 to 1990. Although the decade has not reached its ambitious goal of having safe drinking water supplied to all people of the world, it has created awareness and has initiated international support programs for some of the poorest countries.

A similarly important role is envisaged for the International Decade for Natural Disaster Reduction (IDNDR). Disaster mitigation practices, ranging from structural measures to developing relief organisations for handling local disasters, exist in most developed countries, and they have 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 of the world, and their disaster management methods are often poorly developed. Therefore, one of the most important aspects of sustainable development is 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 IDNDR.

Recent floods on major rivers in China, as well as river floods and storm surges in the flood plains of Bangladesh have made evident that great efforts are required to make the world a safer place to live in. But many disasters also result from the lack of water, as droughts in many parts of the world show again and again, and here also it is well known that their impacts can be mitigated by careful evaluation of the drought potential and by suitable actions based on it. Because of the urgency of helping prevent the consequences of natural disasters, engineers and scientists working in the planning, construction, and management of water resources systems strongly endorse the IDNDR and its objectives.

The need for education and training

Education toward improving the water consciousness and water management ability of all nations should be promoted. For this purpose, extensive educational programs instituted at all levels in society might be helpful for promoting prudent use and conservation of water. Water consciousness at the grass-roots level fostered through all stages of education can best ensure sound handling of scarce water resources, especially in developing countries short of water. Education is needed of the public for the management and protection of groundwater, or for rural water schemes created by regional authorities. Linkages should be established with good health and domestic hygiene practices. Unless people understand its importance, institutional controls will not work.

The need for a broad education of the people in water issues is particularly urgent when the people themselves are part of the water distribution system, as is the case for domestic water supply and for irrigation. Only when the farmers understand the need for water conservation, they will be interested in good water management for efficient crop irrigation.

Each nation primarily depends on its own professionals to provide the know-how and expertise required for water resources development; however, it may depend to some extent on some expert advice brought in from other countries. In order to develop the skills needed to effectively solve design and water management tasks, the technical abilities of its engineers must be upgraded continuously through education of the most qualified young people and by continuously improving the professional abilities of the practicing professionals. The teachers required for this purpose should be local persons, who have been trained on actual projects, and who have supplemented their knowledge by advanced studies in reputable schools.
Education and training should always be reviewed and adjusted in light of the following considerations:

Why should there be a training program?
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 doing the training?
Where should the training take place?
When should the program be held?

The local teachers should be able to instruct students not only in their specific fields, but they should also provide information about the impact of development on the environment - both factually and philosophically. One expects of them an awareness and concern for the fragility of natural ecosystems that they can transmit to their students. A good basis for this is an expanded systems approach, one that incorporates environmental issues into a multi-objective decision problem and leads to an appreciation for multi-disciplinary co-operation and integral management. An example of such a study is the report by the US National Research Council and the American Society of Civil Engineers on integration of water and environment in Egypt. Finally, academic programs should be structured to be effective in meeting the demands of society, and teachers should be trained who are capable of implementing them.

To be kept informed of new developments, teachers must have access to good information sources. Two ways are participation in regional and international meetings and through other means of technology transfer, e.g. dissemination of written information. For the teaching of teachers, many countries with well developed training programs offer these to developing countries, and local efforts are supported by material provided by the international associations. For example, an IAHS/UNESCO panel has produced a report on the Education of Hydrologists. IUPAC's Committee on Teaching of Chemistry (CTC) produces twice yearly an international newsletter on chemical education, which is distributed widely and free of charge to developing countries. In addition, the IUPAC-CTC promotes the use of low-cost, locally produced equipment, through hands-on instruction in courses offered locally. Other IUPAC Divisions assist in quality assurance development and give general advice on analytical chemistry; they also provided the expertise to run a hospital quality assurance course for technicians (in Nairobi, Kenya, 1993).

Teaching and research go together. Much of the research needed for solving problems associated with eco-hydrology, climate change, regional water resources systems planning, such as for development projects of water supply and sewage disposal systems for mega-cities, require extensive resources in equipment and expertise from many different fields. Team effort and research cooperation are required on an international scale. Integrated research is also necessary on integrated water resource management methods, for both rural and urban areas, that are adapted to the particular needs of different regions of the world. To serve these purposes, the establishment of coordination centres has been proposed; in them, priorities of research and development can be set for a region, and these are then approached through coordinated research by teams consisting of members of many different specialties.

The role of international experts in knowledge transfer. - The cumulative experience of engineers and scientists all over the world forms the 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 scientists or the engineers from a developed country should make every effort to concentrate on the needs of their colleagues in the developing country, and try to become true partners. A lot can be learned from colleagues from developing countries. The water sciences combine physical, chemical, and biological principles of universal validity with local geographic and geological conditions, which exist for each region of the world. For the inclusion of the regional factors one has to go to the land and study the local conditions, and in this process the scientist of the region is the leader.

For water resources development of a region, a person is needed who has an excellent knowledge of both the social and the 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 region in which the hydrologist or engineer or water scientist 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, one who also has a professional toolbox with the applicable fundamental methods. Hence, international associations should increase participation in the work of scientific and technical committees of engineers from developing countries to promote exchange of ideas and experiences, and to obtain from them local information and special knowledge.

The foregoing concepts apply also to the development of professional competence. In the past, 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. Today, local scientists and engineers are trained and motivated to solve their own problems. The expert from the developed country assumes in this approach 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 is more likely to have knowledge of the regional situation.

In recent years one has recognized the breadth and has obtained the means to understand and quantify the interactions of man and land and water and life. Water resources development today is an integrated activity and requires an integrated approach. This approach differs from the prevailing fragmented approach to the individual problems. The challenge to the scientific and engineering community is to invent more effective ways for the collection, transfer, and application of knowledge to be used in integrated water resources development. The approaches used for water resources development not only affect the development of local communities of a small region, but may also influence and affect a river basin, a continent, or even the whole world.

Final remark

We have come to the end of our assessment of the need for sustainable water resources development. Sustainable development was shown to be the only promising development concept for agreeable living conditions over long time spans. We identified the reasons why this concept is so difficult to apply, but we were also able to show that many of the methods by means of which water is managed already meet the criteria for sustainability that are elaborated in chapter 3. We stated the basic conditions to be satisfied by sustainable systems: that an adequate institution exists, that priority is given in a national or regional budget for operation and maintenance, and that channels are provided for the flow of information from the research community to the engineers who plan and design, and to the managers who operate and maintain water resources systems, so that they adapt efficiently to the ever changing demands and constraints set by a dynamic society, a changing environment, and changing technologies. And in this last chapter we have finally pointed out that an important role in this process has to be played by national and international associations. COWAR has prepared this report in order to remind the public and these associations of these tasks.

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LIST OF ACRONYMS

ASCEND 21	-	Agenda for Science in Environment and Development into the 21st Century.
BOD	-	Biological oxygen demand
COWAR	-	Committee on Water Research
CTC	-	Committee on Teaching Chemistry
ESA	-	External Suffort Agencies
FAO	-	Food and Agriculture Organization
GCM	-	Global Circulation Models
GCOS	-	Global Climate Observing System
IAH	-	International Association of Hydrogeologists
IAHR	-	International Association for Hydraulic Research
IAHS	-	International Association of Hydrological Sciences
IAWQ	-	International Association for Water Quality
ICID	-	International Commission on Irrigation and Drainage
ICOLD	-	International Committee on Large Dams
ICSV	-	International Council of Scientific Unions
ICWE	-	International Conference on Water and the Environment
IDNDR	-	International Decade of Natural Disaster Reduction
IGBP	-	International Geosphere-Biosphere Programme
IHP	-	International Hydrological Programme
ISWA	-	International Solid Waste Association
IUPAC	-	International Union of Pure and Applied Chemistry
IWRA	-	International Water Resources Association
IWSA	-	International Water Supply Association
KDA	-	Karachi Development Authority

NATO	North-Atlantic Treaty Organization
NGO	Non-Governmental Organisation
OECD	Organization for Economic Cooperation and Development
OHP	Operational Hydrology Programme
OPP	Oranji Pilot Project
PIANC	Permanent International Association of Navigation Congresses
PRC	Peoples Republic of China
RTC	Real-Time Control
SIL	Societas Internationalis Limnologiae
UITA	Union of International Technical Association
UATI	International Union of Technical Associations and Organizations
UN	United Nations
UNCED	United Nations Conference on Environmental and Development
UNDP	United Nations Development Programme
UNDRO	United Nations Disaster Relief Organization
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WASNA	Water Sciences Network for Africa
WHO	World Health Organization
WMO	World Meteorological Organization

The Committee on Water Research (COWAR) is a joint committee of the International Council of Scientific Unions (ICSU) and the International Union of Technical Associations and Organizations (UITA). In existence from 1964 to 1994, COWAR will be succeeded by follow-up committees sponsored by the scientific (ICSU) and the engineering (UATI) communities.

ICSU was created in 1931 to promote international scientific activity in the different branches of science and their applications for the benefit of humanity. Since its creation it has vigorously pursued a policy of non-discrimination, affirming the rights and freedom of scientists throughout the world to engage in international scientific activity, without regard to such factors as citizenship, religion, creed, political stance, ethnic origin, race, colour, language, age or sex.

ICSU is a non-governmental organization with two categories of membership: scientific academies or research councils, which are national, multidisciplinary bodies (92 members), and Scientific Unions, which are international, disciplinary organizations (23 members). The complement of these two groups provides a wide spectrum of scientific expertise, enabling members to address major interdisciplinary issues which none of them could handle alone. In addition, ICSU has 29 Scientific Associates.

UITA was created on 2 March 1951 at the initiative of UNESCO. It is an international non-governmental organization. UITA is a grouping of international non-governmental technical associations the purpose of which is:

- to identify, promote and co-ordinate their actions in fields of common interest;
- to facilitate their relations with the organizations connected to the United Nations system.

UITA takes part in the preparatory work of the annual and pluriannual programmes of the bodies of the United Nations system: its members may be recipients of specific contracts and take full advantage of all the aid systems available for their actions in favour of developing countries.