Environmental Education Module

Freshwater Resources

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In this report the term water is used to mean water on the continents, normally freshwater, thus excluding saltwater in the oceans.

1 INTRODUCTION

Life on earth cannot exist without water. When the Greek philosopher Empedocles about 450 BC, named the four basic elements, they were water, air, fire and earth. Water is, in either solid or gaseous state, almost everywhere, making human, animal, and plant life possible.

The past 30 to 40 years have been a period of unprecedented development of water resources in the world. The explosive population growth has accelerated the development, since the production of more food is dependent on access to more water. Land is of course indispensible for agricultural production, but in most countries it is water, not land, which is the binding constraint.

It is now widely recognized that the increased use of water has caused serious environmental impacts, some of which may be irreversible. We have often forgotten that both man and water are parts of a fragile ecosystem where an external impact affecting one component may easily disturb the balance and cause adverse reactions among other components. Water scarcity and water contamination are today threatening the very existence of man in many areas.

This report is prepared as an educational module addressed to curriculum developers and teachers at secondary school or graduate level. The report may also be of use when organizing courses on environmental issues, and as support material in assessment of water resources projects. Its objectives are to:

* explain and document the importance of water resources in a sustainable development

* provide basic knowledge of the availability of our water resources and its relation to environment, in a global and local context

* provide the necessary knowledge of water resources for the execution of sound water management, based on an ecosystem approach

* describe the present situation and problems connected to the use of water resources and its relation to environment, including methods for prevention and mitigation

* provide a curriculum framework to guide revision and new development of educational materials

The report does not discuss or recommend in detail educational principles or methods to be used in applying the module. These will be more or less the same as for other environmental topics, and the reader is referred to other reports in the UNESCO Environmental Education Series.

The report consists of 13 Chapters, differing greatly in length depending on the topic discussed. Following the introduction, Chapter 2 and Chapter 3 provide the basic concepts and characteristics connected to water resources and its relation to environment. The concept of "ecosystem approach" will be the key concept throughout the report.

In Chapters 4 to 10, the specific environmental problems connected to the different uses of water are discussed. Starting with the consumptive uses of water like urban and rural water supply, water in agriculture and industry, it is followed by the non-consumptive uses such as hydropower, fisheries and navigation, and water in recreation. The same environmental impacts may be caused by different users. Therefore, some impacts may only be discussed in connection with one of the users. Establishment of dams, for example, is discussed in the Hydropower Chapter, but may also have been built primarily for irrigation or flood control purposes.

In the remaining Chapters, some examples of successful improvements of contaminated waters are given, as well as a discussion on water resources management and legislation.

In the last Chapter, the topic of water resources in environmental education is briefly discussed, and the method of Environmental Impacts Assessment is recommended as a useful teaching aid.

2 WATER RESOURCES IN SUSTAINABLE DEVELOPMENT

2.1 Historical Review

Through history, rivers and streams, lakes and groundwater, have provided resources and services including water for drinking, washing, transport, waste disposal, energy production, agricultural production, fish production, and also recreation. It was probably along tropical rivers that the earliest stages of man's biological and cultural development originated [1].

The small-scale use of water by the early settlements had only negligible impact on the environment. However, more substantional man-made modifications to the quantity and quality of nearby water resources started several thousand years ago.

Man realized that streams and rivers in their natural states seldom provided adequate water to satisfy his needs at the right time and at the right place. Construction of irrigation canals and building of dams and levees started, making water availability more compatible to human needs.

Water supply systems of considerable size and complexity existed in Persia, Egypt, and in Babylon, some of them more than 4 000 years ago. Some of the most impressive achievements are of course the great engineering works on the Nile, the Euphrates, and the Tigris. Also in parts of Central and South America, and China, evidence of ancient major water supply systems exist.

Associated with the collapse of the various empires, most of the giant ancient constructions broke down and people often returned to traditional water collection by hand from rivers, lakes and wells. Some systems survived, however, like the extensive storage and distribution system in Sri Lanka dating back some 2 000 years.

In Sri Lanka, the fifth-century monarch, King Dhatusena, was once asked by his captors to show where his most valuable royal treasure was hidden. He then led them to a newly constructed artificial lake with a circumference of about 90 kilometres. In fact, the ancient kings of Sri Lanka considered the management and conservation of water as important as the defence of the country. A complex system of rules and regulations were developed to manage and operate the water reservoirs, water tanks, and water channels.

The present day global environmental problems connected to water resources largely arise from the technological development and population growth over the last 150 years, with an accelerating increase in the last 50 years. As early as 1935, the Hoover Dam on the Colorado River of the American Southwest was widely regarded as one of the great engineering triumphs of the twentieth century. Other recent large-scale water projects are the Aswan reservoir, completely modifying the behaviour of the lower Nile, the Kariba and Cahora Bassa reservoirs of the mighty Zambezi, and the over 200 m high dam at Bakhra, India, hailed by the then Prime Minister Jawaharal Nehru as "one of the temples of modern India".

Has development gone too fast? Has "Big become Beautiful and Prestigious", not only "Profitable"? On all continents we find examples of huge water projects where the various implications and consequences have not been as expected. An example could be the ecological disaster happening to the Aral Sea in the previous USSR which is actually vanishing, primarily as a result of diversion of inflowing rivers for irrigation purposes. The negative results may be large-scale resource depletion, ecological destruction, and socio-cultural disruption. However, it should not be forgotten that successful large-scale water projects are also reported, where a negative development has been changed to the better. Hopefully, man has started to learn from experiences.

2.2 Sustainable Water Development

The World Commission on Environment and Development [2] defines the term "sustainable development" as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The Commission also states that it is impossible to separate development issues from environmental issues because many forms of development erode the environmental resources on which they are based, and environmental degradation can undermine economic development.

The Commission, however, fails to address one of the most crucial problems of an increasing number of countries; i.e. water scarcity as a limiting factor in the face of increasing population growth. Particularly in and around major cities we observe serious environmental implications of the increased water scarcity.

It has proved difficult to make the concept of sustainability precise. In order to meet the challenge of providing food to the world's increasing population, successful development will inevitably involve some amount of, say, land clearing, river damming, and swamp draining. Thus, sustainability does not necessarily means conservation.

The UN Food and Agriculture Organization provides the following definition (1988) of sustainability:

> "Sustainable development is the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable, and socially acceptable".

The importance of water resources in sustainable development has long been recognized. The United Nations Water Conference, convened in 1977 in Mar del Plata, Argentina, recommended improved management and development of water resources as a prerequisite for improving economic and social conditions, particularly in developing countries.

The Mar del Plata Action Plan contains recommendations on the following eight major areas: assessment of water resources; water use and efficiency; environment; health and pollution control; policy, planning, and management; natural hazards; public information, education, training, and research; regional co-operation; and international co-operation.

Today it appears that in many respects the Mar del Plata recommendations are as relevant for the nineties as they were for the eighties. The constraints or obstacles to sustainable water development seem to be well known and recognized by the international community, but the ability to put knowledge into practice is to a great extent lacking. In water supply and sanitation, for example, some of the major obstacles are [3]:

1) Fragmented sector policies

2) Weak or non-existent institutions and inadequate coordination among sector agencies.

3) Lack of adequately trained and motivated manpower

4) Use of technologies inappropriate for developing country conditions, and lack of knowledge of lower-cost technologies

5) Lack of community involvement

6) Inadequate operations and maintenance

7) Problems with resource mobilization and utilization, including cost recovery.

The challenge for the coming years will be to tackle these and other obstacles to avoid irreversible environmental consequences to be passed on to the next generation. Of outmost importance will be to promote a development of the water resources not exceeding the carrying capacity of the natural ecosystem. This means that the real causes of environmental problems have to be dealt with, not only the symptoms. The environmental issues must be integrated in all institutions and organizations so that such issues become normal components in decision making [4].

2.3 The Ecosystem Approach

An ecosystem may be defined as a spatial unit of Nature in which living organisms and the physical environment interact. There is a dependence between the numerous actors or components. In a traditionally stable ecosystem,an external impact affecting one component may disturb the stability, causing adverse reactions among other components of the system. Far too often, man's interest has focused on one element only, say flood control or water quality, ignoring the interactions within the ecosystem functioning as a whole.

The two terms "ecosystem" and "environment" are often incorrectly used almost interchangeably. The important difference is [5] akin to the difference between "house" and "home". In the former, we see ourselves as outside and separate from the system, in the latter we are actors in the system. The ecosystem approach is a holistic approach, including social, economic *and* environmental interests in a life-support system.

In many ways, we are now drawing on the experiences gathered by small rural communities living close to Nature. They harvested what Nature offered and the balance of the ecosystem was maintained. The worlds growing population and accelerated technological development destroyed this pattern in most countries, and excessive exploitation of natural resources started.

In brief, what characterizes the ecosystem approach is [5]:

- The integrated use of knowledge from various fields of specialization (hydrology, biology, technology, economics, law, etc). Only after a synthesis of available and relevant knowledge has been prepared, should the decision-makers decide.

- Focus on links between environmental elements and man in a holistic perspective, in which man is an actor and not only an economic/technical user.

- A multi-media approach (land, water, air, living organisms), which at the same time is geographically comprehensive, e.g. relating to whole catchments.

The latter statement needs some further comments concerning the geographical extent of the practical use of the ecosystem approach. In principle it can be applied to geographical areas of all scales, with the globe as the upper limit. Possible climatic changes due to human activities, trans-regional transport of air pollution, the possible distortion of the ozone-layer, are examples of problems affecting the globe as a whole.

On a smaller scale, we normally prefer to confine our ecosystem to well-defined river catchments. The scale may still be considerable, like the big international rivers running through many countries. However, the total catchment can easily be divided into sub-catchments and sub-sub-catchments as found applicable. (Section 3.1.)

An ideal case for applying the ecosystem approach would be a river catchment still in its natural or near-natural state. However, the approach is equally valid also when the catchment is heavily under pressure from man's activities. The aim is not necessarily to bring the conditions back to the natural state, but to reverse the trend and promote a development towards ecological improvements over time, like restoring deteriorated rivers, lakes, and wetlands.

2.4 The Growing Concern for Water-Related Environmental Issues

In the 1960's, the environmental movement started with a growing concern for what man's activities are causing for our global and nearby environment. Clean air, pure water, balanced ecosystems, could not be taken for granted in any country or region. The environmental movement, increasing in intensity during the late 1960's and the early 1970's, provided a more holistic approach than the previous conservation concerns. It became clear that many environmental problems were not local problems, but of a global nature. In the late 70's and early 80's people seemed to be distracted from the environmental situation - perhaps in the hope that these serious problems would disappear or that they did not exist anyway [6].

In the 1990's, the concern for environmental issues will probably increase its momentum. Of water-related environmental issues - and in fact most are in one way or the other related to water - people in many parts of the world have heard problems connected to some of the following issues:

* Desertification
* Deforestation
* Land degradation
* Acid Rain
* Farm field runoff
* Groundwater contamination
* Eutrophication
* Waterborne diseases
* Wastewater treatment
* Salinization
* Waterlogging
* Water erosion and sedimentation
* Groundwater mining and land subsidence
* Floods of increasing magnitudes
* Saline intrusion
* Industrial water pollution
* Large man-made lakes and resettlement of people

The understanding of the interaction between water and soil, and water as a limiting factor for development in many areas, are issues which will have to be seriously dealt with in the coming decade. The most serious situation will develop in parts of Africa and Asia where the amount of water per capita will be drastically reduced.

To cope with the water problems in the future, people's awareness and concern have to be further increased. Water of sufficient quantity and quality can not be considered as a free gift to humanity, but as a precious resource to be managed for the optimum benefit for all users.

2.5 Population Growth

Any discussion on sustainable development and global environmental issues will be absurd without bringing in the problems and consequences of rapid population growth. As Fig. 2.1 illustrates, a virtual global population explosion has started in the 20'th century. The consequences may be enormous with unprecedent impacts on the environment by increasing soil erosion, deforestation and desertification. It is difficult to understand how the basic needs of water and food can be met in the future if the present trend is not changed.

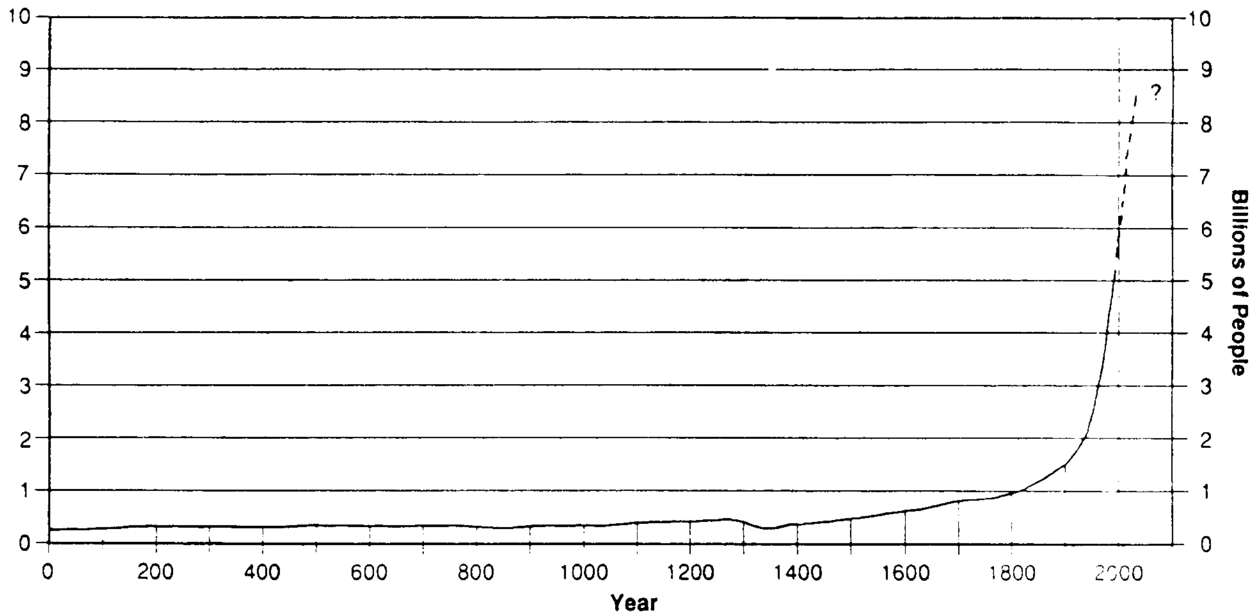


Fig. 2.1 Population growth (Various sources).

Table 2.1 shows the population growth from A.D.O to 1990, and projections [40] for year 2000 and 2025. The most alarming fact is that of the increase of almost one billion from 1990 to 2000, some 94% will take place in the developing countries. As Table 2.1 shows, the annual rates of growth vary considerably, with the lowest average of 0.60% in developed countries and the highest average of 3,05% in Africa.

Some countries in Asia and Latin America have managed to reduce the growth rate considerably, by up to 50% during the last 30 years. The United States, with a growth rate of almost 0.9% per year, has one of the fastest growing population in the developed world.

	Population (billion)						Annual Growth rate (%) 1985-90
	1800	1900	1960	1990	2000	2025	
World	1.0	1.5	3.0	5.3	6.3	8.5	1.87
Developed countries				1.21	1.26	1.35	0.60
Developing countries				4.09	5.00	7.15	2.26
Africa				0.64	0.87	1.60	3.05
Latin America and Carribean				0.45	0.54	0.76	2.14
Asia				2.98	3.42	4.57	2.05
Middle East				0.13	0.17	0.29	2.91

Table 2.1 Actual and projected population growth, and growth rate [UN-sources, 1991]

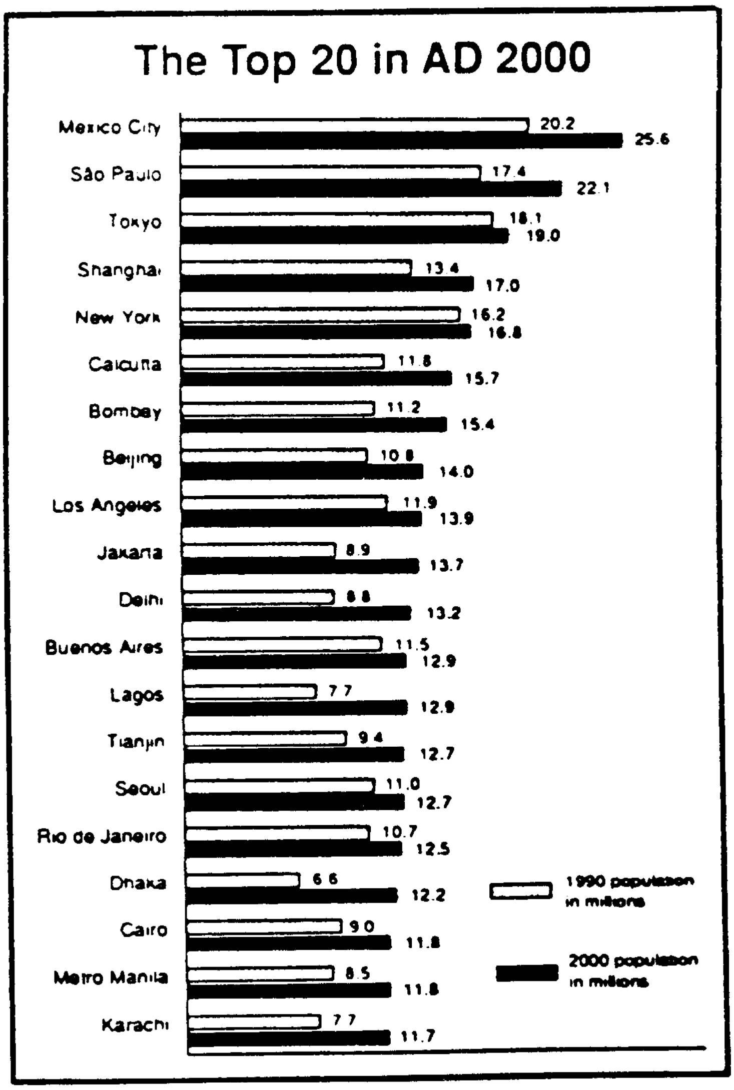


Fig. 2.2 Population growth, 1990-2000, of the world's largest cities (UN-source, 1992)

Growing urbanization is today a major environmental problem. The expanding city populations will need more water and more food, which may not be readily available from domestic sources. Fig. 2.2 shows projected growth of the world's 20 largest cities towards year 2000, with Mexico City ranking first, reaching an estimated 25.6 million people by the turn of the century. It has been found that natural growth of populations, rather than migration from urban areas, is now the prime cause of the rising numbers.

There should be no doubt that the rapid population growth is the most serious global problem in the years to come. The decline of fertility rates cannot be taken for granted in all countries. Investments in female education show some of the highest returns for development and for environment. Better-educated mothers raise healthier families, have fewer and better-educated children, and are more productive at home and at work. Also efforts to expand family planning programs have shown promising results. Choices about family planning and education policies today will determine world population levels, and the consequent pressures on the environment, in the next century [7].

3 THE HYDROLOGICAL CYCLE

In this Chapter an introduction is given to the basic principles and processes to be considered in the assessment and evaluation of the earth's water resources and its relation to environment. Disregarding water contained in the earth mantle, all the waters of the earth are taking part in the gigantic solar-energy driven system called the hydrological cycle, illustrated in Fig 3.1.

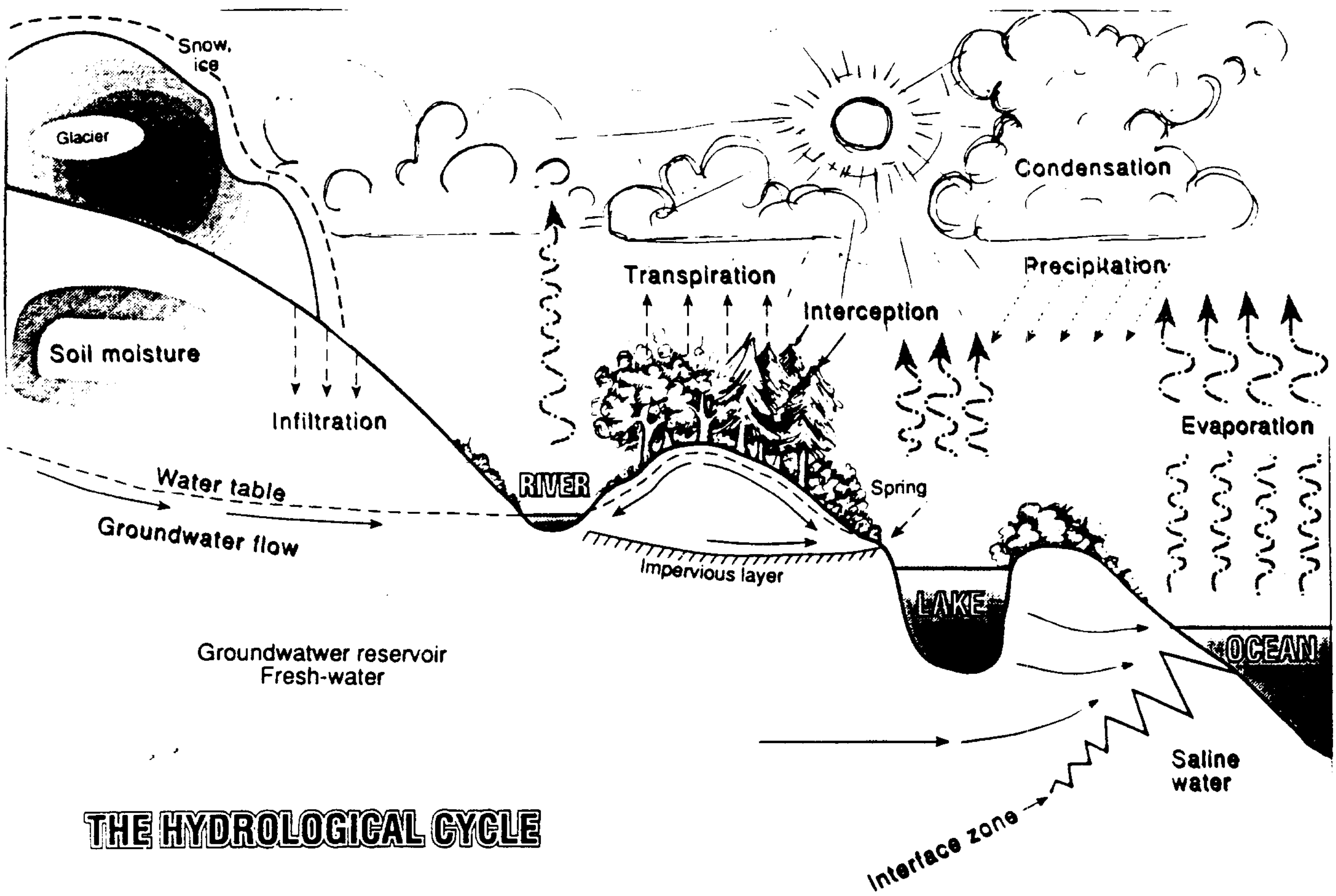


Fig. 3.1. The Hydrological Cycle.

3.1 The Water Balance

In one form or another, water occurs practically everywhere. We believe that the total amount of water contained in the hydrological cycle has been virtually constant during man's history.

The hydrological cycle has no beginning or end. As a natural desalting and purifying process, fresh-water evaporates from oceans and the vapour becomes part of the atmosphere. Water vapour is also transported to the atmosphere through evaporation from fresh-water bodies like lakes and rivers, from all kind of landsurface permanently or occasionally wetted by water, normally by precipitation, and by transpiration from vegetation.

Through the condensation process, the water in the atmosphere finally is returned to earth as precipitation on land and ocean surfaces. Some is intercepted by vegetation, buildings, etc., some may run over ground surfaces and into streams, or may infiltrate into the ground. The infiltrated water may percolate to deeper zones to be stored as groundwater which sooner or later will flow out as springs or seep into streams or for a temporary storage in lakes, and be transported by river runoff to the ocean.

Thus, the hydrological cycle undergoes various complicated processes of evaporation, condensation, precipitation, interception, transpiration, infiltration, percolation, storage, and runoff. Figures and descriptions of the cycle are therefore necessarily oversimplified. On a worldwide basis the volumes of moisture involved in each phase of the cycle are relatively constant, but viewed in terms of a limited area, the quantities in any part of the cycle vary within wide limits. These variations are the primary subjects of study in hydrology. For example, if temporary great volumes of water are concentrated in the precipitation phase, the result may be flooding in river courses. Conversely, small amounts of water in the precipitation phase may lead to drought conditions.

The fundamental basis for a description of the hydrological processes is the continuity equation, often formulated as a water balance equation:

$$P = E + Q + A + \Delta S$$

where

P	=	precipitation
E	=	evaporation
Q	=	runoff
A	=	water abstraction from the catchment minus additional water inflow to the catchment due to man's activity
Δ S	=	water storage at the end minus storage at the beginning of the time period considered (can sometimes be neglected when the water balance equation is applied to long time intervals)

The water balance equation is a very useful tool as part of an ecosystem approach for studying man's impact on the water cycle and related environmental effects. All elements in the equation can be manipulated by man with subsequent environmental impacts.

The equation can be applied for the earth as a whole, a continent, a region, a catchment, or part of a catchment.

It is often useful to look at water movements and volumes on a smaller scale. The use of hydrological catchments may reveal many details of the area's water problems. A hydrological catchment can be described as a valley or basin in which the water accumulates or where the water flows towards a lower discharge point. If a river is fed by two streams, each stream will have its own catchment. The ridges or elevations between the watersheds of the streams form the surface boundaries of the catchments.

Having defined a catchment, measurements and estimations of precipitation, evaporation, runoff, and consumption uses can be made. It is then possible, for example, to make an approximation of how much water is being infiltrated, and ultimately reaches the groundwater.

It should be emphasized that the hydrological cycle contains much more than the water we observe as precipitation, runoff, etc. Of equal importance are the groundwater and soilwater, providing water to plants and trees and returned to the atmosphere as evapotranspiration.

3.2 Global Water Resources

Water covers three-quarters of the earth's surface, with a total volume of some 1454 million km^3. This is equivalent of a layer some 2.65 m deep, covering the entire planet.

However, 94% of the total water volume is salt-water in the oceans. Table 3.1 and Fig. 3.2 provide some approximate data on the distribution of the earth's water, "the hydrosphere", revealing the very small portion available as fresh-water for the use of man. The figures given should be considered as indicative only, but provide the basis for some interesting considerations.

Groundwater (4.12%) constitutes our main fresh-water resource. However, about 95% of the groundwater is stored in deep layers and of limited interest to man. The rate of exchange, or replacement time of groundwater is on an average estimated at 5 000 years, some more than 20 000 years. Its involvement in the hydrological cycle is therefore barely noticeable.

Location	Volume mill. km^3	Percentage of total	Rate of exchange (years)
Oceans	1370	94.2	2600
Groundwater	60	4.12	5000
Glaciers	24	1.65	10000
Lakes	0.23	0.016	10
Soil moisture	0.07	0.005	0.92 (11 months)
Atmospheric Vapour	0.014	0.001	0.03 (10 days)
Rivers	0.001	0.0001	0.03 (12 days)
Total	1454.0	100.0	

Table 3.1 Estimates of world waters (Various sources)

The second greatest fresh-water resource is the glaciers (1.65%) with a still longer average replacement time of 10 000 years, and not easily accessible to man.

Then, in much smaller proportions, we find lakes (0.016%), soil moisture (0.005%), atmospheric vapour (0.001%), and rivers (0.0001%). However, the rate of exchange is now a matter of weeks and months, and this water therefore takes a very active part in the hydrological cycle. Most of the lake water is stored in a few great lakes where the rate of exchange may be more than 10 years. One quarter of the total lake water is stored in Lake Baikal, Lake Tanganyika, and Lake Superior.

Not all the water on the continents is fresh-water. Both lakes and groundwater are in some cases mineralized, normally saline. The water is then difficult to use directly without removing the salts, an expensive and very energy-consumptive process.

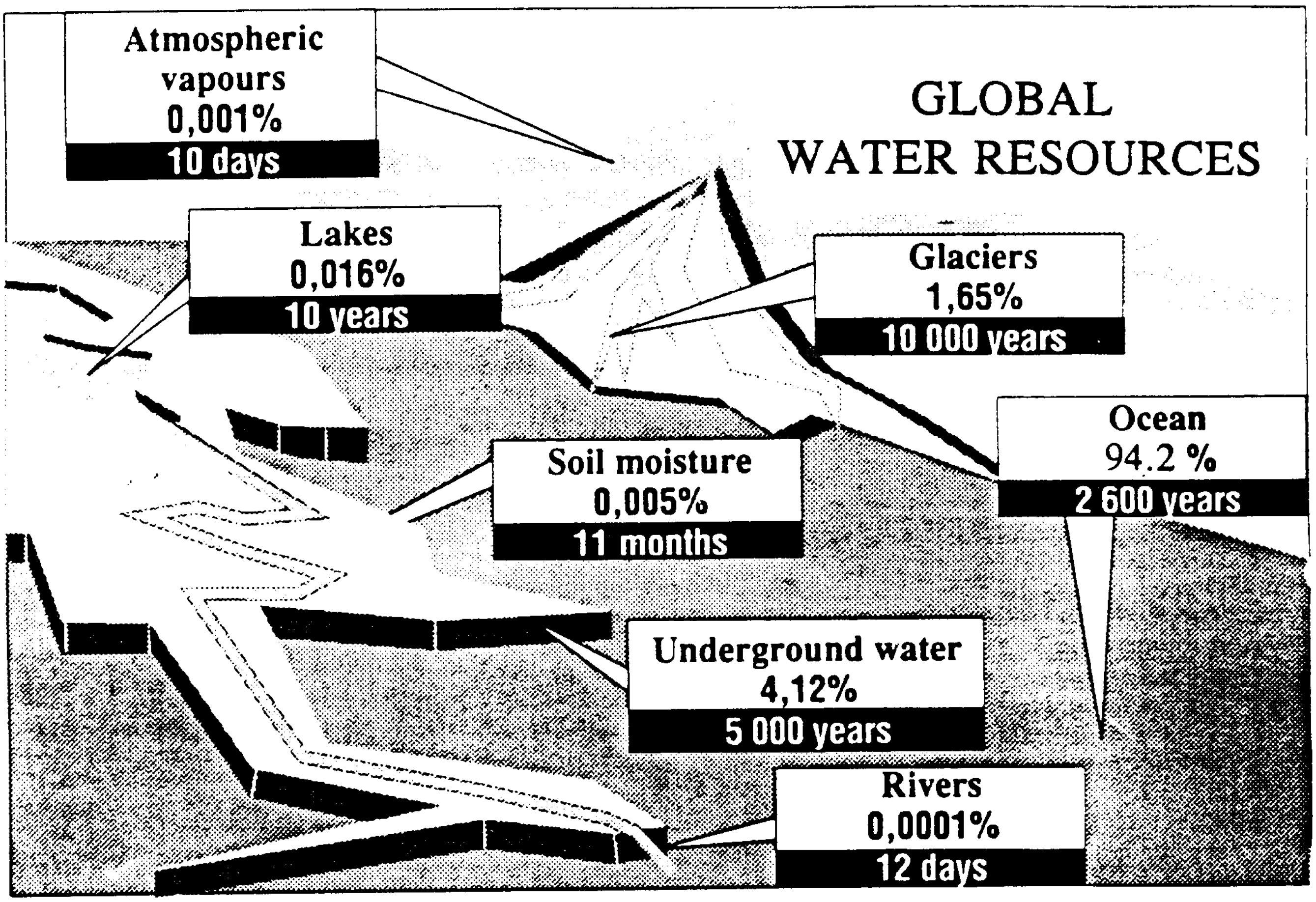


Fig. 3.2 Illustration of the distribution of world waters, including the duration required for each element to entirely replenish itself (Source: Unesco).

3.3 Water Resources Assessment

When dealing with water resources on both a global and local scale, one simple but important question always arises: How much water is normally available for the various users at any given time of the year? What are the uncertainties connected to such estimates? What is the quality of the available water resources? As the balance between demand for, and availability of, water becomes more finely tuned, the need for more precise and reliable assessments of the status and trends of the resources increases rapidly.

> *Water resources assessment is the determination of the sources, extent, dependability, and quality of water resources, on which is based an evaluation of the possibilities for their utilization and control [8].*

For a sustainable water resources development, reliable information on the quantity, quality, flood and low water statistics, various users demands, etc, is a prerequisite. This imposes a considerable challenge on the water resources assessment agencies during the 1990's.

The basic data to be collected in a water resources assessment programme can be divided into two groups:

A. Physiographic data (topography, geology, soils, vegetation, etc.)

B. Hydrological data (water cycle components, including quality of water)

The long-term nature of hydrological data cannot be overemphasized. A key aspect of the water cycle is variability, from one year to the other, and throughout the year. Fig. 3.3. shows the long-term fluctuation of River Nile flow at Khartoum, Africa, and Fig. 3.4 illustrates the various annual runoff fluctuations in different rivers within the La Plata river system in South America.

Long hydrological and meteorological time series can be analyzed for investigation of the effects of man's activity. These changes may, however, be small compared to the effects of natural climate variability, and high-quality data are required to distinguish the man-induced changes which may otherwise be masked by measurement errors.

What kinds of hydrological data are needed for assessing water-related environmental impacts? The most basic elements are [8]:

- precipitation
- river levels and flows
- groundwater levels
- soil moisture content
- evapotranspiration
- water quality of surface water and groundwater

The most basic statistics include:

- mean annual, monthly, and seasonal values
- maxima and minima, and selected percentiles
- measures of variability, such as standard deviation
- continuous records in the form, for example, of a river flow hydrograph

For environmental considerations, information on eutrophication of lakes and other disturbances affecting the natural freshwater ecosystem, like deforestation, are also required.

It should be beyond any doubt that water resources assessment is the very basis for sustainable development of the world's water resources. This is not, however, recognized by the relevant decisionmakers. It is difficult to understand how a water project, say, an irrigation scheme or water supply to a city, can be designed without a proper water resources assessment. However, the activities required are costly, and in many countries in the developing part of the world the lack of funds is a major constraint, those available being not even sufficient for the most elementary operations. In fact, in an increasing number of developing countries a rapid deterioration in operation and equipment has been observed in the 1980's. A major cause for concern for the future lies in the obvious insufficiency of data on groundwater and water quality.

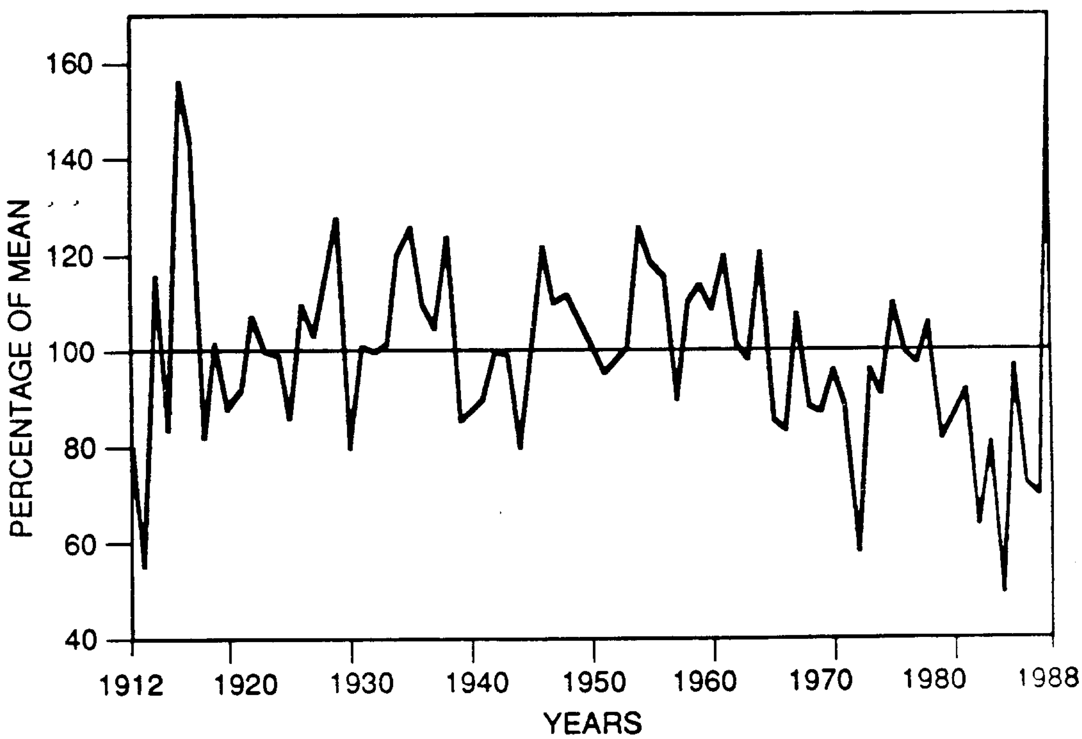


Fig. 3.3 Long-term fluctuation of Nile flow at Khartoum.

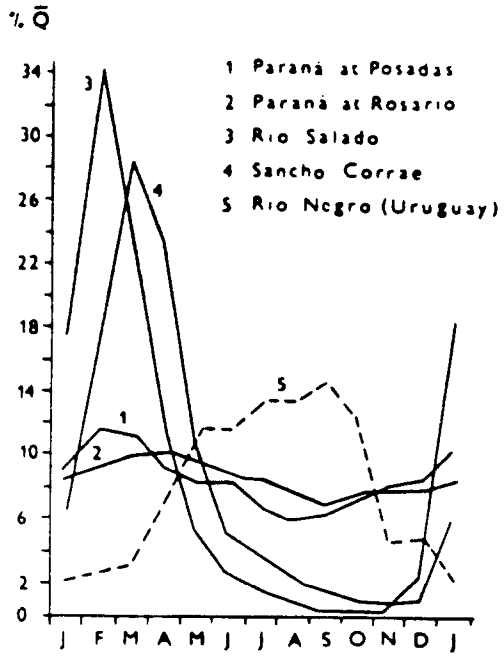


Fig. 3.4 Runoff fluctuations of rivers within the La Plata River System, South America [1].

3.4 The Influence of Man

In most inhabited river catchments the hydrological cycle is being modified by man, both quantitatively and qualitatively, as illustrated in Fig. 3.5,. Extensive irrigation, for example, will increase the rate of evapotranspiration in a catchment and consequently reduce the quantity and change the quality of the surface water runoff.

In fact, our basic concept of a constant hydrological cycle purifying the waters of the earth has become more doubtful. It is true that the cycle continues, but the rain may be acid. With the increasing populations and the industrial/agricultural additions to the water flow, the volumes of the hydrological cycle are also being affected.

One of the most extreme change of the hydrological cycle is observed in cities were the paved surfaces completely change the runoff conditions.

Keeping in mind the recommended ecosystem approach (Section 2.3), a further discussion of man's influence on the hydrological cycle should take into consideration also the catchment characteristics like soils and vegetation, and the climatic factors, see Fig. 3.6. The hydrological cycle is affected by both the climate and the catchment characteristics which in turn are affected by the hydrological cycle.

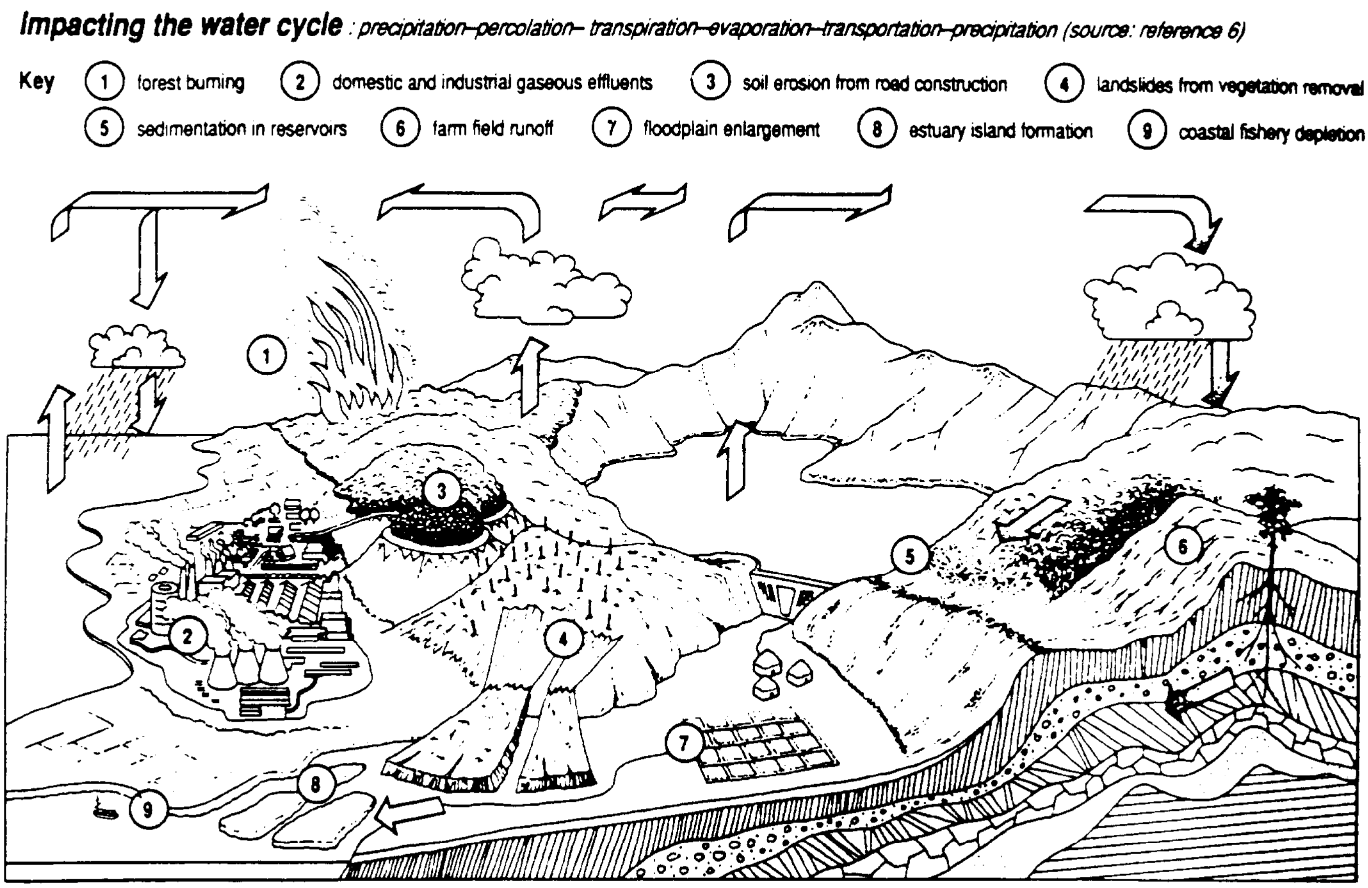


Fig. 3.5 Illustration of man's impact of the hydrological cycle [8].

Man's activities impacting the hydrological cycle may be classified as follows:

A. Changes in land use and vegetation
   * agriculture (irrigation, drainage of swamps)
   * deforestation and afforestation
   * urbanization
   * industrialization

B. Changes in the topography and river/stream drainage system, like construction of
   * dams
   * barrages
   * embankments
   * polders
   * terraces and contour ploughing

C. Direct water diversions from/to the catchment
   * surface water diversion
   * groundwater abstraction, or artificial recharge

The environmental impact of the various activities will be discussed in other sections of this report. Their impacts on the environment may be either negative or positive.

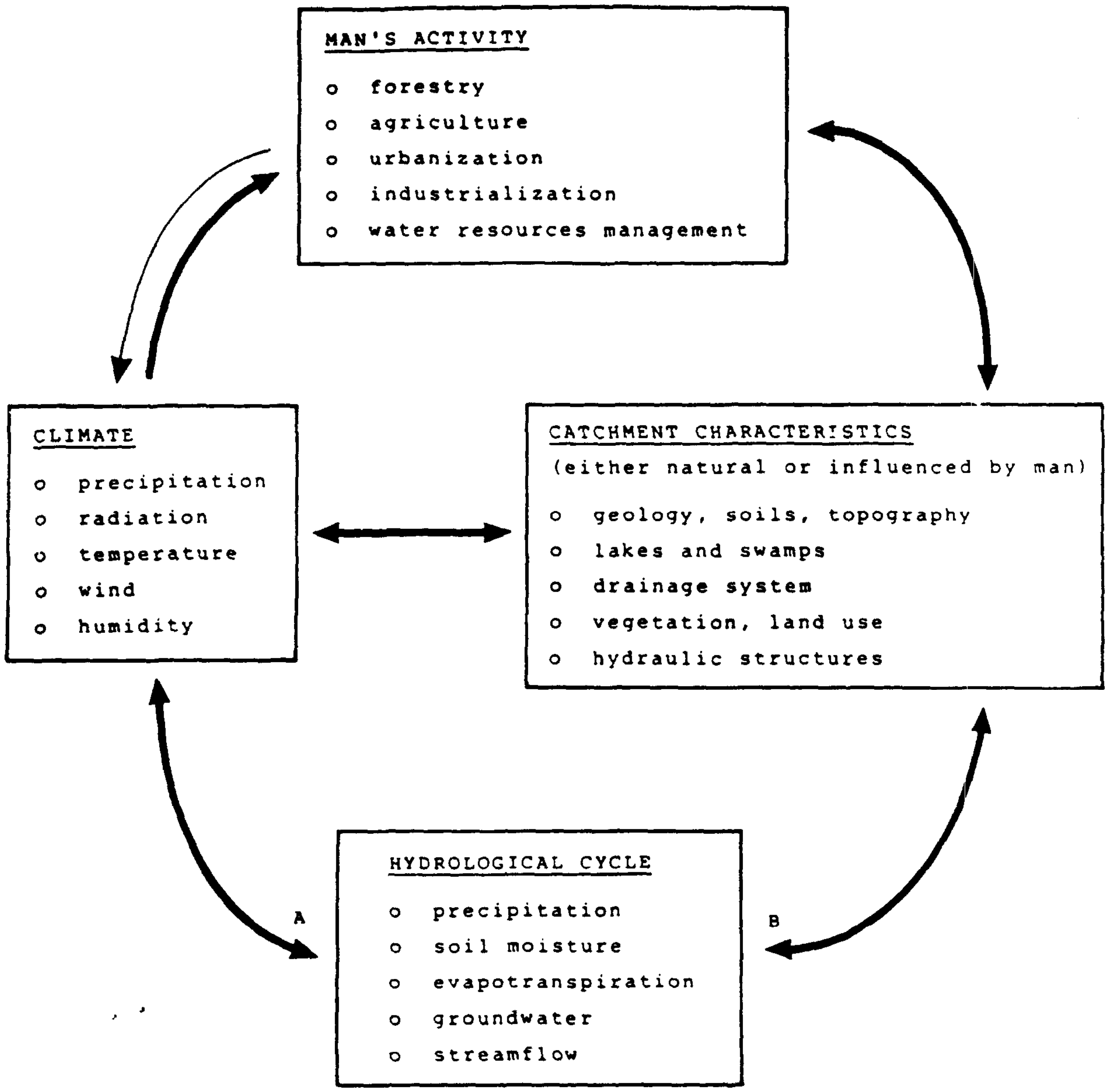


Fig. 3.6 The principal interactions between man's activities, the climate, the catchment characteristics, and the hydrological cycle [10].

An important aspect of the new ecological-based approach is that the total water availability in the catchment (ecosystem) is a main limiting factor to development and population growth.

A schematic illustration of man's interventions in various ways with the natural hydrological cycle is given in Fig. 3.7. Water is a natural resource to be shared by a number of competing users, with different demands as regards both quantity and quality. Most users may introduce impacts of negative consequences for other downstream users, or on the hydrological cycle as a whole.

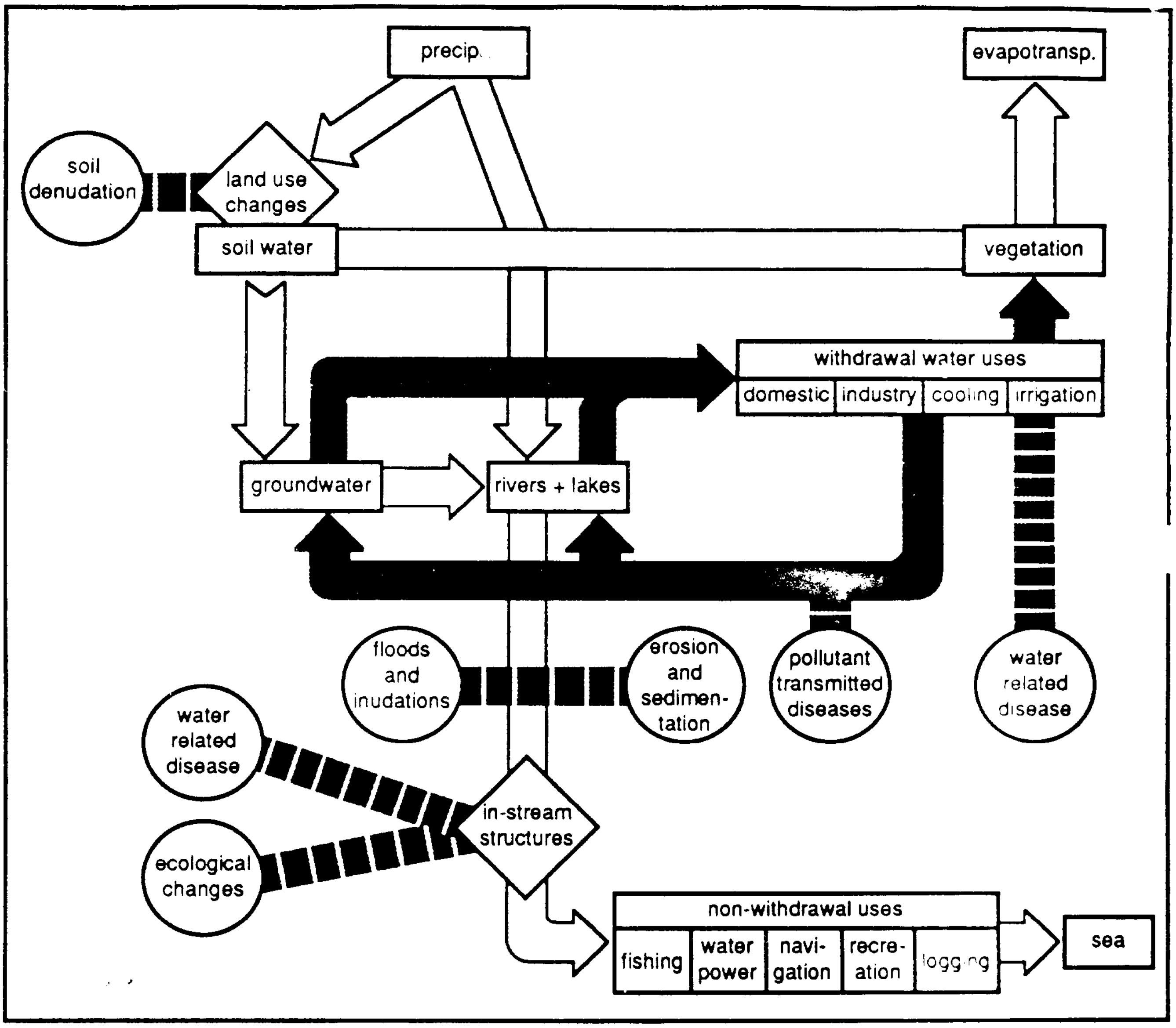


Fig. 3.7 Illustration of man's various interventions with the hydrological cycle. Natural water flows are white, anthropogenous flows black. Circles denote disturbances [11].

3.5 Water Scarcity

Water is a finite resource and many areas suffer from water scarcity. For water to be useful for human activities, it has to be available when it is needed, in sufficient quantity and proper quality.

Fig. 3.8 shows the natural water deficiency and the water surplus zones of the earth. A water deficiency exists if precipitation is not sufficient to supply the water needed for well-watered vegetation. The map indicates large areas in the developing world with a marked water deficit. Only a small fraction of Africa, for example, has adequate rainfall for optimum growth during all months of the year.

There is no doubt that water scarcity is increasing rapidly with growing population and urbanization. The continents of greatest concern are Africa and Asia. In some Arab countries, it is estimated that by year 2000, the demand for water will exceed the available supply.

In many countries water scarcity is becoming an increasing constraint not only on household, provision, but on economic activity in general. Downstream cities can become so short of water that their industries are seasonally forced to curtail operations [7].

Table 3.2 shows the decreasing trend of the water availability per inhabitant in several regions on all continents, from 1950, and projections for year 2000. The trend is alarming, and when we add the problems of uneven distribution of water within countries and regions, limited storage capacities and increasing pollution, the possibility to provide sufficient water supply to cover the need of the growing population is not promising.

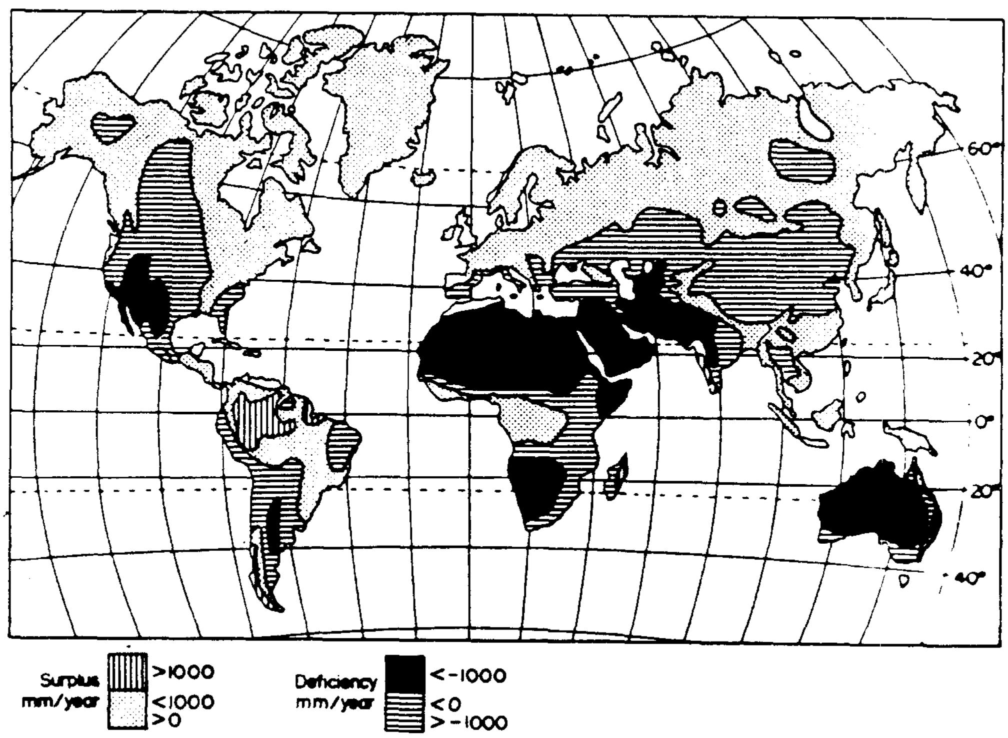


Fig. 3.8 Water deficiency and water surplus zones in the world [12]. See text.

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

Table 3.2 Water availability per inhabitant [13].

3.6 Acid Precipitation

Acidification of the aquatic ecosystems became a major concern in the late 1970s. Acid precipitation results when sulphur and nitrogen oxides combine with water vapour in the atmosphere. Such pollution can travel long distances through the atmosphere, cross national borders, and therefore be a threat to environment far away from its sources.

Most aquatic ecosystems are very vulnerable to acid deposition. It affects the land as well as rivers, lakes and groundwater. The impact depends on the system's buffering capacity and the presence of limestone in the catchment may neutralize acidity. The addition of crushed limestone to the waters has been tried as a mitigation measure, sometimes with promising results. The only way to reduce the problem on a global scale, however, is to reduce the air pollution by decreasing the emissions of pollutants.

It should be mentioned also that volcano eruptions are a considerable "natural" contributor to acid precipitation.

The effects of acidification have been most noticeable in Europe, North America, and Eastern China. In numerous lakes and rivers fish populations have declined and in some cases, like in Norway, fish in many lakes have been eradicated.

3.7 Global Climatic Change

The possible effect of human activities on the global climate has until recently been considered negligible. However, recent research using general circulation models [14] has indicated that the greenhouse effect caused by increasing concentrations in the atmosphere by carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide may have a pronounced warming effect. The greenhouse effect is illustrated in Fig. 3.9. Such a warming may have a great effect on the water flux through the hydrological cycle, causing increased evaporation and subsequent changes in precipitation and river runoff.

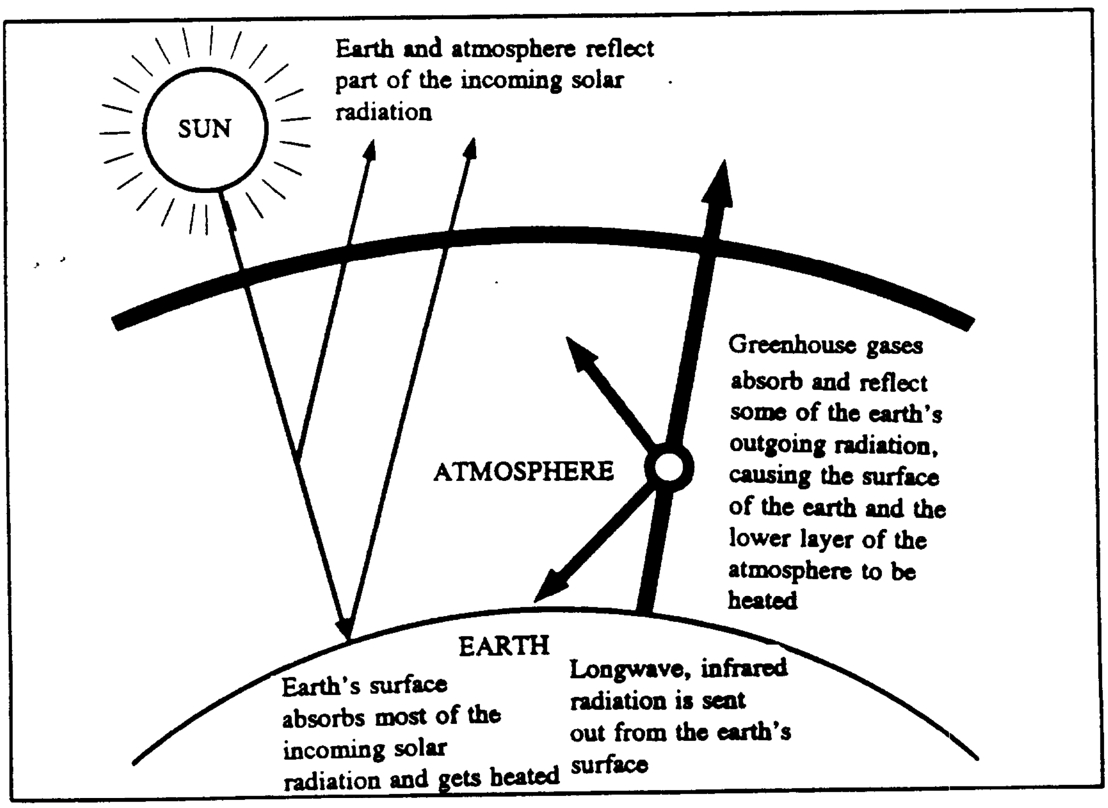


Fig. 3.9 Illustration of the greenhouse effect.

A major problem for scientists has been to distinguish between the influence of man and the "natural" changes that have always taken place through the geological eras. Paleoclimatic research shows that frequent alterations between cold and mild climate took place in the areas around North Atlantic in the period 30-70 000 years ago, and also at the end of the last ice age in this area, 10-11 000 years ago. During the glacial periods in the temperate regions, the mean temperature of the tropics has been estimated 0.8 - 1°C lower than today. It is now well documented that climatic change has been very common throughout the earth's history, and climatic stability may be regarded as the exception [15].

Table 3.3 presents some geological eras of interest when searching for analoguos ancient situations, i.e. when climatic conditions comparable to today prevailed. What were the effects on the hydrological cycle? During the Pliocene optimum, paleoclimatic reconstruction shows that the precipitation probably increased in most of Eurasia and North Africa with about 2-300 mm a year. Also during the Mikulino interglacial period, the precipitation and runoff were higher than today in most of Asia. In Africa, the areas with no runoff coincided closely with today's.

GEOLOGICAL ERA	GLOBAL TEMPERATURE INCREASE
Pliocene optimum (4.3 - 3.3 mill years ago)	3 - 5 °C
Mikulino interglacial optimum (125 000 years ago)	2 - 3 °C
Holocene optimum (6 200 - 5 300 years ago)	1 - 5 °C

Table 3.3 Some geological eras and related temperature increase [16].

The most recent warm period, the Holocene optimum only 5-6000 years ago, shows a rather varying picture with regard to precipitation and runoff. Generally, precipitation increased in high and low latitudes. In Africa, the areas of no runoff were much smaller than today. In Sahara, for example, the precipitation was 2-300 mm higher than today. In the middle latitudes of Eurasia and North America, however, the precipitation decreased.

An example of existing evidence on the long-term climatic changes is the presence of fossil groundwater. Some great present groundwater reservoirs in today's arid regions, like Sahara, were filled up under considerably more humid climatic conditions than today. Now this is fossil water tens of thousands years old. If this water is pumped, it will not be replenished under present climatic conditions.

It has been estimated that the global mean temperature has increased by about 0.5 °C in the last hundred years. It is not possible to establish if this increase is caused by the increase of the greenhouse effect or natural reasons. It is also disputable if the increase is statistically significant, actually, in some parts of the world a reverse effect has been observed.

It has also been estimated, though still disputed, that if the human-caused emissions of the greenhouse gases are not reduced, this will cause an increase of the global mean temperature of about 1°C above the present value by year 2025, and 3°C above today's value by year 2100, with a sea-level rise of about 1 m. If the world community agrees to take actions to reduce the greenhouse gas emissions, the increase of temperature will be reduced, but not eliminated.

Regardless of the cause, what will be the effects of global warming on water-related environmental issues? Our basic thesis that experiences from the recent past is the key to the future will no longer be valid, and this will add considerably uncertainty to many calculations, for example estimations of design floods. According to the Intergovernmental Panel on Climatic Change [14], relatively small climate changes can cause large water resource problems in many areas, especially arid and semi-arid regions, and those humid areas where demand and pollution have led to water scarcity. Drastic change in the present climatic vegetation zones will occur. It appears that many areas will have increased precipitation, soil moisture and water storage, thus altering patterns of agriculture and other water uses. Water availability will decrease in other areas, a most important factor in already marginal situations, such as the Sahelian zone in Africa.

The regions facing the greatest risk in terms of serious threats to substaining the population are

Africa:	Maghreb, Sahel, the North of Africa, Southern Africa
Asia:	Western Arabia, Southeast Asia, the Indian subcontinent
North-America:	Mexico, Central America, Southwest USA
South-America:	Parts of Eastern Brazil
Europe:	Mediterranean zone

Especially in arid and semi-arid regions, runoff is very sensitive to small changes in climate. For example, 1-2 °C temperature increase coupled with 10% reduction of precipitation could result in a 40-70% reduction in annual runoff [14].

It is also expected that changes in frequency and intensity of hydrological extremes like floods and droughts in response to global warming will be more significant than changes in hydrological mean conditions. The increased environmental effects may be considerable.

4 WATER SUPPLY AND SANITATION

4.1 The Uses of Water

In daily life, one of our most important needs is a regular supply of clean drinking water. In a temperate climate the normal bodily water requirement for an adult is about 2.2 litres a day, while in a hot climate the requirement can increase to more than 9 litres a day. Some of the water will be obtained from the consumption of food. However, the way of living is a decisive factor. It is claimed that a Kalahari bushman, in his extreme arid environment, can survive on 1 litre a day.

The figures given above should be considered as requirements for survival only. Water is also required for personal hygiene, cooking and washing dishes, laundering, and house cleaning. Depending on the sanitary conditions, water may also be required for toilet flushing.

The term water supply may be defined as the water entering the distribution system, or, in rural areas, what is readily available from a stream, a reservoir, a dug well or the yield from a pumped well. The water supply may have pronounced seasonal and/or annual fluctuations.

The consumption of water per person a day varies enormously from the water scarce poor rural areas to the rich residential urban areas with no water rationing, and where even a swimming pool may be included. The daily consumption per person in poor rural areas in a developing country may be as low as 15-20 litres, while in an urban residential areas the figures are about ten times as much, 150-300 litres, or more. As an example, a daily consumption of 150 litres in urban areas of the industrial countries, may be broken down by use, as shown in Table 4.1.

Water use	Consumption per person per day	
	Litres	Per cent
Lavatory	62.5	41
Washing (baths and showers)	55.5	37
Dishwashing and preparation of food	9.0	6
Drinking	7.5	5
Washing clothes	6.0	4
Cleaning	4.5	3
Watering the garden	4.5	3
Washing the car	1.5	1
Total	150.0	100

Table 4.1 Typical break-down of water consumption per person per day in an urban residential area [17].

4.2 The Global Situation

The lack of safe drinking, water and adequate sanitation for a great number of people in the world is one of today's most critical environmental problems. While the estimated water and sanitation coverage is close to 100% in the industrialized countries, the situation in the poor developing countries is far from satisfactory.

In 1980, the General Assembly of the United Nations declared the period 1981-1990 as the International Drinking Water Supply and Sanitation Decade. The global target "Safe drinking water and adequate sanitation for all people in 1990" was widely publicised and a mood of enthusiasm and high expectations was generated.

It soon became obvious that the goal of the decade was unrealistic. However, the increased efforts during the Decade created an awareness about the sector and a more systematic approach to the problems.

Even if the goal of the Decade was clearly unrealistic, two factors particularly had a negative impact on the development. Firstly, the world population continued to grow rapidly, from about 4.5 billion in 1980 to 5.3 billions in 1990, with most of the increase (about 614 million) in the developing countries, particularly in urban areas. Secondly, the downturn in the world economy made less funds available for the sector in many countries.

In the early 1970s it was estimated that only one third of the people in the developing world had access to safe drinking water and adequate sanitary excreta disposal. As a result of the decade, much more reliable statistics have become available.

Table 4.2, Fig. 4.1 and Fig. 4.2 show the changes in water supply and sanitation coverage from 1980 to 1990 for the developing countries, on a regional and global basis. The table shows that during the period an additional 1347 million and 748 million people respectively, were provided with water and sanitation facilities. However, with the increase in population during the same period, the per cent coverage has not changed as favourably as could be hoped. Overall, the number of people without safe water decreased from 1825 million to 1232 million, while the number of people without suitable sanitation remained virtually the same.

Among the developing countries, the water supply and sanitation coverage in 1990, see Fig. 4.2, was:

- 82% for urban water supply
- 63% for rural water supply
- 72% for urban sanitation
- 49% for rural sanitation

Region/ sector	1980 Population	1980 Per cent coverage	1980 Number served	1980 Number unserved	1990 Population	1990 Per cent coverage	1990 Number served	1990 Number unserved
Africa								
Urban Water	119.77	83	99.41	20.36	202.54	87	176.21	26.33
Rural Water	332.83	33	109.83	223.00	409.64	42	172.06	237.59
Urban Sanitation	119.77	65	77.85	41.92	202.54	78	160.01	42.53
Rural Sanitation	332.83	18	59.91	272.92	409.64	26	106.51	303.13
Latin America and the Caribbean								
Urban Water	236.72	82	194.11	42.61	324.08	87	281.95	42.13
Rural Water	124.91	47	58.71	66.20	123.87	62	76.80	47.07
Urban Sanitation	236.72	78	184.64	52.08	324.08	79	256.02	68.06
Rural Sanitation	124.91	22	27.48	97.43	123.87	37	45.83	78.04
Asia and the Pacific								
Urban Water	549.44	73	401.09	148.35	761.18	77	586.11	175.07
Rural Water	1823.30	28	510.52	1312.78	2099.40	67	1406.60	692.80
Urban Sanitation	549.44	65	357.14	192.30	761.18	65	494.77	266.41
Rural Sanitation	1823.30	42	765.79	1057.51	2099.40	54	1133.68	965.72
Western Asia (Middle East)								
Urban Water	27.54	95	26.16	1.38	44.42	100	44.25	0.17
Rural Water	21.95	51	11.19	10.76	25.60	56	14.34	11.26
Urban Sanitation	27.54	79	21.76	5.78	44.42	100	44.42	0.00
Rural Sanitation	21.95	34	7.46	14.49	25.60	34	8.70	16.90
Global totals								
Urban Water	933.47	77	720.77	212.70	1332.22	82	1088.52	243.70
Rural Water	2302.99	30	690.25	1612.74	2658.51	63	1669.79	988.72
Urban Sanitation	933.47	69	641.39	292.08	1332.23	72	955.22	377.00
Rural Sanitation	2302.99	37	860.64	1442.35	2658.51	49	1294.72	1363.79

Table 4.2 Water supply and sanitation coverage 1980 and 1990 for developing countries, by regions. Population in millions [9].

The high population growth was particularly significant in the urban areas (see also Fig. 2.2). The number of cities in the world with 5 million people or more increased from 24 in 1980 to 35 in 1990. Of these, 15 in 1980 and 24 in 1990 are found in developing countries, particularly in Asia and Latin America. The population of these cities in the developing countries increased from about 130 million in 1980 to 228 million in 1990.

As expected, Table 4.2 shows that there are significant variations in the water and sanitation coverage in the various regions.

Africa, with most of the world's least developed countries, fell significantly short of the Decade targets. However, urban water supply coverage increased by 4% to 87% in 1990, while urban sanitation coverage increased by a rather impressive 13%, to 78% in 1990. This is encouraging when we know that the population of 23 cities in Africa south of Sahara grew from 21 million in 1980 to 36 million in 1990, and in the region north of Sahara the population in 8 cities grew from 17 million to 25 million.

In Africa's rural areas the situation is less encouraging. Despite an increase in coverage, less than half of the population has access to safe water, and only one out of four people has access to adequate sanitation facilities.

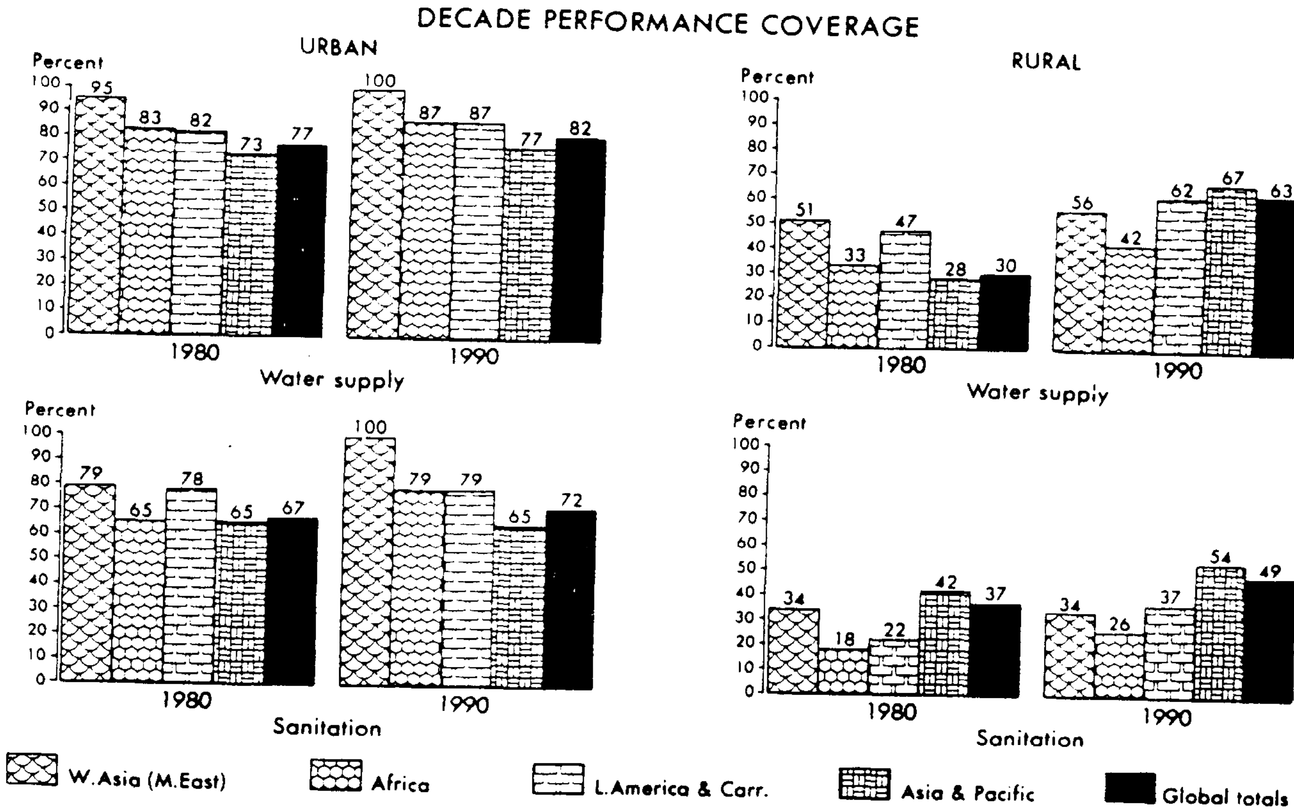


Fig. 4.1 Water supply and sanitation coverage 1980 and 1990 for developing countries [9].

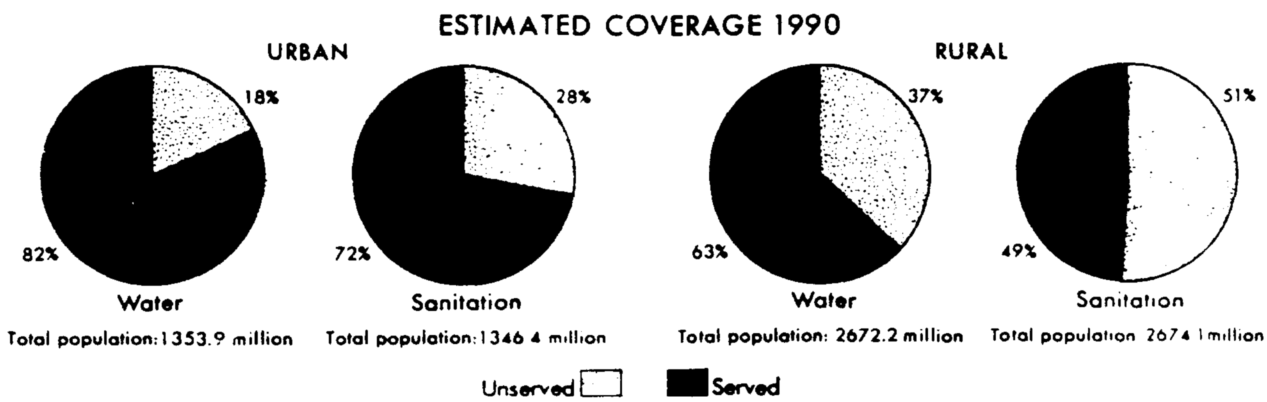


Fig. 4.2 Estimated water supply and sanitation coverage in developing countries in 1990 [9].

In Latin America and the Caribbean, the status of urban water and sanitation is about the same as for Africa. The slow development in the rural areas is disappointing with still only 37% rural sanitation coverage.

In Asia and the Pacific, the growth of the cities has caused enormous problems, slowing down the progress in urban water supply and sanitation. In the rural areas there has been a noticeable increase in the water supply, to a great extent due to reported improvements in China. The development in rural sanitation is less encouraging.

In Western Asia, the situation in the urban areas is considered to be satisfactory, with nearly 100% coverage, while rural water and sanitation still have coverage of only 56% and 34%, respectively.

What will be the development towards year 2000? A dream of achieving 100% coverage is probably as unrealistic now (in 1992) as it was in 1980. Further population growth and increasing urbanization make the prospects grim. Also the peri-urban problem will increase. Hundreds of millions of people, the "urban poor", will live in the peripheries of the cities. The environmental and health impacts of uncontrolled solid and liquid waste disposal from underserved settlements may be enormous. The number of urban dwellers in developing countries in cities of 5 million people or more is expected to increase from 228 million in 1990 to 350 million by the year 2000. Globally, it is estimated that the number of people in urban areas without adequate water supply facilities will increase by more than 80%, and the number of people without adequate sanitation facilities will increase by nearly 70%. This means that both Africa and Asia will be worse off in terms of numbers unserved by the end of the century than at the start of the 1980's.

In the rural areas significant progress is expected in Asia and the Pacific, and to a lesser extent in Latin America and the Caribbean. In Africa, only a modest increase in coverage is expected.

Table 4.3 shows the development from 1980 to 1990, and projections for year 2000 at the present rate of progress.

Year	Total World Population Billion	Water supply and sanitation coverage in the developing countries, in per cent			
		Urban		Rural	
		Water	Sanitation	Water	Sanitation
1980	4.5	70	69	30	37
1990	5.3	82	72	63	49
2000	6.0	77	67	89	58

Table 4.3 Development in water supply and sanitation coverage in the developing countries 1980 to 1990, and projections for the year 2000 (UN-source).

During the 1980-1990 Decade, total global funding for largely water and sanitation sector in the developing countries was about USD 10 billion a year. Recent estimates conclude that, if water and sanitation service coverage should be maintained as in 1990, USD 14 billion a year will be required during the 1990-2000 decade. A major shift towards intermediate and low-cost technologies is required, particularly in urban and peri-urban areas. Rural services may have to be provided entirely through the utilization of low-cost technology, while 50% of the services in urban areas may have to be provided through high-cost technology.

As part of the future strategy for sustainable development and management of water resources for rural communities, the following two principles have been proposed [18]:

1. Water (and land) resources should be managed at the lowest appropriate level. Centralized top-down management has often proven inadequate to address local water management problems, and fails to involve the local communities.

2. Water should be considered as an economic good, with a value reflecting its most valuable potential use. Access to enough water of adequate quality and quantity is a fundamental human need, but efficient allocation of water resources can only come from a full recognition of the costs and benefits associated with alternative uses. Whether or not different categories of users are charged the full economic cost of providing their water supplies, that cost must be apparent and accounted for.

4.3 Health Impacts of Water Supply and Sanitation

The connection between environmental health, poor water supply and inadequate sanitation is well documented, even if the relationships may be complex and not always understood. It has been claimed that 25 000 of the world's children die every day from water-related diseases.

Classic waterborne diseases are cholera, typhoid fever, infectious hepatitis, and some diarrhoeas and dysenteries. The often deadly diarrhoeal diseases are closely related to poor hygiene and faecal-oral transmission. This latter group of diseases is common in poor communities, particularly among children. It has been estimated that diarrhoeal diseases cause the death of more than 5 million children under five years of age in the developing world. They also remain an important cause of mortality well into adult life.

Infectious water-related diseases are often divided into four major groups as follows [19]:

1. Water-borne diseases: The pathogen is in the water and a person drinking it becomes infected. Examples are cholera, typhoid fever, infectious hepatitis, and some diarrhoeas and dysenteries.

   Preventive strategy: Improve quality of drinking water. Prevent casual use of other unimproved sources.

2. Water-washed diseases: These are diseases whose transmission will be reduced following an increase in the volume of water used for hygienic purposes irrespective of the quality of the water. Examples are diarrhoea diseases, cholera, dysentery and other diseases already mentioned under water-borne diseases. Other examples are skin and eye infections like scabies and trachoma. Also louse-borne typhus and relapsing fever belong to this category.

   Preventive strategy: Increase water quantity used. Improve accessibility and reliability of domestic water supply. Improve hygiene.

3. Water-based diseases: These are diseases where the pathogen spends a part of its life cycle in a water snail or other aquatic animal. Infection is by skin penetration upon contact with fresh water. The degree of sickness depends on the number of adult worms which are infecting the person. The snail is living in stagnant or slow-moving water and its distribution may be increased by the construction of water reservoirs or irrigation canals. Examples are schistosomiasis (bilharzia) and the guinea worm disease.

   Preventive strategy: Decrease need for contact with infected water. Control snail population. Reduce contamination of surface water by excreta.

4. Water-related insect vector: These diseases are spread by insects which either breed in water or bite near water. Examples: Malaria, yellow fever, filariasis (elephantiasis) and onchocerciasis (river blindness) are transmitted by insects breeding in the water. The West African trypanosomiasis (sleeping sickness) is transmitted by the tsetse fly which bites near the water.

   Preventive strategy: Improve surface water management. Destroy breeding sites of insects. Decrease need to visit breeding sites. Use mosquito preventive measures.

A fifth category can now be added - diseases resulting from the nitrates, heavy metals, and pesticides, too often found as pollutants of drinking water.

The availability of clean water on its own may not be sufficient to improve health conditions unless it is accompanied by other measures. It should be combined with improved excreta disposal and with health education to ensure that the available water is used for hygienic purposes. Many countries are now fighting the diarrhoeal diseases with improved water and sanitation as an essential component of primary health care.

The importance for health of adequate sanitation cannot be over-emphasized. Infective agents from sick persons are too often transferred through their excreta to surface water and/or groundwater. When the water is then used for drinking or preparation of food, the infection is spread to other persons. The use of human excreta directly as fertilizer in the production of food also involves a serious risk of transmitting infection to the food products themselves.

Schistosomiasis is a disease which has proven extremely difficult to control. This old disease - in Egypt calcified eggs are found in mummies 3000 years old - probably ranks second only to malaria in terms of human suffering and economic loss in the tropical region. Today, in three different species, the disease affects 200 million people in Africa, Japan, the Philippines, Thailand, Laos and other parts of Asia, the Middle East, the West Indies and parts of South America. Of the estimated 20 million people who have chronic schistosomiasis, approximately 200 000 die each year of schistosomiasis.

The snails, the carriers in a part of the parasite's life cycle, have in modern times been spread to new areas through large-scale water projects such as construction of water reservoirs and irrigation canals during the last 40 years. It has been said that if people did not use the canals as a toilet, Egypt would be free from schistosomiasis. The parasite's survival is dependent on regular excretion by human beings releasing eggs into the water. On contact with water, the larvae hatch and swim to their intermediate host, the snails. At maturity they seek a human home. When people are wading in the same water, the parasites bore their way through the skin. The human body provides the breeding ground and a suitable place to lay their eggs. The cycle is illustrated in Fig. 4.3.

Improved sanitation appears to be the immediate solution, and recent studies show significant decreases in schistosomiasis after the provision of safe water and latrines. However, there is always a risk that, for example, sewage pipes break and excreta are released in the water. Research is continuing to find an effective vaccine or an environmentally safe molluscicide to fight the schistosomiasis problem.

The Guinea worm disease, or dracunculiasis, is caused by drinking water containing a minute crustacean which is infected with larvae from the Guinea worm. It is estimated (1990) that an additional 10 million people are infected by the disease every year in some 21 countries in Asia and Africa. However, since this disease is transmitted only by drinking contaminated water, it can be eradicated through provision of safe water. In fact, by the end of the 1980's, the Guinea worm is close to eradication in Pakistan, India, and the Middle East. It seems to be feasible to eradicate the disease on a world wide basis during the 1990's.

Still, the most serious water-related tropical disease is malaria. At any given moment, 160 million people suffer from the disease, and an estimated one million people die of malaria every year.

The ideal breeding grounds for the mosquito vectors are swamps, marshes and stagnant pools. At one time, experts were confident that new pesticides would put an end to malaria and eradicate the mosquitoes. Thousands of tons of pesticides have been sprayed with some effects on the mosquitoes, but also with serious ecological consequences. Insecticide resistance often brings the mosquitoes back to areas where they had been eradicated.

It is a sad fact that the creation of artificial lakes and the introduction of perennial irrigation schemes have favoured the spread of malaria. Intensive research is going on with the aim of developing an effective vaccine, but so far only limited success is reported.

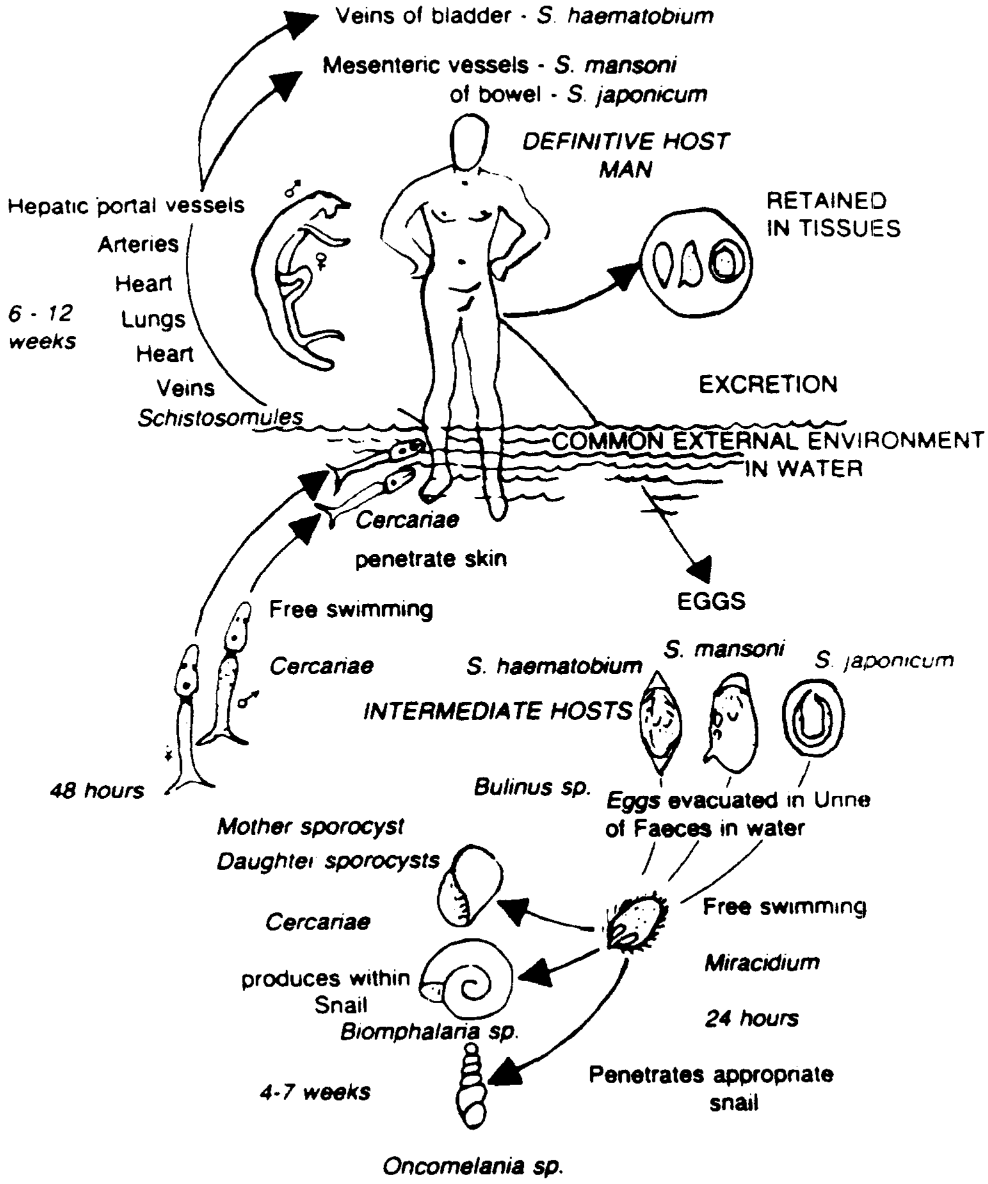


Fig. 4.3 The life cycle of schistosomiasis (UN-source).

4.4 Rural Water Supply

In the industrialized countries, most people in the rural areas have access to drinking water of acceptable standard, though pollution problems of various kinds are serious in some regions. In the developing countries, with the majority of people living in rural areas, roughly one person in three did not have a reliable supply of drinking water in 1990. And it is not expected that full coverage can be reached within the year 2000.

The most common water sources for rural water supply are

* Springs	The spring outcrop should always be protected to avoid pollution.
* Wells	These may be hand-dug shallow wells or drilled deep wells
* Rivers	Direct abstraction from rivers should be the last choice for rural water supply since treatment is always necessary. Small upland streams with protected catchments may, however, be a convenient source for gravity water.
* Reservoirs	The construction of small dams to create a reservoir for water supply is common in many areas, but the risk of contamination and water-related diseases is high, and treatment is normally necessary, even if the upland catchment is protected. Silting of the reservoir may also be a problem.
* River well, or Infiltration galleries	These may be constructed in the river bank if the soil conditions are favourable, i.e. if the banks are composed of sufficiently granular material to allow percolation and abstraction of reasonable quantities of water.
* Rainwater	Collection from roofs can provide a valuable additional water supply in many areas, if thoroughly protected.

Surface water for water supply may involve direct abstraction at river intake, storage in upland reservoirs, or storage in lowland reservoirs with pumps. In rural areas small streams are often the best choice for gravity water supply due to the relatively simple operation and maintenance, even if the quality of the water may be questionable and treatment is needed. A thorough low flow analysis of the river flow is important to avoid deficiencies in dry years, or a sequence of dry years. Very often, the hydrological data for small streams are either missing or inadequate, and the estimation of the design low flow will involve considerable uncertainty.

In many cases, groundwater development will produce a more stable supply and also water of better quality than that of surface water. This, however, does not often apply to the common hand-dug large diameter shallow wells or springs which are the main source of drinking water in many rural areas in developing countries. Such wells are often subject to contamination from various sources and have to be very carefully protected. Machine-drilled deep wells, on the other hand, often produce high quality water, even if in some areas the contents of fluoride or other salts, nitrate, manganese or iron, may cause the groundwater to be chemically less-suited for use in water supplies. Deep wells also should be carefully protected against any source of pollution of the groundwater reservoir.

The most important design criteria should be simplicity, reliability, and durability, but also the availability of skilled manpower, materials and capacity of operation and maintenance should be considered. Of the number of parameters to be analyzed, water consumption per capita is one of the most important and Table 4.4 gives some typical design values.

Level of Service	Consumption litres/head/day
Hand pumped wells and single public standpipes. Water carried 100-500 m or more. 200-250 persons per tap	15-20
Public standpipes with taps. Water carried less than 100 m and less than 200 persons per tap	20-35
Shared external standpipe, yard tap. Public standpipes with taps for less than 25 persons per tap.	20-60
House connection	100-150

Table 4.4 Water consumption per capita.

The task of fetching and carrying water, often long distances, belongs in most rural areas to women and to some extent children. It is therefore an important goal to locate the well or the tap not more than a few hundred metres from the dwelling. The amount of water used seems to increase considerably only if the tap is in the house or closer than 100 m from the house. All studies point out that women are the main interest group of domestic water supply projects. They are, however, rarely involved in any decision-making on water. Participation of women in, for example, village water committees is therefore generally advocated. The shortening of the water collection journey may be expected to leave more time for other valuable activities, possibly of an economic nature.

Some of the main constraints delaying the development of a safe drinking water supply in the rural areas of the developing world are summarized in the following:

1. Appropriate Technology

   The experience from past and present development work in the sector of rural water supply clearly demonstrates the need for increased efforts in the field of appropriate technology, which in this context is often equivalent to low-cost technology. In many cases too costly and too complicated technical solutions have been selected.

There seems to be an urgent need to concentrate on simple, low-cost technology in order to simplify the transition of responsibility to the villages for the operation and maintenance of their water supply schemes. For examples, large diesel-pump schemes have virtually come to a stand-still in many regions, due to economic constraints, lack of skilled operators, lack of spares and fuel, etc.

Examples of low-cost methods are the handpump for water supply, Fig. 4.4, and the simple pit latrine for sanitation. The handpump is a simple and cheap method of bringing the water from a sealed shallow well to the surface. A variety of handpumps exists, with a more or less reliable performance. Local manufacturing of handpumps should be promoted.

A serious problem connected to handpumps and also other kinds of equipment and instruments is the lack of standardization within many developing countries.

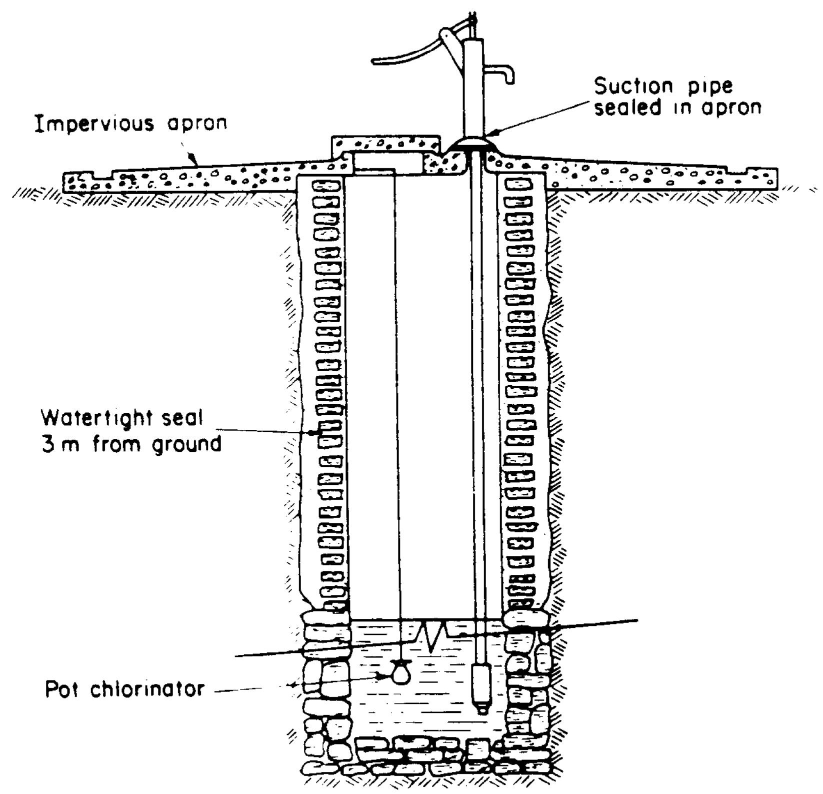


Fig. 4.4 Dug well with hand-pump [20].

2. Rehabilitation, Operation and Maintenance

As mentioned in the preceding section, broken down or badly functioning water facilities are numerous in the developing countries. In most cases rehabilitation will be cheaper than to provide other solutions. Village responsibility for operation and maintenance will place additional importance on reliability. As women are the main users of water supply facilities, they should be trained for operation and maintenance activities at village and higher levels.

3. Community Participation

Community participation is a vital aspect of rural water development and maintenance. This has too often been neglected, and completed projects are often handed over without any chance of achieving their aim - because the community (village) is not motivated and prepared, or even capable or running the scheme. The basic objective of community participation is to achieve a higher degree of awareness and concern among water users, while increasing their involvement and responsibility for satisfying their needs.

Ideas for pump siting, choice of technology, maintenance needs, quality surveillance, construction requirements, even funding, come best from properly managed pre-project discussions. It is important that all parts of the community are consulted, the women in particular.

4.5 Rural Sanitation

For most people in rural areas, a reliable water supply at a reasonable distance will have a higher priority than improved sanitation facilities. Some facilities, like the fields, may have served the purpose for generations. However, since the connection between good health and adequate sanitation is undisputable, the necessity of "safe" sanitation has now been fully recognized by health authorities. The needs will vary depending on population density, social and economic factors, and the status of the present system. Non-sewered on-site sanitation is normally all that is needed, but in villages with high water usage, sewers and off-site disposal may be necessary.

The global situation, however, is not encouraging, with only 49% coverage in 1990, and a projected increase to a mere 58% in year 2000.

The rather complex connection between sanitation and health often makes it difficult to convince people that improvements are needed. The potential for change is strongly dependent on people's habits and way of life, on culture and tradition.

In the industrialized countries water-based toilets have become the most common solution, though they also cause serious environmental problems. A common water closet requires 6-10 litres per flushing, an unreasonable volume of water when the sole function is to transport the waste in the closet from one place to the other. The then polluted water may damage/pollute during transport and the place to which it is transported. The total costs of installations are so high that in developing countries this alternative is feasible only for a very small proportion of the population.

However, modifications of the water closet have been developed, which make the system less costly. A squatting hole can be used instead of a closet seat and the toilet can be flushed manually (pour flush toilets) with only 1-3 litres of water at a time, and with direct outlet to the ground or a septic tank in the vicinity of the house. Care should be taken that the waste is filtered through the zone of unsaturated soil, above the groundwater level.

Table 4.5 gives examples of types of toilets, or latrines, varying according to the location of the site for the final disposal and whether or not the latrine depends upon water for its operation.

	Water-Independent	Water Dependent
Off-Site	1. Bucket Latrine 2. Vault and Vacuum Truck Latrine	1. Conventional Sewerage 2. Smaller Bore Sewer System
On-Site	1. Convential Pit Latrine 2. VIP Latrine 3. Compost Latrine 4. Chemical Toilet	1. Self-Flushing Latrine 2. Pour Flush Latrine 3. Aqua Privy 4. Septic Tank System

Table 4.5 Classification of Latrines

In rural areas in developing countries preference should always be given to dry methods of sewage disposal. The ventilated improved pit (VIP) latrine, Fig. 4.5 is a simple and cheap design which makes excreta disposal an odourless affair with a minimum of fly and mosquito nuisance. Several other devices exist. Especially where the water table is high, location of the latrine becomes important in order to avoid pollution of the groundwater. When the pit latrine is full, a new one has to be built. In some cases double-pit latrines are built.

Compost, latrines which make more systematic use of the composting process are common in some developing countries, particularly in Vietnam. In contrast to the pit latrine, a compost latrine is permanent. The compost can normally be used as fertilizer without any hazard to health.

The minimum characteristics of a satisfactory latrine may be defined as follows:

i) It must have a durable and structurally safe squatting floor;

ii) It must have adequate provision for the control of smells and houseflies. For pit latrines this is best achieved through the installation of a screened vent on the pit of the latrine, see Fig. 4.5;

iii) It must provide adequate privacy, for the user. This can be achieved through the provision of stable walls and a roof, together with a door or a modesty wall.

A further discussion on the different kinds of adequate sanitation facilities is considered beyond the scope of this text. It should, however, be mentioned that the introduction of

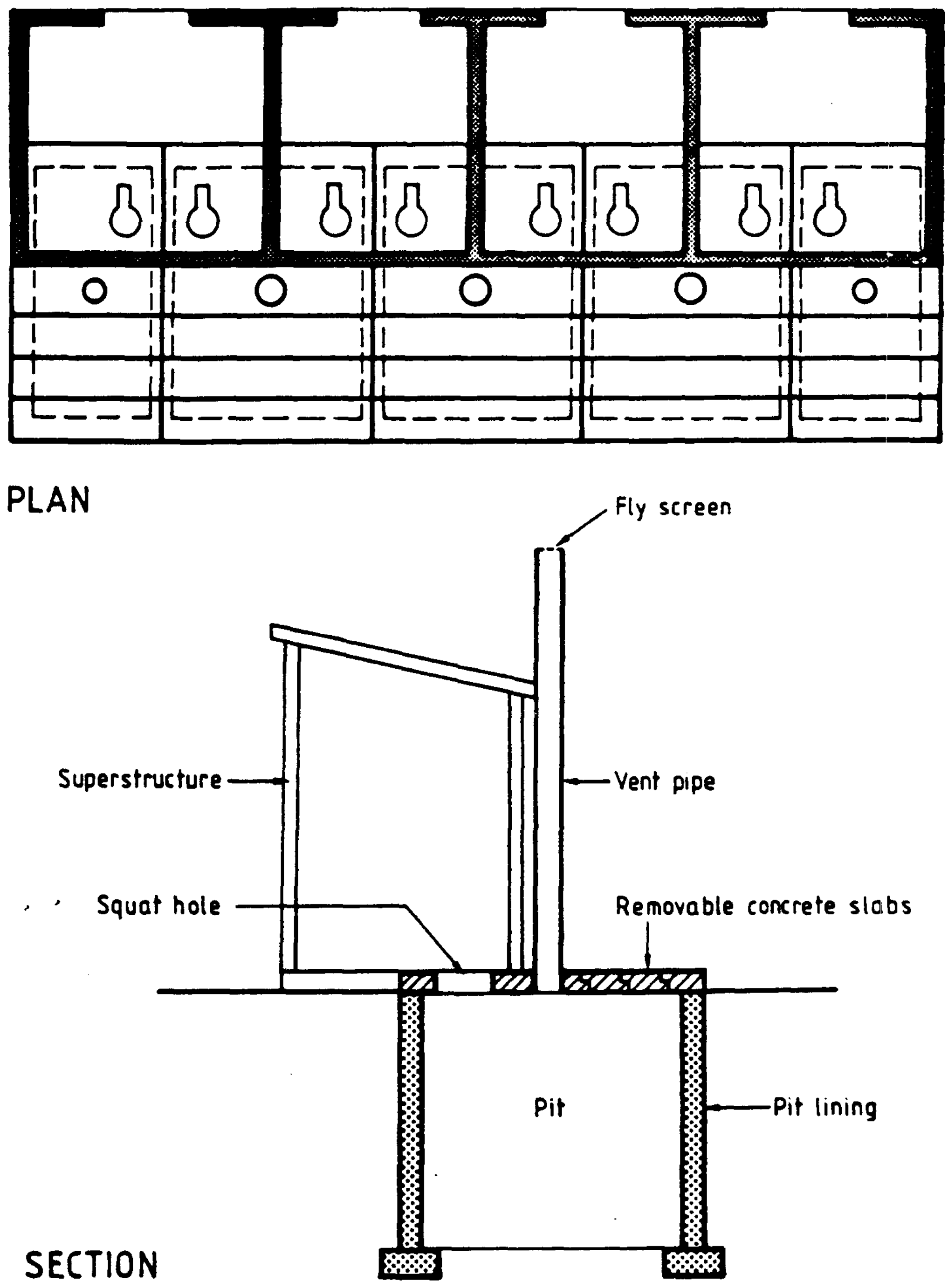


Fig. 4.5 VIP latrine for communal or institutional use. Example from Ghana [20].

water-consuming flush toilets and septic tanks sharply increases the possibilities of pollution and hazard to the environment.

4.6 Urban Water Supply

The accelerating urbanization process poses great challenges on institutions having responsibility for a reliable and qualitatively acceptable water supply for all the various water uses in the towns and cities. In the developing countries, the average coverage of safe drinking water in urban areas was estimated at 82% in 1990 and a decrease to 77% is projected for year 2000.

A moderate steady increase in demand for water can usually be met by a city, provided there is an equilibrium between the number of people, the availability of energy, available sources and the size of the water distribution system.

However, in many cities of the developing countries the authorities have lost the ability to keep up with the control of the water supply due to the tremendous migration of people from villages to the cities, and the natural rate of growth. Some urban centres have been growing at rates of 5 to 10 % per year. Lack of individual household water distribution systems in the compounds, suburbs and "shanty-towns" is a typical feature of the rapidly growing cities of today. Often the reason is that the municipalities do not have the financial sources to pay for installing the distribution systems, and in many cases the residents cannot afford to pay the charge for water.

A typical solution is to provide standpipes in central locations, however, sometimes they are not sufficient to meet the increasing demand. In many cities at present only half of the basic human water needs are met.

Another problem is that the old piping system, i.e. main distributors, cannot cover extensively growing city areas and the systems of old pipes are leaking large quantities of water, often more than half of total supply. Their carrying capacity is often reduced because of the encrustation and biological growths inside the pipes.

Urban water must in future be used more efficiently. Unaccounted-for water, much of it unused, constitutes 58% of piped water supply in Manila, and about 40% in most Latin American countries. The reclamation of wastewater is helping conserve water in a growing number of cities, including Mexico City and Singapore, and will probably continue to expand [7].

During dry periods especially water is supplied intermittently in many townships. However, because of the peak demands, sooner or later large diameter pipes have to be installed. Nevertheless, considering the population growth and the industrial development, the extension of the pipelines is usually sufficient only to maintain the same requirements of long ago.

The water sources for urban water supply may be either surface water from rivers and lakes, or groundwater. Sometimes the conjunctive use of both surface water and groundwater is the most feasible solution.

Groundwater Supply

Groundwater will often be the selected choice since it is normally of the best quality and is subject to less seasonal fluctuations. However, as the city grows and the demand for more water increases, groundwater is often pumped at rates which exceed replenishment. This over-exploitation of groundwater has taken place at high environmental costs with problems such as the lowering of the groundwater table and loss of agricultural production, land subsidence, deterioration of water quality through agricultural and industrial activities, and salt water intrusion.

An increasing number of countries are facing problems with land subsidence related to excessive withdrawal of groundwater. Some examples:

* Mexico City, the world's greatest urban population estimated to surpass 30 million by the year 2000, has sunk about 11 metres into the lake bed it is built on.

* Houston, the metropolis on the Texas Coast, has withdrawn so much groundwater that the land within a 64 kilometre radius has dropped about 3 meters

* Venice, originally located on some small islands at the head of the Adriatic Sea, has been slowly sinking into the sea mainly due to withdrawal of too much groundwater. Efforts led by Unesco have been mounted to stabilize the situation [21].

* In Bangkok, the lowered groundwater level (45-50 meters) has resulted in a subsidence level of 50-60 cm over a 20-25 year period and has aggravated the city's flood problems [22]. The low groundwater level has also caused salt water intrusion into the wells. Several wells that previously yielded excellent water have been abandoned.

* In Australia, within a number of basins, the groundwater withdrawal is reaching volumes that can not be sustained by natural recharge.

* In China, Shanghai City subsided 2.63 meters between 1921 and 1965. However, this development has now been stopped due to replenishment of the aquifers by surface water. In North China where the cities are depending on groundwater the subsidence is increasing. In the eastern suburbs of Beijing, it averages 20-30 cm a year.

* In Japan, in the Kwanto Plain where the cities of Tokyo, Chiba, Kanagawa and Saitama are situated, an area of 2 400 square kilometres is affected by subsidence [21]. In Tokyo the amount of water withdrawn has been steadily reduced.

The ways to stop the impacts of over-exploiting, or mining, the groundwater are simple and evident, but may not be easy to implement. The withdrawal can be reduced and better regulated, and the consequences have to be faced by the city. Sometimes alternative water sources are available, like surface water. Surface water may also be recharged to the groundwater, as was the case in Shanghai City. But recharging the groundwater may be a hazardous task and great care should be taken to avoid contamination. Once an aquifer has been contaminated it may be nearly impossible to remove the pollutants.

It is important to note that the process of land subsidence can be stopped, but not reversed. Even a complete stop in pumping and the injection of new water will not restore the land to its original elevation [22].

Salt water intrusion is another serious environmental problem associated with groundwater withdrawal. It occurs when the groundwater level is lowered to a level where salt water can intrude through waterbearing beds in the direction of the pumped well and contaminate the water. It is a slow process, but tends to be irreversible. Since a large portion of the world's people live in cities along the coasts of oceans, and also on islands, this problem affects a great number of people. Bangkok has been mentioned, and Jakarta and Manila are other examples. It is also a very acute problem in the capital island of Maldives [22].

Surface Water Supply

Some towns and cities are located close to rivers and lakes with sufficient water easily available. Such surface water must always be treated before domestic use. However, transfers may also be required which may have environmental impacts, for example through the construction of dams.

Some examples of long distance transfer of water are [21]:

* Germany's port city of Bremen imports water through a 250 kilometre pipeline from the Harz Mountains in the central part of the country. This was considered a better solution than treating the contaminated and saline water of the adjacent Weser River.

* Singapore's increasing water demand is covered by a 50 kilometre long pipeline from nearby Malaysia, an example of water transfer between nations.

* Undoubtedly, the world's largest water transfer takes place in the western United States. The serious shortage of water in the western regions was a serious constraint to development. There are three water transfer facilities: the Los Angeles Aqueduct, the California Aqueduct, and the Colorado River Aqueduct. The latter's water transfer system of canals, conduits, and tunnels stretches over 500 kilometres. About 600 m^3 per second is carried in the system. The water has a natural content of salt originating from erosion and weathering in the Colorado river catchment which has become a serious problem.

The amount of water required for domestic per capita consumption will vary considerably depending on climate, reliability of supply, the existence of a sewerage system, and the social and economic conditions. Average values vary between 40 and more than 200 l/head/day. Table 4.6 gives examples of the effect on consumption by houses of different standards, exclusive of avoidable consumers' wastage.

Housing class	Description	Range of per capita consumption l/head/day
High	Detached houses, luxury apartments having 2 or more WCs, and 3 or more taps per household	150-260
Middle	Housing and apartments having 1 WC and 2 taps per household	110-160
Lower	Tenements, government housing, shared houses having at least 1 tap per household but sharing WC	55-70

Table 4.6 Examples of per capita consumption according to housing class.

4.7 Urban Sanitation

A world-wide common failure is to regard the disposal problem as less important than the consideration of potable water supply. The historical roots of such an assumption originated in times when it seemed acceptable to pour the waste water into the street, in the best case into the nearest watercourse. In small townships and rural areas, the water courses may have enough self-purifying capacity to handle the contaminated water. With rapidly increasing population, however, a growing per capita demand for more water to improve living conditions, and industrial development, loads of pollutants are placed on the receiving water bodies in larger amounts than they can handle and this often leads to the killing of aquatic life. It also affects the human communities living downstream.

Urbanization is often the major source of pollution of the groundwater. This may be through leaks from pipelines and storage tanks, hazardous industrial waste disposal, underground injection wells used for disposal of waste, etc., see Fig. 4.6.

In many towns and cities in the industrialized world the disposal of waste and the treatment of waste water are now well controlled. The waste water treatment is performed in special facilities using well-known processes to clean the water.

In the developing world the situation is serious. We know that the coverage (1990) of adequate sanitation facilities for people is only 49%, hopefully increasing to 58% in year 2000. Hundreds of millions of people live in the margins of cities where the environmental and health impacts of uncontrolled solid and waste liquid waste disposal are unprecedented.

Most rivers close to urban areas in development countries are today heavily polluted with domestic sewage, industrial effluents and solid wastes, even if some efforts are being made to improve the situation in some regions. Lack of financial resources is, however, the main constraint. Since the majority of the industries are often located in and around the urban centres, the adverse effects of the effluents from industrial plants have a very concentrated areal effect. A further complication is the lack of central sewerage systems in many urban areas.

Examples are manifold. Only 209 of India's 3119 towns and cities have even partial sewage systems and treatment facilities [22]. Some 114 towns and cities discharge raw sewage into the holy river Ganges. In China, the wastewater and solid wastes discharged by the large and medium-scale industrial enterprises have reached 80 million tons per day and one million ton per day, respectively.

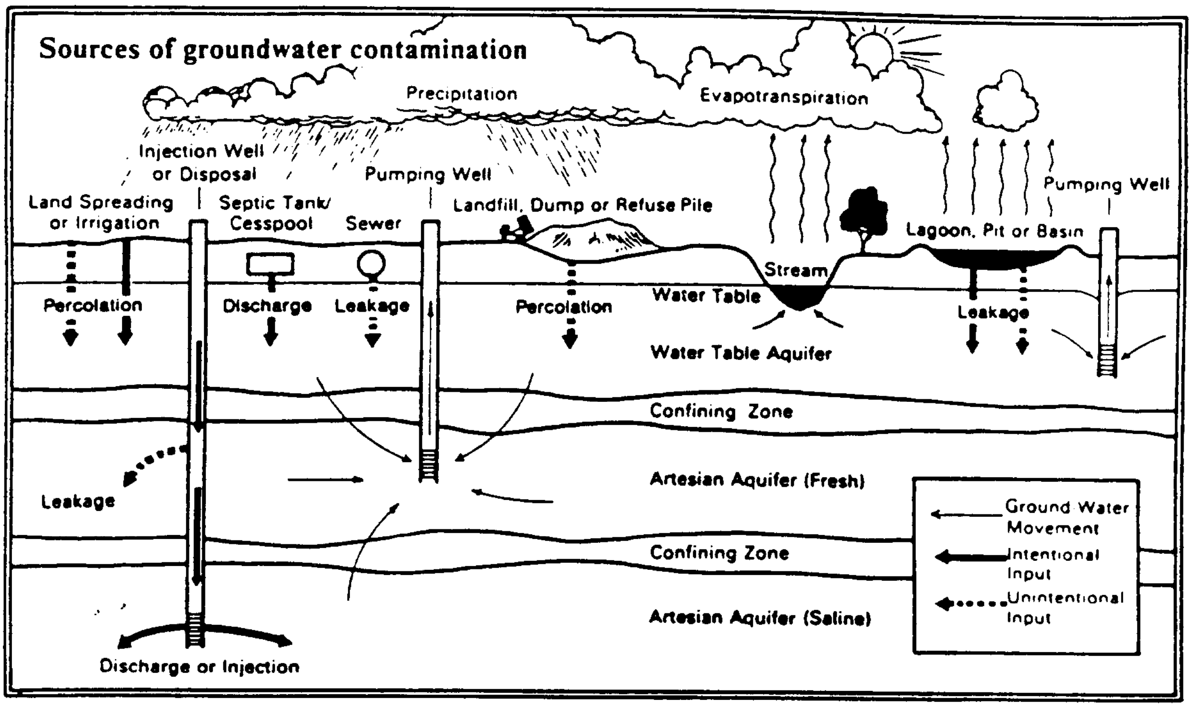


Fig. 4.6 Sources of groundwater contamination [23].

5 WATER IN AGRICULTURE

5.1 Extent of Irrigation

Of the cultivated part of the earth's surface, about 17% is irrigated. It is estimated that between 1950 and 1985, the total world irrigated area tripled and now provides one third of the total food production. Irrigation accounts for about 63% of the total withdrawal of water and directly affects millions of people. More than half of the irrigated area is in the developing countries.

It is important to distinguish between withdrawal of water and consumption of water. Of the total water withdrawn for irrigation more than 70% is consumed or "lost" through evapotranspiration, while less than 30% is returned as effluent to, say, a river. The high figure for consumption is special for irrigation, compared to other main water users.

Projections show that even with a considerable increase of the irrigated area, withdrawals for irrigation will probably decrease from 63% in the 1980s to about 55% by the year 2000 [13]. This is mainly due to more efficient irrigation techniques.

Asia has by far the largest area under irrigation, about 33% of its cultivated land. China, Pakistan and India account for more than half the world total. Outside Asia, the previous U.S.S.R, the Untied States, and Mexico, have the largest areas under irrigation. In most of Latin America, irrigation is relatively unimportant. In Australia, irrigation is used more intensively than in any other country. In North Africa, the traditional irrigation in the Nile basin is well known. Egypt irrigates 100% of its cultivated land. In Europe, with a few exceptions, large-scale irrigation is uncommon in most countries.

It has been estimated that more than 95% of the irrigated land, world-wide, is served by surface irrigation, the most water-consuming practice. The exceptions include parts of Europe, California, Israel, Cyprus, and some areas in South America, where the water saving sprinkler and drip irrigation systems have been introduced. Land degradation through surface irrigation can be prevented by carefully constructing contour ridges.

As will be discussed on the following pages, irrigation has a number of serious environmental impacts compared to ordinary rainfed farming. Also the often underestimated investment costs, the delays in construction, the yields below forecasts, and problems involved in operation and maintenance, have given rise to concern. It is now expected that rainfed agriculture may significantly increase in several countries in the developing world, like Burma, Indonesia, and the Philippines.

5.2 Water Sources

In humid climates, drainage may be the main action required, and the rivers receive the superfluous water drained from the fields. There has been some controversy over the hydrological effects of drainage, with studies showing both an increase and a reduction of flows [24]. Drainage of a previously wet soil tends to reduce subsequent floods, while drainage of a drier permeable soil increases runoff by providing a faster route for rainfall. In drier areas, only complementary irrigation, for example by sprinklers, may be needed.

In arid and semi-arid areas, characterized by low annual rainfall of irregular nature and uneven distribution, the provision of irrigation is a condition for both small- and large-scale agricultural activities.If surface water from rivers or streams is available, this will be the obvious choice as the source of water for irrigation. Regulation of the rivers with the establishment of reservoirs if often necessary. The impacts of dams are discussed in Chapter 7.

In some areas, groundwater may be used to supplement surface water supply and to intensify agriculture. If not contaminated, surface water is normally considered to offer certain advantages in terms of temperature and chemical constituents.

In other areas, groundwater is the only source of water for irrigation. If pumping exceeds the natural (and artificial) recharge, this may cause serious environmental problems, see Section 4.6.

5.3 Quantitative Impacts on the Hydrological Cycle

Of man's interference with the hydrological cycle, abstraction of water for irrigation purposes is probably the most widespread and quantitatively most profound activity. All land-use changes, like change of vegetational cover, soil characteristics, etc., will change the rate of evapotranspiration and seepage. Since plants are the major consumers of water, a large proportion of evapotranspiration can be considered as agricultural consumption [24].

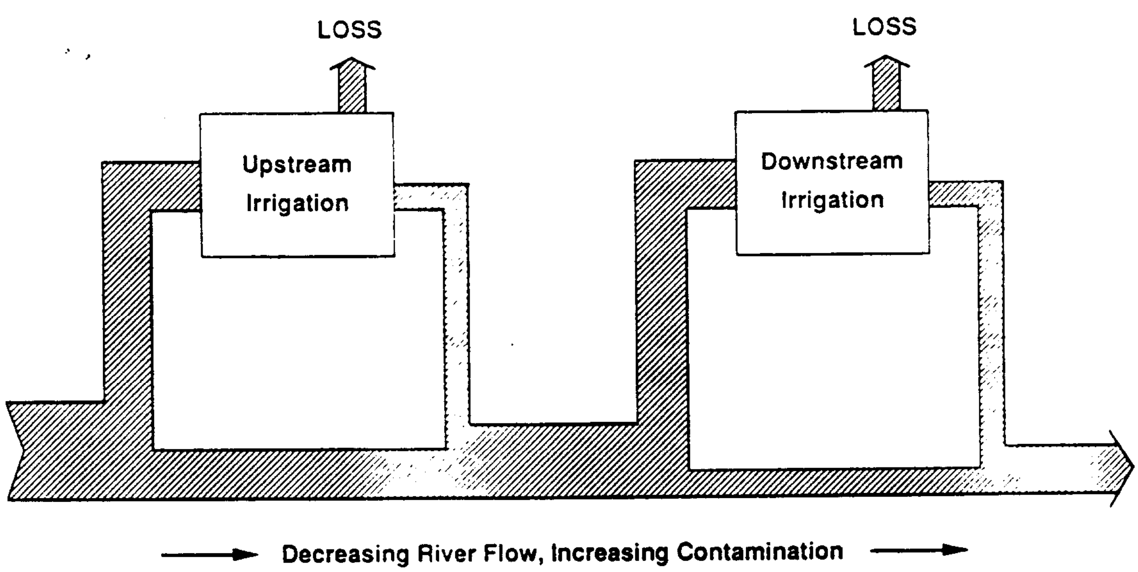


Fig. 5.1 A large part of the water abstracted from the river will be consumed by irrigation.

When water for irrigation is abstracted from surface streams through canals or pipes, a major part of it will be consumed and returned to the atmosphere, as illustrated by Fig. 5.1. In the growing season, large-scale irrigation will cause irretrievable losses for downstream inhabitants.

Also extensive use of groundwater for irrigation purposes may have great impacts on the hydrological cycle by increasing the evapotranspiration and reducing the groundwater baseflow into the rivers.

Some examples:

* In the United States, agriculture accounts for about 85% of all water use [23]. Increasing use of irrigation has caused extensive water withdrawals from rivers and streams in the Lower Colorado and Rio Grande catchments.

  In California, the single biggest consumer is irrigation of pastures for livestock. Diversion of water for agriculture has dried up a great part of the ecologically valuable wetlands.

* The Aral Sea in the Central Asian Republics of Uzbekistan and Kazakhstan is now an example of an ecological disaster. The Aral Sea was until 1960's the fourth largest inland sea, only ranking after the Caspian Sea (Russia), Lake Superior (USA), and Lake Victoria (East Africa).

  At equilibrium, when evaporation balanced precipitation and river inflow, the natural rising and falling of the water level averaged 1 - 1.5 meters. In 1989, the Aral Sea had lost 67% of its volume and 40% of its area. The water level had dropped 14 meters. The reason? Although some can be attributed to a relatively dry regional climate in the first half of the 1980s, more than 80% of the Aral depletion is due to excessive water withdrawal for irrigation from inflowing rivers.

  The economic and environmental impacts are enormous, affecting some 35 million people. Former maritime towns are found several kilometres from the shore, the former sea bottom is turned into desert, the mineral content of the sea-water has tripled with a profound disturbance of the marine ecosystem, drinking water sources have become polluted - all environmental effects of a deeply erroneous agricultural policy.

  About 90% of the inflow to the Aral Sea was before 1960 coming from the rivers Amu Darya and Syr Darya, two of the largest rivers in the region. In the early 1960s extensive irrigation schemes were developed along both rivers. The irrigated area increased from 2.9 million to about 7.5 million hectares, used to grow cereals, melons, but most of all to grow 90% of all the cotton in the previous Soviet Union.

  A dramatic decrease in irrigated areas seems today unrealistic. Some improvements in irrigation techniques are being introduced, but most probably the Sea will continue to shrink until it stabilizes at about 20 meters below the 1960 level.

However, the mystery about the Aral Sea may still not be fully understood. There should be no doubt that the water withdrawal for irrigation is the main reason for the present decrease in water volume. But it is also reported that ancient historical documents fail for some reasons to mention the existence of the Aral Sea. The area is, on the contrary, described as swampy flatlands. Other documents in facts describe the formation of the Sea, probably caused by rivers changing their courses.

It seems that the major rivers of the area have in some periods drained to the Caspian Sea, and in other periods drained to the Aral Sea. The first proof of the existence of the Sea is from 600 A.D. Then the Sea disappeared around year 1300, to reappear around year 1500.

The exessive pollution of today is certainly caused by man only, and is the real disaster of the area. However, the Aral Sea itself may also be governed by a natural rhythm that in periods causes its depletion.

5.4 Salinization and Waterlogging in Irrigation Practices

Salinization and waterlogging are called the "twin evils" [25] connected to environmental effects of irrigation practices. They have been introduced mainly through the switch to perennial agriculture, and the irrigation of marginal areas. Vast areas of agricultural land have been abandoned or lost fertility because of salinization and waterlogging. It is no doubt that erroneous irrigation is the main contributor to desertification in croplands.

The inflow and outflow of materials from an ecosystem must be balanced. Under non-irrigated conditions there exists a balance between the rainfall on the one hand, and the interaction between stream flow, groundwater, and evapotranspiration on the other hand. This balance may be seriously disturbed when irrigation is introduced, resulting in a considerably recharge to the groundwater.

As a result of natural weathering, some salts will always be present in all kind of soils, the quantity depending on the original rocks. When rainwater comes in contact with the soil, some of the salts will be dissolved and consequently all water will contain traces of salt. Soils become toxic to most plants when the salt concentration reaches 0.5 - 1.0% [25]. In dry areas the natural salt content may reach 12%. The rainfall is not sufficient to flush out the salt as is the case in more humid areas. Also the groundwater may contain a natural salt content, sometimes in a quantity making it unsuitable for human consumption.

Waterlogging occurs when poorly drained soil receives more water than it can absorb, promoting conditions hindering plant growth, see Table 5.1.

Groundwater depth	Harvest as a portion of normal yield, in %	
m	Wheat	Cotton
2-3	100	100
1-2	50	65
0.5-1	20	50
0.5-0	0	10-20

Table 5.1 The impact of waterlogging on crop yield, Shaanxi Province, China [25].

If the groundwater level is permitted to rise close to ground level, say, because of irrigation practices, the water will be drawn further upwards through capillary action and the land becomes waterlogged. Additional quantities of salt will be dissolved during this process. If the water reaches the surface, it will quickly evaporate, and salt will be accumulated on the land surface. Under such conditions, vast areas may be covered with a white, infertile saline crust.

In some areas alkalization may occur if the groundwater contains sodium or sodium bicarbonate. When the water evaporates, the land will be alkaline with consequent cementation and impermeability in the soil which becomes barren and infertile. Problems with alkalization are reported from Northern India, Pakistan, Armenia, Afghanistan and Iran.

To avoid salinization developing as a result of irrigation, there is a very fine water-soil balance to maintain. It is essential that if salt is added to the soil by water, the same amount has to be flushed away. This is extremely difficult to manage. Perennial irrigation will always increase the groundwater level, primarily because water is added through seepage from the irrigation channels. This may be a considerable volume of water. In some cases half of the water is lost through seepage from irrigation channels. Also the creation of dams for regulating the water may increase the groundwater level up to several kilometres from the reservoir.

The inevitable result of all irrigation is a huge increase in evapotranspiration. Water is spread thinly over a wide area, thus raising direct evaporation losses. The salt will remain in the soil. Also, evaporation from reservoirs may increase the salt content of the water to be drawn for irrigation.

Over-irrigation, both in quantity and frequency, is obviously also contributing towards waterlogging and salinization.

The development of successful irrigation will have to include measures to control waterlogging and salinization. The most important measure will be to allow for proper drainage so that surplus water can be drained away sufficiently fast to prevent waterlogging. The lining of the irrigation canals is one method to reduce seepage, but it may be expensive.

Another method (tried in the United States, China and Pakistan and elsewhere) is to dig tube-wells to pump away the groundwater and lower the water level. Again, the costs involved are considerable. A third method is the introduction of overhead sprinklers to minimize the water use. Also drip-irrigation is being tried, which is the most water-saving method.

However, the most realistic measure to combat the waterlogging and salinization problem on a global scale seems to be the building of drains to remove the excess water. On a worldwide scale, the costs involved to introduce this technique are enormous. The related management and maintenance tasks may be equally enormous.

If improved conditions are achieved in one particular area, this may worsen the problems for downstream users. The improved drainage upstream has the desired effect of flushing away the salts, thus increasing the salt content in the water for downstream users.

The salinization problem has probably always been present, but not on the scale we find it today. One reason, of course, is the ever increasing irrigated areas. Another reason may be that the regulation of rivers with the construction of storage systems, and the higher consumption of water, have decreased the natural floods which flushed away the accumulated salts.

Water logging and salinization are undoubtedly among the most serious environmental problems of today, with direct relevance to the world's food production. How serious is the situation? Figures vary, but most probably more than 50% of the world's irrigated land now suffers from waterlogging and salinization. It is estimated that 200 000 to 300 000 hectares of irrigated land are taken out of production every year due to such problems. It has been claimed that as much irrigated land is now being taken out of production due to these problems as new irrigation schemes are bringing into production.

The situation in some countries [22] and [26]:

* In Pakistan, 65-70% of the total irrigated areas is estimated to be salinized, waterlogged, or both.

  Historically, when large-scale irrigation was introduced in Pakistan, a parallel drainage system for the outlet of excessive water should have been built. This was not done, and the groundwater table has risen in the entire Indus plain, as illustrated by Fig. 5.2. Reclamation programmes have been initiated and some affected land is being brought back in production. In some areas farmers have switched from wheat cultivation to salt-tolerant farm forestry and orchard operation.

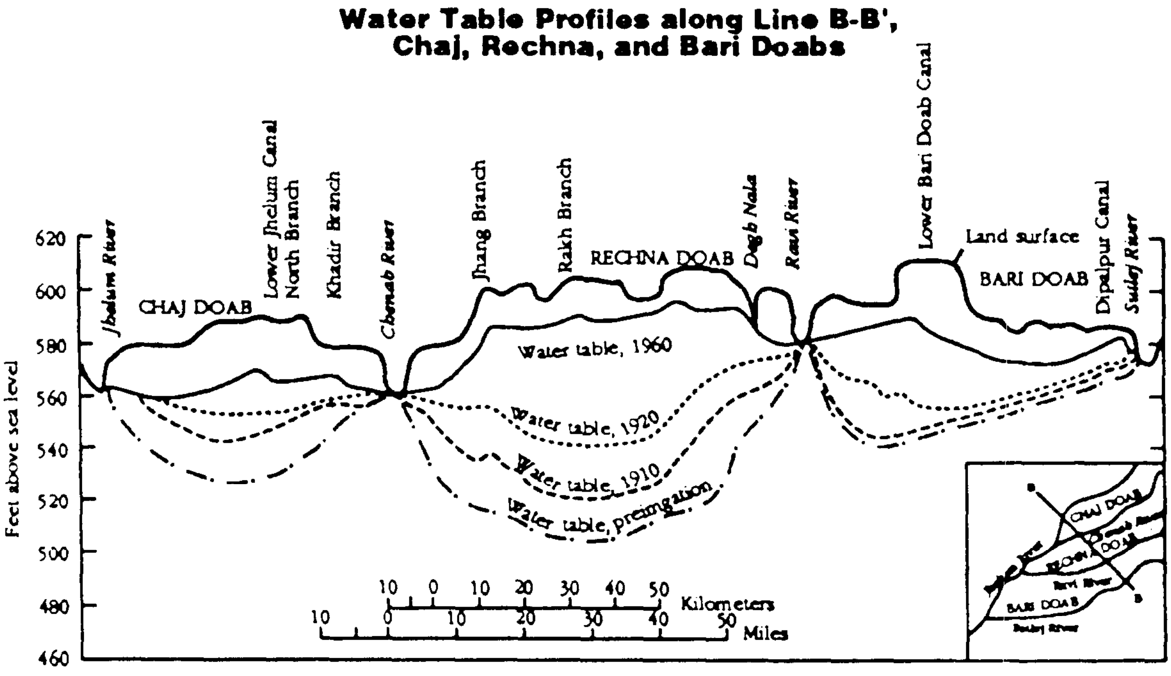


Fig. 5.2 Example of rise of groundwater table due to irrigation practices in Pakistan [22].

- In Egypt, as much as 35% of the total cultivated surface is affected by salinization, and 90% by waterlogging.

- In Iraq, more than 50% of the irrigated land suffers from salinization and waterlogging.

- In Syria, 50% is waterlogged or salinized. In the country's arid climate, with evaporation exceeding precipitation in many locations, it is estimated that 70% of the soils put under irrigation are potentially saline.

- In India, the amount of land devastated is nearly 25%.

- In the United States, it is estimated that 25-35% of the country's irrigated land suffers from salinization, and the problem is getting worse.

- Australia is the country in the Asia and Pacific Region with the highest areas affected by soil salinity, both naturally and as a consequence of irrigation. In the lower Murray valley as much as 70% of the old irrigated lands suffer from salinization. Much of the problem has been caused by overgrazing and tree removal, because trees are no longer there to regulate the groundwater level.

5.5 Agricultural Runoff

The runoff resulting from man's various landuse activities may substantially affect the quality of the water in rivers, lakes, reservoirs, and also the groundwater. The problem of increased salinity was discussed in the previous Section. The use of pesticides (insecticides, herbicides, fungicides, molluscicides) is another serious threat to the aquatic environment. The classic example of an environmental hazardous chemical is the DDT insecticide which has been sprayed into the environment since World War 2. Such chemicals have proved to be very dangerous since they are stable and only very slowly destroyed by natural processes. DDT is now banned in most countries.

However, the use of pesticides originating from agricultural practices is still one of the most important reasons for water pollution. Due to the high costs, some pesticides are used only to a limited extent in developing countries. An alarming tendency, however, is that pesticides which are banned in most industrialized countries due to their environmental hazard, have been dumped on the markets in developing countries [26].

The use of chemical fertilizers is another serious threat to the aquatic environment. About half of the fertilizers used are lost through drainage of surface water, through percolation to the groundwater, and through evaporation. Fertilizers contain phosphates and nitrogen and can create excessive nitrogen content in the water which may be hazardous to health. It may also cause eutrophication in lakes and stagnant water.

Livestock also produce waste which is converted into nitrates and may in some areas be a significant source of contamination of surface water and groundwater. It has been claimed that in the United States the livestock accounts for 5 times more harmful organic water pollutant than do people, and twice the amount of pollutants that comes from industry [23].

The use of pesticides and chemical fertilizers has undoubtedly helped increase food production, but has also seriously polluted the water supplies in many areas. More efficient ways to use these chemical remedies have been developed and have to be introduced on a worldwide scale to change today's alarming situation. A number of encouraging results of drastically reducing pesticide use are being reported from both industrialized and developing countries. Also more efficient use of chemical fertilizers is being developed. An important priority for achieving sustainable agriculture is to increase the use of organize fertilizers, including crop, animal, and human waste [23].

5.6 Recycled Wastewater Irrigation

In all countries, the disposal of wastewater from urban areas involves a serious threat to the environment. Treatment plants are necessary to raise the quality of the wastewater so that it can be released to rivers or recycled for other uses. However, we know that in many urban areas even raw sewage is diverted for irrigation use.

The idea of recycling wastes to agriculture is not new [27]. In China and other parts of Asia, night soil (human faeces and urine) has been used to fertilize crops and replenish depleted soil nutrients since ancient times. Human waste is also used for fish pond fertilization in several countries. In Europe, wastewater irrigation was popular (Paris, London, Berlin) during the late 1800s and early 1900s. Also in the United States sewage irrigation was underway those in years.

The potential environmental benefits of applying wastewater irrigation are threefold. It will decrease the pollution in rivers and streams, it will conserve water, and it will provide nutrients to improve the soils. However, the negative impacts may be serious if the recycled wastewater is not of sufficient quality. The farm products may be contaminated and be a threat to human health, and untreated wastewater may spread the toxic content to the soil and also water sources.

However, today many countries have recognized the importance of wastewater recycling through irrigation, but based on well-treated water and highly restrictive health regulations.

In the developing countries, it has been estimated that some 80% of the wastewater flow from urban areas is currently used for perennial or seasonal irrigation. Much of it is unplanned and uncontrolled, however, and poses a serious threat to human health.

In many urban areas [27] like Santiago, Lima, Teheran, Bombay, and Kabul, untreated wastewater is diverted by subsistence farmers and used to grow vegetables and salads for nearby urban markets.

In other urban areas, fully treated wastewater is diverted to farming operations organized for the irrigation of controlled crops. Examples are found in Melbourne, Mexico City, and Khartoum.

The health effects of excreta used direct in aquaculture, as in Java, are disputed. Also effects of wastewater use in aquaculture (as in Calcutta) are not sufficiently studied. There is an obvious need for microbiological and epidemiological research to determine the public health impacts. With the relatively low levels of coliforms present in the ponds over the growing season, the fish are likely to be of good enough quality for human consumption providing they are well cooked and high standards of hygiene are maintained during fish preparation.

6 WATER IN INDUSTRY

Industrial water uses include water for mining, various factory uses, and cooling water for industrial and thermal energy production. Total industrial withdrawal of water is estimated at about 21% of total use, but industrial demand is increasing much faster than agricultural demand. One serious environmental effect is that most of the water is returned to the natural water cycle, often into a stream or a pond, heavily polluted with chemicals and heavy metals. However, in an increasing number of countries, environmental authorities are imposing strict regulations on treatment of the wastewater, often with all costs involved to be covered by the industrial companies themselves. Since the 1970's, technical development in many industrial branches have increasingly been directed towards recirculation of process water, see Fig. 6.1. This is both water-saving and reduces costly wastewater treatment measures. However, studies of acid and toxic precipitation (Section 3.6) have shown that industrial wastes can enter the hydrological cycle in ways other than through effluent discharges.

The emergence of new technologies is one of the most important recent trends in industrial development [28]. Some of these technologies can reduce industrial discharges by using raw materials and energy more efficiently. Advances in biotechnology have led to improvements in efficiency of treating industrial effluents.

6.1 Industrial Effluents

Almost all industrial processing involving water is a potential source of pollution for rivers, lakes and reservoirs, and groundwater.

The wide range of the industrial consumption of water is illustrated by the examples in Table 6.1. The table gives typical gross consumption figures for industries using water in their manufacturing processes. The very high values connected with the production of steel, paper and wood pulping, and tanning should be noted. Also cooling water for thermal power stations reaches very high quantities. The actual consumption may be considerably less if water is recycled.

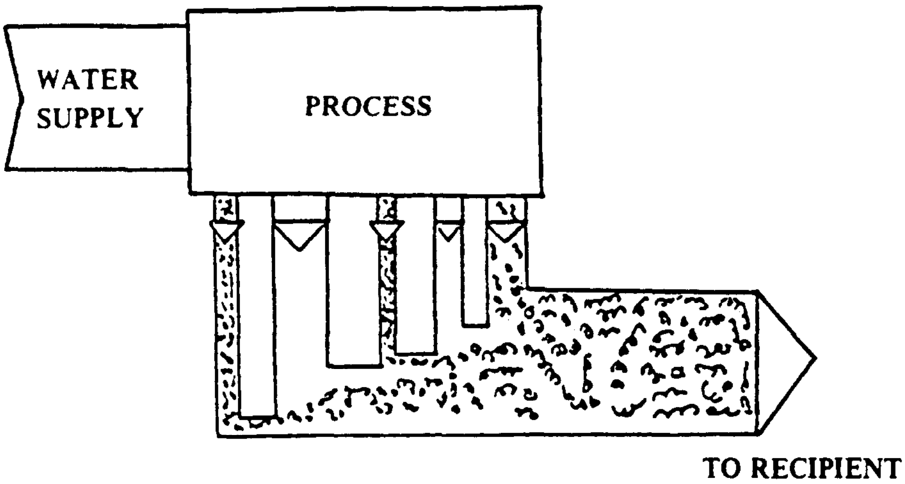
The industrial pollutants contained in effluent water may be chlorinated organic compounds, minerals and oils, phenols, nitrogen, phosphorus, mercury, lead, and cadmium. Industries frequently referred to as being the most significant water polluters include chemical and plastics industry, metal finishing and the iron and steel industries, pulp and paper industries, distilleries, and food industries. Also the increased transport of oil on roads and inland waters has contributed to pollution of both surface water and groundwater.

Product	Unit of output	Typical water consumption, m3/unit of output
Steel	ton	10-300
Paper	ton	100-500
Wood pulping	ton	30-850
Tanning	100 m^2	5-350
Milk processing	1 000 l	4.5
Electric power generation (coal-fired)	tons of coal burnt	450
Cotton dyeing	ton	10-250
Whisky	1 000 l	70
Beer	1 000 l	10-15
Bread	ton	2-5
Ammonia	ton	420
Sulphuric acid	ton	3-20
Petrol	1 000 l	7-34
Laundering	tons of goods washed	30-50

Table 6.1 Examples of industrial water consumption.

In the 1970s, mercury attracted particular attention in some industrial countries. There was detected an above minimum safety level in fish and also in freshwater sediments. Banning imposed on use of mercury in various industries resulted in reductions in environmental concentration.

In a great number of countries in the developing world, the lack of treatment of industrial effluents is alarming. In India, most of the effluents from tanneries and the pulp and paper production are poured untreated into rivers or ponds. In Malaysia, palm-oil and rubber effluents in addition to other industrial wastes and sewage, have caused 42 rivers to be labelled as "dead" [22]. In Australia, the wastes from factories processing dairy products have caused serious deterioration of several groundwater reservoirs. The list of such examples can easily be extended.



Renovated plant with efficient water recycling

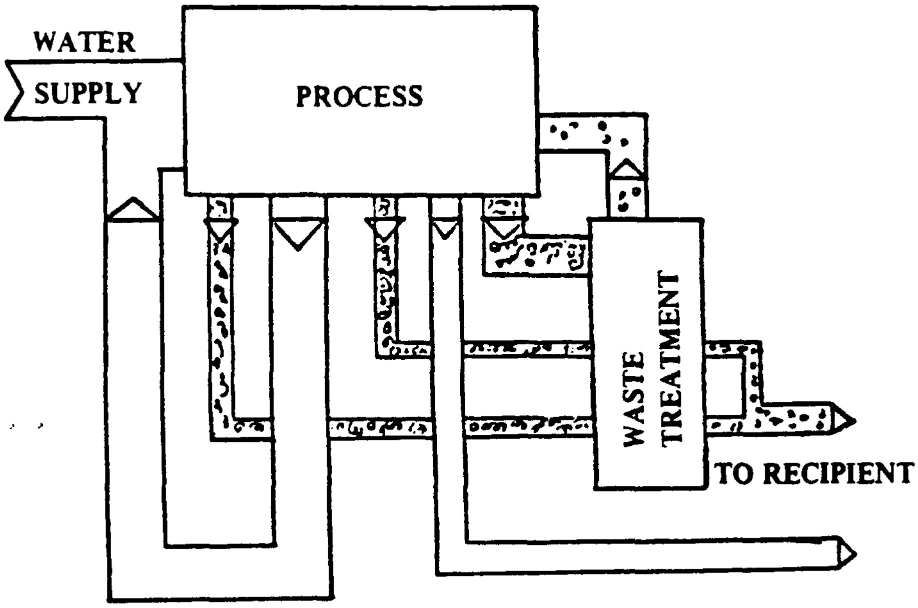


Fig. 6.1 Effect of recycling [29].

In many cases, the wastewater from major water-consuming industries can be reused as water for irrigation after necessary treatment. In the sugar industry [29] this is generally considered the best method of disposal, after treatment to remove oil, grease and suspended matter, and correcting the pH value. The most cost-effective approach for treatment of the wastewater is to subject it to simple biological anaerobic treatment in lagoons, followed by treatment in aerated lagoons or oxidation ponds.

6.2 Hazardous waste

The World Health Organization has defined hazardous waste as having "physical, chemical or biological characteristics which require special handling and disposal procedures to avoid risk to health and/or other adverse effects". The traditional low cost methods of hazardous waste disposal are landfill, storage in surface impoundments, and deep-well injections In Europe, the most common method, over 75%, is disposal on land. In the United States deep-well injections are more common than in Europe, see Fig. 6.2.

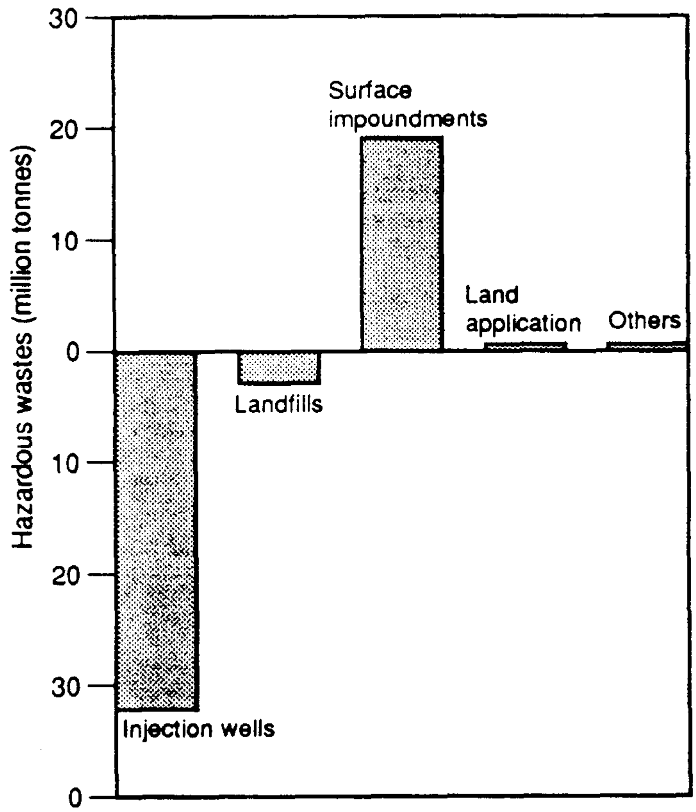


Fig. 6.2 Disposal of hazardous waste in USA, 1981 [28].

Most of the methods of disposal posea threat to nearby surface water and groundwater. There have been numerous cases of groundwater contamination by chemicals leaking from injection wells and unsatisfactory landfills and surface impoundments. Wastes stored in unlined canals and ponds near Denver, Colorado, contaminated groundwater over an area of about 40 km2. [28].

Accidents involving hazardous toxic substances can never be completely avoided and they will always pollute nearby waters. Strict regulations may of course limit the occurrences, and should be strongly promoted, but a certain risk of such accidents will always be present. One approach to reduce the risk is treatment of hazardous wastes to make them less toxic. A better approach may be to reduce the use of toxic substances. An important principle should always be that the industry causing a toxic hazard should clean up - and pay compensation.

An accident in Basel, Switzerland, in 1986 may serve as an example of such point release of a toxic substance. Due to a fire in a chemical warehouse, 30 tons of pesticides were released into the River Rhine, leaving a 200 kilometre downstream of the river biologically dead for several years.

It has been claimed that the threat of accidental release of hazardous substances is today greatest in some developing countries. Restrictive regulations in the industrial countries have caused some producers of toxic substances to move their factories abroad where they can operate at less expense.

One of the most frightening toxic substances for most people is the radioactive material escaping into the air, soil, and water when a nuclear reactor collapses, like the Chernobyl disaster in Russia in April 1986.

6.3 Mining

The locations of mines are determined by the location of the ore, often in mountainous areas where the streams are small, but many exceptions to this rule may be found. Both surface water and groundwater are frequently polluted by effluents of mining or milling operations, and by rainfall and stream action on solid mine and mill wastes. The mining of copper, lead, zinc, iron, uranium and other minerals may release various harmful components to the water. In the United States, drainage from coal mines is a major pollution problem.

Acid mine drainage discharged into rivers, streams, and lakes, has affected aquatic biota in many regions. One of the most usual methods to treat the acid water is to lead it to a tailing lagoon and add lime to precipitate the dissolved metals. To obtain required quality, for example for use in irrigation, more rigorous treatment is required. A normal layout includes a lagoon to collect the coarse fraction of the tailings, followed by one or several clarification lagoons.

In summary, the most important water-related environmental problems in connection with mining and dressing of metalliferous areas are [29]:

1. Increased erosion, resulting in increased sediment transport in rivers, siltation of reservoirs, irrigation systems and coastal areas, often with detrimental effects on fish production and on fisheries;

2. Precipitation of metal hydroxides and flocculation of finegrained colloidal material, which may sterilize the bottoms of rivers and concentrate in stillwaters and polls, which often are important habitants for fish;

3. Toxic effects on aquatic organisms resulting from increased concentrations of dissolved metals and from discharges of flotation reagents and of other chemical additives or oil, used in the processes. Damage may also occur if

the receiving water is used as drinking water supply, for irrigation or aquaculture;

4. Damage of aquatic ecosystems due to discharges of very acidic waste waters, including acid mine waters and leakages from tailing piles;

5. Increased concentrations of radioactive nuclides that may be released from the minerals during mining operations;

6. Fertilization and eutrophication of receiving waters as a result of discharges of plant nutrients, released from the minerals or originating from the use of explosives in the mine (primarily nitrate).

6.4 Thermal Pollution

The major volume of water used by industry, and in particular by thermal power plants, serves as cooling water. When this water is released, the effect will be thermal pollution in the receiving river or lake. The temperature of the used cooling water will normally be warmer than the receiving water body, and may cause considerable changes in aquatic ecosystems.

The heated water influences all biological life, like feeding habits and reproduction rates of fish, changes in nutrient levels, eutrophication, and degradation rate of organic material. In Germany we find examples where the maximum capacity for power production in thermal plants along a river has been reduced by governmental restriction.

Recycling and re-use of cooling water offer great potential for water savings. Technologies for recycling cooling water include cooling towers with natural or forced mechanical draft and cooling ponds with spraying units or with large surface areas. There are often problems involved in re-using other process water for cooling purposes, and extensive treatment may be required to obtain the purity required [30].

However, the warm water can often be put to beneficial use, for example in aquaculture, for residential and industrial heating, and in hothouses for growing tropical and sub-tropical crops in temperate regions.

7 HYDROPOWER DEVELOPMENT, DAMS

7.1 Water, Energy and Environment

Waterfall energy can be considered as a particular type of renewable solar energy. In the hydrological cycle water is evaporated from the surface of the earth, and part of the returning precipitation is the no-cost feeding source for streams and rivers, see Fig. 7.1. One cubic meter of water has to fall about 400 meter to produce one kilowatthour. The mechanical energy from falling water has been made use of for centuries, but the main hydropower development has taken place in the 20'th century, and has been accelerating in the last 20-30 years.

On a world basis, conventional hydropower now covers about 20% (Table 7.1) of the electricity demand, the remaining 80% mainly covered by plants using fossil fuel (coal, oil, natural gas) and nuclear power. Of the world's total demand for energy, hydropower covers only about 7%.

Continent	% Hydro of total electricity production (1986)	% Hydro of exploitable potential (1989)
Africa	21	4.1
Asia	19	10.9
Australia	24	18.5
Europe	18	62.8
North America	20	72.9
South America	76	11.4
Previous USSR	13	7.0
World Total	20	16.6

Table 7.1 Hydropower percentage of the total electricity production, and exploited hydropower as per cent of the total exploitable potential.

In some areas, geothermal power is used to generate electricity. The energy is tapped by withdrawal of steam or hot water from underground reservoirs in areas where this resource is easily available, normally in relatively young geological formations. The power plant is on site which is advantageous in minimizing land requirements. Cooling water is not needed since the steam is condensed and recycled. Some adverse environmental impacts are experienced, like land subsidence, release of hydrogen sulphide (unpleasant smelling), and liquid effluent containing salts and heavy metals. This waste water may be disposed of by re-injection or desalination.

The use of renewable energy sources like solar photovoltaic systems, wind power, and ocean energy are expected to increase, but on a world scale their contributions are still negligible, about one per cent of total.

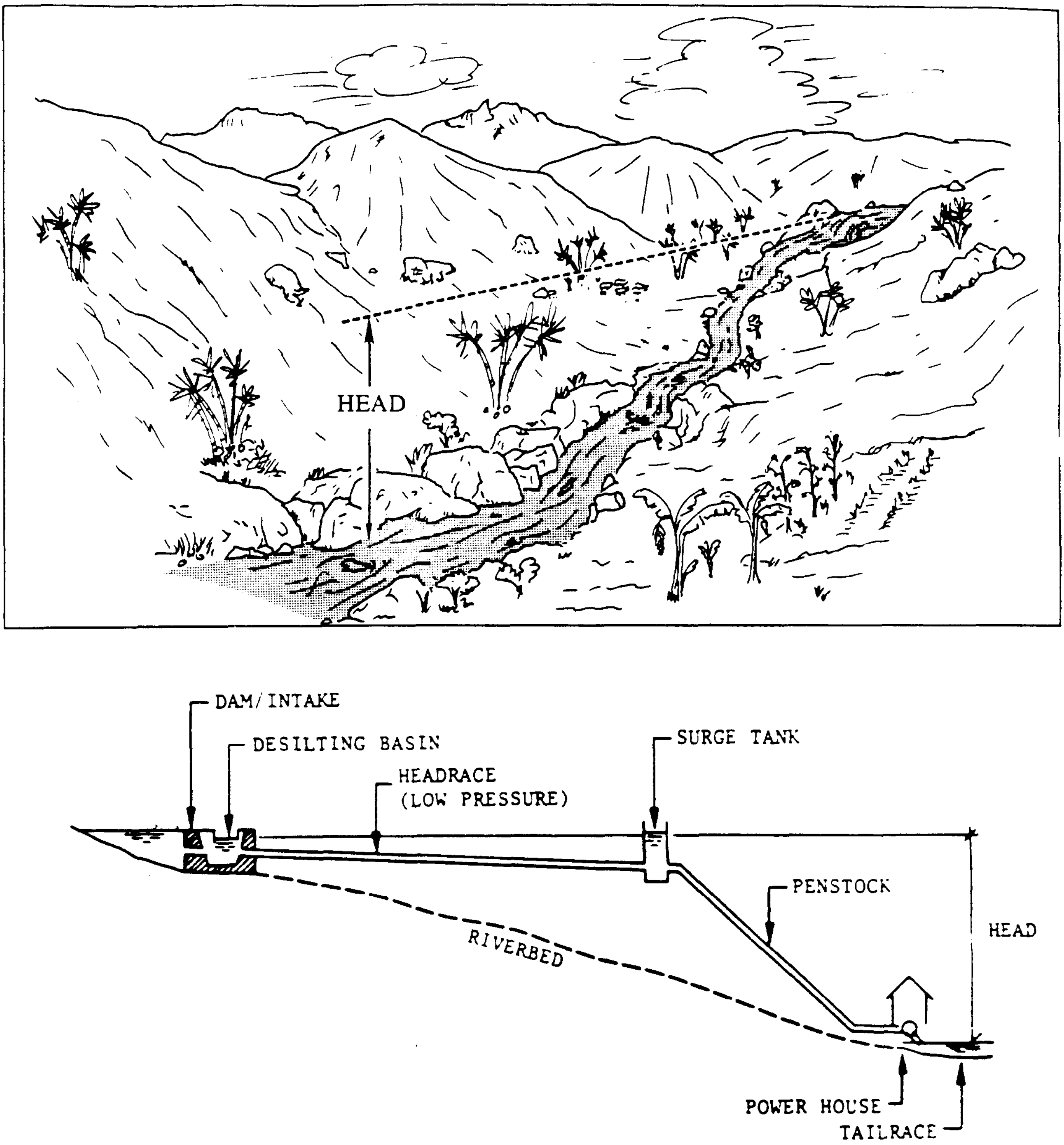


Fig. 7.1 Development of hydropower [31,32].

The main environmental advantage connected to hydropower plants is that they generate a "clean" renewable energy with no polluted wastewater, and create no atmospheric pollution. These unique environmental characteristics have come much into focus in view of recent concerns over threats of climate change (Section 3.7) caused by burning fossil fuels. It has been estimated that if all hydropower plants in the world were replaced by fossilfuelled plants, the total amount of carbon dioxide due to human activities would increase by 10%.

Since many hydropower projects involve construction of small or large dams, multipurpose schemes are common. Hydropower production can then be readily combined with other uses of water for irrigation and flood control, and also be integrated into schemes for water supply and even canal operation, see Fig. 7.2.

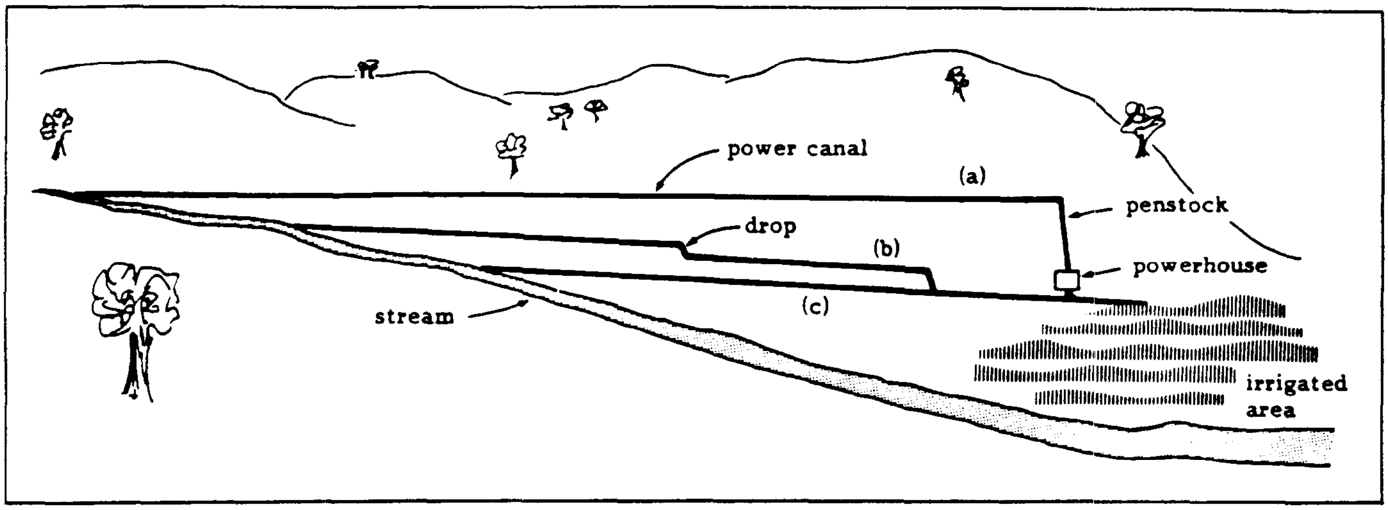


Fig. 7.2 By proper design, the same power canal (a) can provide water for both power and irrigation, replacing irrigation canals (b) and (c) which are not designed to minimize head losses [31].

As Table 7.1 shows, the exploitation of hydropower has been greatest in Europe (62.8%) and in North America (72.9%), and least in Africa (4.1%) and the previous USSR (7%). Both Asia (10.9%) and South America (11.4%) still have large potential available, and it is likely that exploitation of their hydropower resources will be substantial in the years to come.

It has been estimated that the developing countries have about 60% of the world's exploitable hydropower capacity.

However, the figures given on exploitable hydropower potential may not be fully realistic. There are also substantial environmental disadvantages associated with hydropower schemes, especially the larger projects and the creation of large man-made lakes. The most important impacts associated with hydropower development may be listed as follows:

* Change of small- and largescale ecosystems

* Impoundments, loss of land

* Spread of water-related diseases
* Regulation of riverflows and reservoirs
* Change in water quality and sediment regime
* Flood risks and dam safety
* Changed conditions for fisheries, agriculture, transport and other economic activities
* Involuntary resettlement of people
* Loss of recreational activities
* Seismicity effects
* Indirect impacts

The impact of impoundment and loss of land, also farming land, have been highly disruptive in many projects, as well as eutrophication in rivers and reservoirs. The spread of water-related diseases has in some areas been clearly linked to the establishment of reservoirs. The most difficult problems of all has been the resettlement of local populations from inundated areas. The changed river flow and water level are connected to numerous downstream problems created by sedimentation, erosion, salinity etc., and may have extensive impact on fisheries and agriculture.

Most of the environmental impacts as well as mitigation measures will be further discussed in the following Sections. However, it is clear that the further development of the earth's hydropower must be based on a careful balancing of the benefits against the negative impacts.

7.2 Characteristics of Hydropower Projects

Hydropower projects vary in size and complexity from micro-hydropower installations of a few kilowatts through small and medium-scaled to gigantic large-hydropower schemes with some thousands of megawatts in installed capacity. It is evident that the environmental impacts of the projects will vary accordingly. However, neglecting the micro-sized installations making use of only a fraction of available water, the environmental impacts of small hydropower tend largely to be of the same type as those caused by large hydropower, though of a smaller geographic scale.

A run-of-river plant is a low-head installation consisting of a low dam in the river course itself and a plant located immediately downstream the dam. The immediate environmental impacts are caused by the dam blocking the river course, and the decrease in water flow between the dam and the plant.

The creation of large reservoirs in the river valley, with very high dams, is technically a further development of the run-of-river plant. Now a stored volume of water is available to regulate the natural flow.

In high-head plants the water is often collected from several high-lying catchments, before led to the plant through tunnels. The water is often led away from its natural course causing dry river beds. The establishment of medium and large reservoirs is normally part of this type of water regulation, see Fig. 7.3.

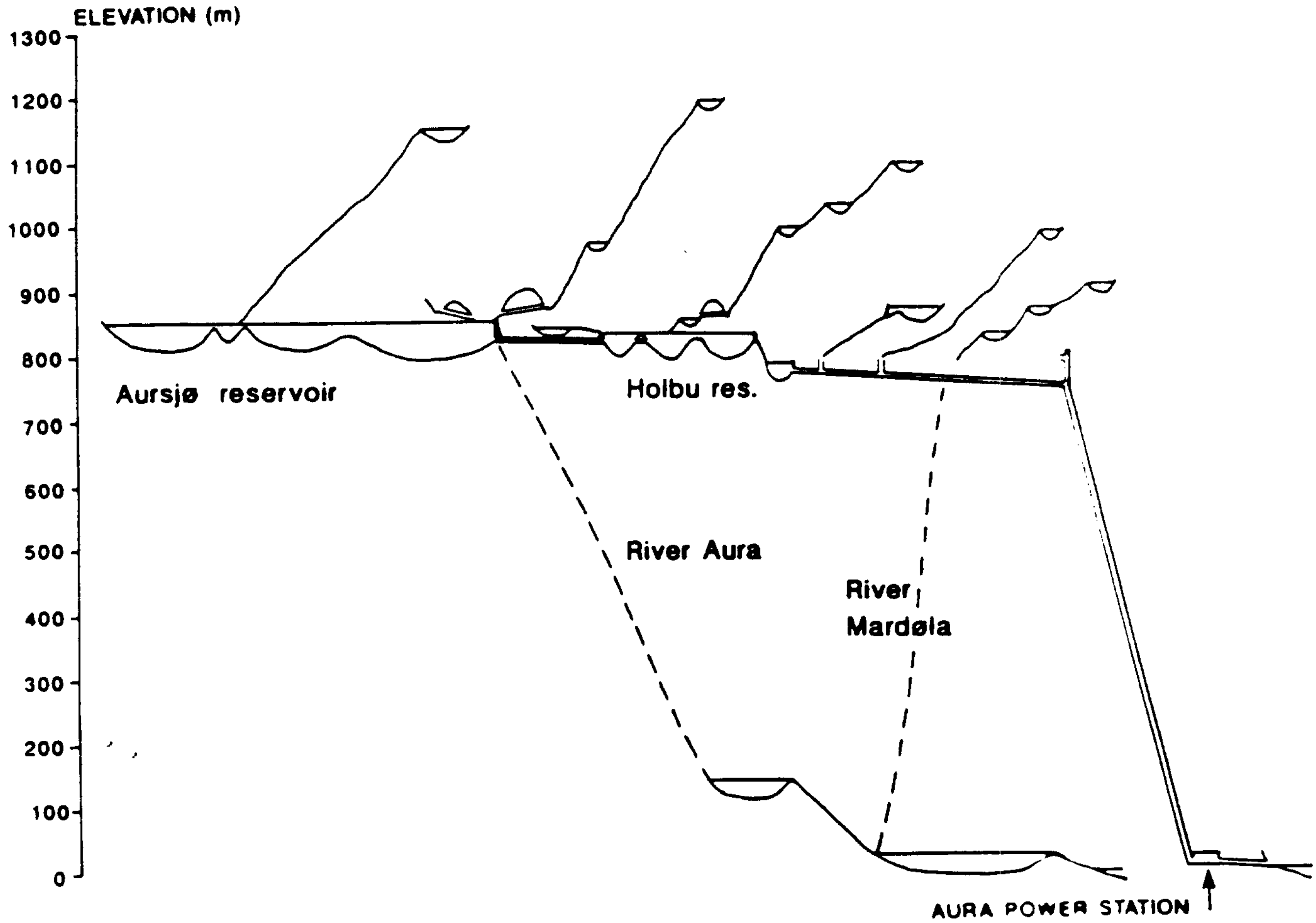


Fig. 7.3 Example of a high-head hydropower scheme (Norway). Dotted lines represent river courses with reduced river flow [33].

As part of large hydropower schemes, so-called roofgutter systems are sometimes developed when tunnels are blasted along valley sides, collecting the water from intersected streams on the stretch, as illustrated in Fig. 7.3.

Some people favour, for environmental reasons, the development of several small low-head hydropower projects instead of a limited number of large high-head projects. This is disputable, since a series of small projects in a river often may be more disruptive to the environment than a single larger project. On a country-wide scale, if hydropower countries like Norway and Canada had chosen to develop the rivers with a series of low-head plants, vast stretches of natural river channels would have been eliminated and the power production much less.

A useful area classification for environmental evaluation is illustrated by Fig. 7.4.

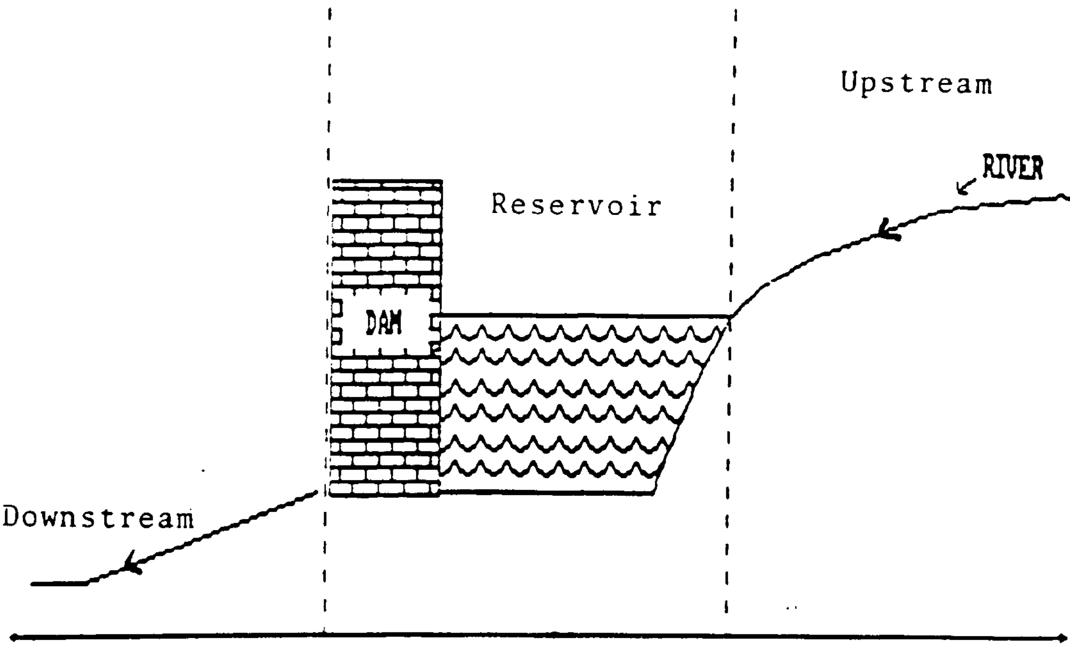


Fig. 7.4 Useful area classification for environmental evaluations.

7.3 Dams

Remains of small dams dating back to the beginning of recorded history are found in China, Cambodia, India, Sri Lanka, and in the Nile. From the midst of the 19'th century, irrigation schemes often included low diversion dams in rivers to feed the irrigation canals at all stages of river flow. The so-called barrages in the Indus are well-known, none of them higher than 15 meters.

The first dam with storage for more advanced regulation of the river flow is said to be the Periyar Dam in India, built in 1895. 95 years later, in 1990, there are in the world a total of almost 35 000 dams higher than 15 meters. Of these, 27 800 are between 15 and 30 meters (more than 50% are in China), 276 are higher than 100 meters. Dams of more than 300 meters are under construction in the early 1990s, the highest reported to be 335 m.

Most of the smaller dams are connected to water supply and irrigation, while the large dams may be of multipurpose use, or for hydropower alone. It has been estimated that 61 large dams in the developing countries account for 60% of the electricity production in these countries.

In all reservoirs there will be seasonal changes of the water level depending on the varying demand. The exposed drawdown strip may in some areas be used for seasonal agriculture, but may also cause health, aesthetic, and access problems.

In parts of the the temperate regions, the effect of previous glacial erosion has been the carving out of numerous natural lakes of varying size, as in Norway and Canada. Such lakes often form ideal bases for establishing storage reservoirs, and limit the environmental impacts of a dam. In tropical regions, large dams are often established in river valleys causing the flooding of large areas and often a series of serious environmental impacts.

7.4 Water Flow

Most major hydropower schemes will include the creation of reservoirs to regulate the water flow. Water is retained in the reservoirs when the electricity demand is low, and released when the demand increases, on a daily, seasonal, and even yearly basis. It is evident that the terrestrial components of the hydrological cycle will be changed, causing considerable environmental impacts: The natural variation of flow is changed, large water reservoirs cause increased evaporation and possibly weed growth, the groundwater reservoirs will be affected, the conditions for erosion and sedimentation processes are altered, and the water quality is changed. The environmental changes may be traced far downstream, at times even out into the sea.

In some hydropower schemes, parts of a river may completely lose its water. Some people regard dried out riverbeds as one of the most negative aesthetical aspects of hydropower development. Most important, also, are the potential conflicts with downstream users. This can in many cases be countered by releasing a minimum flow which also may vary according to varying seasonal demands.

Another measure, if the river course is suitable, is to construct a series of low weirs to create new water surfaces, [34]. They are dams without regulatory installations where the water flows along the whole or a large part of the dam's length. The weir ponds have often favourable aesthetical effect. They also counteract erosion and have positive effects on the flora and fauna.

Conflicts may occur, for example between local farmers. One farmer may want the weir to increase the groundwater level in the adjacent drought-exposed area, while another farmer may benefit from a low water level which offers possibilities to cultivate adjacent low-lying boggy land [34].

In some tropical regions, however, the creation of such ponds may contribute to the spread of water-related diseases (Section 4.3), and should therefore be avoided.

In cold regions, the ice-cover on reservoirs and rivers in the winter season may be affected by the often warmer regulated flow. Where stable ice-covers developed under natural conditions, open water may be common after regulation, causing changes in the local climate and sometimes creating frost mist.

A common effect of hydropower schemes, and often the main reason for the creation of reservoirs, is a reduction of the natural floods. In most cases this is of great advantage for the downstream area. However, in some cases, if the natural floods are nearly eliminated, the rivers ability to "clean up" the river course and carry away nutrients and polluting substances is reduced. Reduced floods may also have negative effect on the migration of fish, and in some countries traditional timber-floating may be disrupted.

7.5 Transport of Nutrients

When a river is regulated, the natural transport and annual fluctuations of nutrients and sediments are distorted. A reservoir will serve as a trap, reducing the downstream transport. This may seriously effect the biological production all the way to the sea. There are examples of even marine fishing having been negatively effected by the establishment of large dams.

Many productive delta areas are dependent on a regular annual supply of muds brought with the flood water. Trapping the mud in a reservoir may have serious impacts on the natural flora and fauna, and agriculture. The Nile Delta and the establishment of the Aswan Dam provide the most famous example (Section 7.16). Another effect of reduced supply of mud may be a gradual land subsidence, and increasing problems connected to saline intrusion and marine erosion.

When river water is affected by reduced sediment content, its erosional power increases and may cause additional downstream problems. The previous sedimentation in a delta is now replaced by the process of erosion.

Eutrophication, or excessive fertilization, may effect stagnant water, natural lakes, and all kind of reservoirs. When nutrients are trapped in the reservoir, this may lead to increased growth of algae or higher-order aquatic plants (water weeds). Problems connected to eutrophication and aquatic plants in reservoirs will be further discussed in Section 7.9.

7.6 Groundwater

A river system regulated for hydropower development will affect the groundwater in various ways, and may be regarded as positive by some users, and negative by others. Along river stretches, the adjacent groundwater level increase or decrease, depending on the regulated water level in the river as compared with previous natural conditions.

The establishment of a reservoir and the water level fluctuations caused by its operation will change the groundwater level in surrounding areas. This may have negative impacts on forestry and agricultural activities causing waterlogging and in dry climates also salinization (Section 5.4). However, positive impacts are also reported, where the increased groundwater level favours agriculture.

7.7 Biodiversity

Both submerging and changes in the natural waterflow may affect vegetation and wildlife. The effects will be most pronounced in large-scale projects, in particular projects including huge dams.

Animals may have the possibility to move to nearby areas, if they exist, but opportunities for hunting and tourism may be reduced. Large reservoirs may also create barriers for the regular annual migration of some species. Also roads, power lines and other constructions connected to hydropower project may affect wildlife habits.

The local climatic changes in the vicinity of a large dam, and the changed groundwater level, may also affect the biodiversity. In extreme cases, valuable types and species may be lost.

7.8 Fish

The establishment of a dam obviously blocks the migration of fish. In some cases, passage facilities, like fish ladders, may be effective, but they will never replace natural conditions. Propagation of fish in the reservoir can mitigate losses and sometimes produce more fish protein than before the project.

When a reservoir is filled, there is likely to be a considerable rise in the population of the fish species which are favoured by the new lacustrine conditions. This is due to the increased amounts of nutrients from the flooded area. When this nutrient reserve has been consumed, the stock of fish usually decline. The initial highly productive, but unstable phase, may in cold climates last 25-30 years, but under warm climatic conditions it may last only 6-10 years [29]. In Lake Volta, Ghana, the fish catches have been reduced from 60 000 tons five years after the construction of the dam, to the present 4000 tons when the lake ecosystem has been stabilized.

In tropical waters, if the reservoir does not have the oxygen renewal capacity (Section 7.9) to accommodate the amount of organic matter from the inundated areas, oxygen depletion can result in the death of fish and other aquatic organisms.

However, substantial new fisheries have been established in a number of reservoirs. An example is the Saguling reservoir in Indonesia where the new fishery helped resettled people to restore or even surpass their previous income levels. Similar results have been observed in Thailand (Nan Pong) and India (Gujarat) [35].

The dam operation may also affect the composition of species in the reservoir, for example by lowering the water level during the spawning period. Also the change in river flow and reduced supply of nutrients downstream, and to estuaries, can considerably impair both spawning conditions and fishery productivity. The tide-affected estuaries are particularly sensitive to changes in flooding conditions.

At some dam and turbine outlets, high pressure causes air to dissolve in the water making it supersaturated. This may kill fish in nearby water, and in particular in connection with fish farming.

7.9 Reservoir Water Quality

The water quality within the reservoir depends on the quality of the incoming water, pollution from agricultural, industrial and human wastes, and the water retention time in the reservoir. The most serious effects are increase of salinity, especially in areas of high evaporation, and eutrophication from aquatic weeds and biomass decay.

The water quality is also dependent on the stability of the thermal stratification. There are major differences between reservoirs in temperate and tropical regions, and also between shallow and deep reservoirs. In temperate regions, the great seasonal differences in water temperature promote a complete vertical circulation twice a year, but the stratification may be very stable within a season.

In tropical regions, at least in deep lakes, the only moderate temperature differences with depth create stable stratification the whole year. The thermocline separating the deep anaerobic (lack of oxygen) water from the upper productive layer, is generally at a great depth, say about 50-100 meters. The deep water is permanently anaerobic due to the lack of vertical water circulation. The stability of the upper layer with only moderate currents makes it an extremely productive ecosystem. However, increased contribution of nutrients, like phosphorus and nitrogen may rapidly result in serious eutrophication.

The removal of trees, shrubs and other vegetation from areas to be dammed by the reservoir is important to reduce the risk of eutrophication. However, it is impossible to remove all the biomass and this has caused serious eutrophication problems in many tropical reservoirs. In too many cases, the clearing of land prior to damming is also neglected.

Partly submerged trees and shrubs may also be an aesthetical nuisance, and may restrict the movement of boats.

In tropical regions, the growth of aquatic plants (weeds), see Fig. 7.5, on reservoir surfaces may often be considered a result of eutrophication. Plants, like the water hyacinth, may form thick densely interwoven mats, covering large water areas. They may also occur in slow flowing rivers and canals. Well-known examples are the explosive growth of aquatic plants during the first years of the man-made Lake Kariba and Lake Volta in Africa, most probably due to a high level of nutrients in the water originating from decaying organic material submerged in the water. Three years after Lake Kariba came into existence, 1000 km^2 of the surface area was covered by weeds.

The presence of aquatic plants may frequently cause problems for fishing, navigation, and also block spillways and water-intakes. The evapotranspiration from the plants is several times the magnitude of free-water conditions, thus reducing the reservoir storage. The main water supply reservoir for Harare, Zimbabwe, is loosing large quantities of valuable water in this way.

The aquatic weed is difficult to control. Spraying with chemicals often has little effect and also pollutes the water and poisons the fish. In some areas, a limited volume is used as fodder for livestock. The only effective method today is mechanical control, involving cutting, uprooting by hand or machinery - a hopeless method for clearing larger areas.

Intensive research, however, is now in progress to find an organism which is an enemy of the weed. After multiplying, the hostile organisms are spread on the weed. Some successful experiments are reported, but the method is still new and largely untested.

It has been claimed that hydropower may add to global warming effect when reservoirs are cleared in forested areas, or when decaying biomass accelerates eutrophication on inundated land. However, this is most unlikely to be very significant, except perhaps for large water bodies in tropical forests [36].

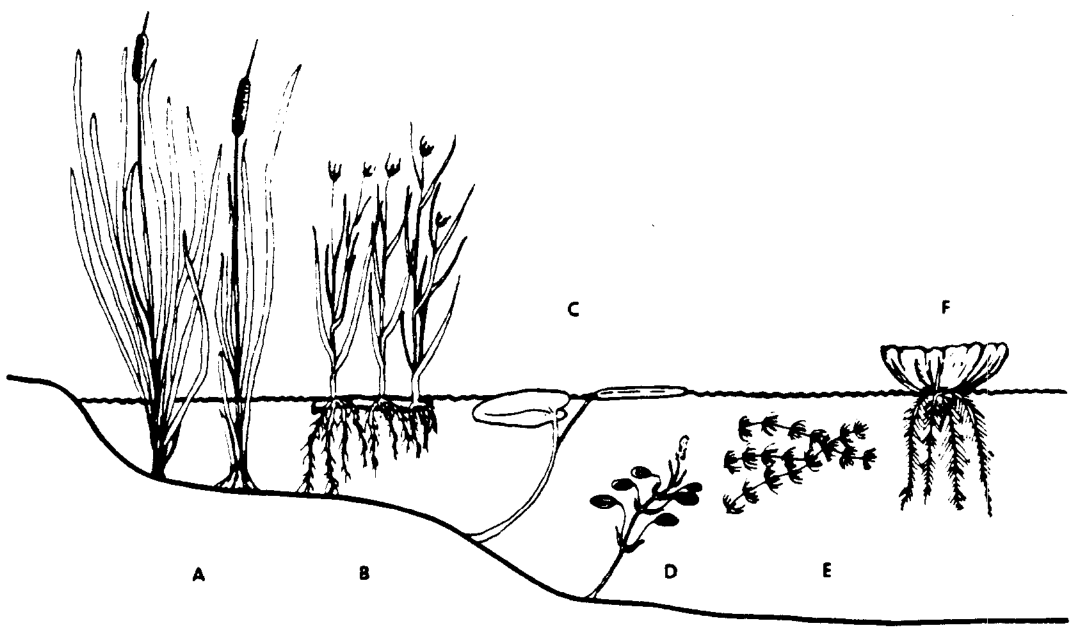


Fig. 7.5 Some life-forms of aquatic plants. A Rooted emergents, B. Partially rooted or free floating emergents, C. Rooted plants with floating leaves, D. Rooted plants with submerged leaves, E. Free-floating submerged plants, F. Free-floating emergent plants, like water cabbage and water hyacinth [37].

7.10 Reservoir Sedimentation

All man-made water reservoirs have a limited life-time, i.e., at a certain future date they will be filled up with sediments. In temperate areas, the process is usually slow and of limited importance, but exceptions are found in areas with high erosional activities, like downstream glaciers.

In the tropics, however, rivers often carry huge amounts of sediments, particularly in periods with flood and heavy rainfall, which are trapped and deposited in the reservoirs. The process is very intense in geologically young areas, like the Himalayas. The upstream activities of man may also considerably increase erosion and land degradation, and subsequently increase the sediment transport in the rivers. Common reasons are increased population settlements, deforestation, overgrazing, and increased agricultural or mining activities. Soil conservation and reforestation measures may therefore reduce the problem.

The sediment transport in rivers is extremely difficult to measure or estimate, but it is a fact that the sedimentation rates in many reservoirs have been greatly underestimated in calculating the life-time of the reservoir, see Table 7.2. In most cases a dead storage is built into the reservoir to act as a sediment trap.

RESERVOIR	EXPECTED	OBSERVED	% UNDER-ESTIMATION
Bhakra	23 000	33 475	45,5%
Maithon	684	5 980	874%
Panchet	1 982	9 533	481%
Ranganza	1 089	4 366	401%
Tungabhadra	9 796	41 058	419%
Mavurakshi	538	2 000	372%
Ukai	7 448	21 758	292%
Nizimsagar	530	8 725	165%

Table 7.2 Underestimation of sedimentation rates in India (unit: acrefeet) [38].

Several dams in the tropics have already been filled up. The life-time of the Tekri dam in India may be reduced from the planned 100 years to 40 years. Poor soil conservation and lack of afforestation in the upstream catchment area have been identified as the most important factors [38]. As seen from Table 7.2, other reservoirs in India suffer from the same problem. However, for the Tarbela Dam in Indus, Pakistan, it was calculated that the Dam would loose 90% of its capacity in 50 years. More recent observations show that this period may be extended to 150 years or more, but the estimates are still very uncertain.

When a dam is filled up with sediments it creates a difficult environmental problem. The surface will normally be difficult to cultivate and we may end up with a "vast muddy wasteland" [25]. And if we want to build a new dam, the best sites have already been exploited. This raises very basic questions concerning future development.

7.11 Climate

The creation of very large dams may modify the local climate in terms of minor changes of humidity and distribution of local fog. Little is known about changes of rainfall patterns, such as possible increase of afternoon showers.

The greater heat-absorbent capacity of water compared to land means smaller and slower variations of temperature both in the water itself and in the air around, than in the nearby areas. On account of the differences in temperature between the water and the surrounding areas, wind may arise [39].

Since the temperature of water released from a reservoir may be higher or lower than ambient river temperature, this may cause minor local climate effects, like the creation of frost mist in cold climates.

7.12 Seismicity

Reservoir induced earthquakes have been observed at a considerable number of dams. They are usually associated with large dams but also with lower heads of 40-60 meters. The oldest observations of reservoir induced earthquakes are from the Quedd Fodda Dam in Algeria in 1932, magnitude 3.0 on the Richter scale, and the Marthon Dam in Greece in 1929, magnitude 5.7 [27]. In the late 1930s, Hoover Dam's reservoir, Lake Mead, in USA induced an earthquake of magnitude 5.0. Other well-known examples are connected to Hsinfengkian Dam in China in 1962, magnitude 6.0, Kariba in Zambia/Zimbabwe in 1963, magnitude 6.1, and Kremasta in Greece in 1966, magnitude 6.3. Earthquakes of magnitudes less than 4.0 do not normally cause damage to houses or other constructions.

The actual process triggering off earthquakes is not well known, but is connected to the weight of the reservoir on the earth's crust, and the establishment of a new balance. Most induced earthquakes occur during the first years after filling the reservoir, and then the frequency will be reduced. Apart from the big shocks reported, a great number of smaller shocks often take place. In Kariba, 61 shocks were recorded during the first 7 months of 1963. Some geologists argue that the magnitudes of induced earthquakes will not be higher than what would be eventually observed, regardless of the dam, but later in time.

In most cases, the induced earthquakes cause limited or no damage to the dam and other structures, and improved knowledge of dam engineering decreases future risks. However, examples of the opposite are found. In India, an earthquake of magnitude 6.3 induced by Konya Dam's reservoir in 1962 destroyed the gravity dam, claimed 200 lives and injured 1500 others, destroyed a large number of buildings, and caused damage in populated areas as much as 230 km from the centre of the quake.

Earthquakes may also be induced by other man-made changes of the earth's crust. In Denver, Colorado, USA, a series of earthquakes were registered in the early 1960s, with magnitudes up to 5.2. They were considered triggered by deep injection of waste fluid.

7.13 Dam Breach

Luckily, dam breaches are seldom. Modern engineering and experience should normally guarantee the safety of the new large dams where a breach will have enormous consequences for downstream areas.

However, historically one per cent of all dams constructed have failed. Examples are Malpasset Dam in France, Machu II Dam (2-4000 human lives lost) and Koyno Dam (see Section 7.12) in India, Canyon Lake Dam, Toccoa Falls, Lower San Fernando Dam and Teton Dams, all in the United States.

One of the most damaging reservoirs ever occurred in 1963 at Vaiont Dam in Italy, when 2 600 human lives were lost. The reason was a great rockslide which fell into the reservoir, creating huge waves overtopping the dam. It is a credit to engineering, however, that the dam itself sustained no major damage.

The most common causes for dam failures are listed in Table 7.3, with overtopping, leakage and erosion topping the list.

Cause of failure	Per cent
1. Overtopping	26
2. Embankment leakage	22
3. Flow erosion	17
4. Foundation leakage	17
5. Sliding	6
6. Deformation	6
7. All other	6
TOTAL	100

Table 7.3 Causes of failure of dams [40].

To avoid dam breaches, proper monitoring and maintenance are important. Many dams in the world are more than 50 years old and suffer difficulties caused by lack of maintenance. New knowledge of hydrological conditions may reveal that the spillway capacity is not sufficient, and the spillway should be redesigned. In other cases, dams were not designed to resist earthquakes.

It is always a difficult problem to settle the balance between economics and safety. The new damsites now considered are often not of first quality and dams will be built on foundations which would not have been selected a few years ago. This poses increased challenges on the engineers.

The establishment of dam safety programs are of vital importance in all countries. The main objective is always to secure public safety.

7.14 Health

The connection between environmental health and water was discussed in Section 4.3. The creation of dams and associated canals and spillways can cause establishment and spread of malaria, schistosomiasis, and onchocerciasis. Concerning schistosomiasis, large annual drawdowns in reservoirs may reduce this disease, as reported from Cahora Bassa, Mozambique.

Onchocerciasis, or river blindness, is widespread in West and Central Africa, in Mexico, and parts of Central America. In some areas of Africa, over 30% of the population are reported blind [25].

River blindness is caused by a parasitic worm carried by a vector, the black fly. The black fly tends to breed in fast flowing rivers. The creation of a dam should therefore, in principle reduce the breeding of the fly, which is also often the case. At Owen Falls Dam, on the Nile in Uganda, dam construction has radically reduced transmission by inundating the breeding sites of the black fly. It is alarming, however, that control afterwards was maintained by DDT released from a dosing device incorporated into the dam [37].

However, fast flowing water in spillways and canals has also proved to provide excellent new breeding grounds, for example in Ghana, and caused a spread of the disease. Mitigation measures can be to construct automatic siphonic spillways and submerged pass pipes.

7.15 Involuntary Resettlement

Several large-scale activities like establishment of new industries and mining, construction of roads and airports, etc., may involve involuntary resettlement of people, ranging from a few families to thousands of people. However, with the creation of dams, and large dams in particular, involuntary resettlement has become a very sensitive and disputed issue. In China, for example, establishment of new large dams will almost always cause displacement of people.

Since many large dams are situated in remote areas inhabited by indigenous groups, serious socio-cultural problems have occurred, and grave injustice has been forced on these people. A further discussion on this issue is considered beyond the scope of this report. It should be mentioned, however, that the World Bank has issued a well recognized Operational Directive providing guidelines for involuntary resettlement and how to deal with the often serious economic social, and environmental problems. A main principle is that the people displaced by a project should as a minimum requirement, be fully compensated for their losses.

The displaced people may move upstream in the catchment and start new activities. New cultivation, clearance of vegetation, and logging, may create additional erosion and increase the sediment transport into the reservoir.

7.16 Aswan Dam Completed
Three Gorges Planned

The establishment of huge man-made lakes in many parts of the world is highly disputed and has had very serious environmental and socio-cultural consequences, often to the surprise of the early planners. In fact, building such dams may be called a global ecological experiment where the consequences and their dimensions can never be fully understood in advance. The major reasons for building such large dams are most often a combination of hydropower, flood control, and irrigation.

To some people, all large dams are bad. To others, the benefits of the dam outweigh the negative social and environmental effects, and most probably more large dams will be built. Based on the comprehensive experience available, we are now better prepared to analyze the consequences, and identify proper mitigative measures to be taken.

In the following, the impacts of one completed large dam, the Aswan Dam of Egypt/Sudan will be briefly discussed, as well as the estimated effects of the planned giant Three Gorges Project in China.

The Aswan Dam, Egypt/Sudan

The Aswan High Dam, the second dam built near the first cataract of the Nile, was completed in 1967. It created a reservoir with a surface area of 6 200 km^2, and a storage capacity of 162 cubic kilometres. It is called Lake Nasser in Egypt, and Lake Nubia in Sudan. The dam has completely changed the hydrological balance of the lower Nile, eliminating the annual floods, and considerably increasing the rate of evaporation.

The filling of the reservoir displaced some 60 000 people in Egypt and 53 000 in Sudan. Some archaeological sites were destroyed.

The purpose of the dam was to:

1. Provide water for enlarged downstream irrigation. Egypt is an arid country totally dependent on the Nile water for irrigation.

2. Provide flood control.

3. Provide increased hydropower generation.

These major goals have been achieved in the period the dam has been in operation. It can therefore be claimed that the decisionmaker's expectations have been met, but at what environmental costs? In the following the various environmental and social/economic effects created by the reservoir, and in the downstream area are summarized:

1. Reservoir effects

   * Sedimentation. The reservoir traps about 85 million m^3 on average every year. At the present rate, it will take 350 years to fill the equivalent of the dead storage in the reservoir.

   * Fishing in the reservoir has become a major activity, engaging some 7 000 fishermen.

   * Navigation has developed on the reservoirs.

   * Spread of aquatic weeds

2. Downstream effects

   * Agricultural production increased due to improved availability of water for perennial irrigation.

   * Agricultural deterioration of land increased due to lack of annual floods submerging the fields leaving valuable silt (acting as nitrogen fertilizer), and washing out salts and remnants from chemical fertilizers and insecticides. Perennial irrigation and poor drainage have added to increased salinization and waterlogging.

   * Water quality changed completely. The turbidity dropped with the reduction of silt load. The amount of dissolved solids increased by about 30%.

   * Channel degradation increased due to increased erosion of the silt-free water.

   * Aquatic weeds have spread dramatically in irrigation canals and in the Nile itself causing a variety of problems. It also increased water losses due to the increased evapotranspiration.

   * Fisheries in both the Nile and in the eastern Mediterranean have declined. The number of species has also declined.

   * Navigation on the Nile has benefited from the more stable river flow.

   * Retreat of the delta coastline is reported, due to the change in river flow.

   * Water-related diseases like malaria and schistosomiasis have had improved conditions for further spreading. It is reported that schistosomiasis has spread somewhat in the delta and also spread to parts of Upper Egypt.

   * The foundations of some buildings, including temples in the Luxor area, may have been weakened by increased groundwater level. The groundwater is also reported to contain more salts than before.

The Three Gorges Dam, China

The planning of The Three Gorges Dam on the Yangtze River has attracted considerable international attention. If built, it will be the world's largest dam, creating a 500 km long lake and flooding the world famous Three Gorges. The purpose of the dam is to produce hydropower (some 20 000 MW installed capacity), to provide flood control, and to improve conditions for navigation. In 1954, floods caused the death of more than 30 000 people. Irrigation is not included in the project.

The long, narrow reservoir with a medium depth of less than 100 meters, will have a storage of only about 48 cubic kilometres, less than a third of Lake Nasser.

The economic, social and environmental costs connected to the building of such a dam are enormous. The most important are summarized in the following:

* Involuntary resettlement of between 700 000 and 1 120 000 people is required, about 60% urban population.

* Improved flood protection will be provided to millions of people living on the downstream flatlands.

* Navigation will be improved.

* The famous scenic beauty of The Three Gorges will disappear.

* A number of unique endangered species will probably disappear.

* Malaria may increase.

* Total fish catch is expected to increase, but a considerable change in fish species will take place.

* Sediments will be trapped in the reservoir, but in this kind of a reservoir, a large part of the sediment inflow may pass on downstream.

SHOULD THE THREE GORGES DAM BE BUILT?

8 INLAND FISHERIES

It is estimated that inland freshwater fisheries and fish farming grew by a factor of six, from 2.2 to 13.4 million tons, from 1950 to 1988. It is now about 14% of total global fish catch in the world [13].

Freshwater fishing is much more common in tropical than in temperate areas. Of the world's total catch, Asia accounts for about 67% followed by Africa with 15%. The fisheries contribute significantly to the protein resources of the world, and it all goes directly to human consumption. The greatest potential for increased production is considered to be within the artisan sector, often closely linked to peasant farming.

Inland fisheries will only in rare cases cause pollution of lakes and rivers. Some pollution may occur from discharge of oil from boats and the dumping of fish or offal into the water, but this will normally only cause local impact on the water. In aquaculture, however, the pollution of local waters can be serious.

The main threat to the inland fisheries is the pollution and eutrophication of the water, caused by effluents from industries (including the fish-processing industry itself), agriculture, and other wastes from man's activities. Also acid rain may infect the water draining to lakes and rivers and be hazardous to many species. Water abstraction for irrigation and regulation for hydropower has modified the natural variation of water flow and destabilized the conditions for fish, and sometimes also destroy the breeding grounds. The hydrological variations are also disturbed by land degradation caused by agriculture, deforestation and overgrazing, both in terms of flood quantity and quality. Lastly, over-exploitation is a too common reason for decrease in fish catch.

In both lakes and rivers, commercial fishing may easily cause conflicts with local people depending on fish as an important part of their basic food.

It is a common experience that inland fisheries are often weak in competing with other water users, and often neglected when river basin development plans are made.

8.1 Lakes and Reservoirs

Large natural lakes in tropical regions are often highly productive and have a generally higher species diversity than in colder regions (see also Section 7.8). Lake Tanganyika has a reputation of having one of the most efficient trophic known for any lake. The fish species in such lakes are often highly specialized and vulnerable to changes. The stocks of different fishes in an ecosystem mutually affect each other in a complex way, and overexploitation of one species can lead to the increase of another. Strict regulation concerning quotas, fishing periods, and areas may have to be introduced.

It may sometimes be desirable to introduce new commercially valuable species in a lake. This playing with the lake ecosystem can be successful, but is also dangerous. The new species can outcompete existing species and thereby destroying existing fisheries. There is also a risk of introducing new diseases to the existing stocks.

The special situation of large man-made lakes is discussed in Section 7.8. Generally, the increased production of nutrients in the first years after a reservoir is built results in increased catch of fish, then decreases until a new balance is created. The large draw-downs of the water level in some reservoirs may have a negative impact on fisheries, and may also affect breeding grounds. Many examples exist of failures in introducing new species in reservoirs, especially from Africa.

8.2 Rivers

River fisheries are normally of less magnitude than in the lakes, and are often seasonal and dependent on the water level. Fishes in rivers are still more vulnerable to pollution and river regulation than in lakes, and many rivers in the industrial part of the world are practically "dead".

The construction of a dam across the river course completely blocking the passage for migrating fishes, and reducing or drying up the river bed, is of course a disaster for downstream fishing (see Section 7.4).

8.3 Aquaculture

Aquaculture is controlled breeding of fish in small bodies of water. It is widespread in tropical regions, especially in Asia, but it is a growing activity also in colder regions.

The use of small ponds is the most common, as well as rice paddies and irrigation canals. The integration of aquaculture in irrigation is of particular interest, especially in the far East, but of increasing interest in Africa where many village-level schemes are based on small dams. Pollution from agriculture is a problem in many of these ponds and canals. In some areas wastewater is used to add nutrients to fish (see also Section 5.6). In other areas, excreta are used. The health effect on people eating the fish is disputed.

Excessive use of fertilizers may quickly cause eutrophication of small ponds and canals. Another serious source of water pollution is the increased use of medicines connected to aquaculture. The artificial ecosystem created in a pond may easily be disturbed, and one effect may be the outbreak of diseases in the fish stock. The use of medicines may also have harmful effects on the nearby environment.

9 INLAND NAVIGATION

Lakes, rivers and canals provide important means of transporting goods and people, both locally and over long distances. Examples of rivers carrying large volumes of traffic are the Nile, the Ganges, the Mekong, the Yangtze, the Mississippi, and the Rhine.

Inland navigation is a non-consumptive use of water. It requires adequate flow conditions in the rivers, such as limited water velocities and a certain minimum depth. In some rivers, floods, low-water, or ice, may restrict operations part of the year. The construction of locks and canals may reduce the water required by other users, as compared to a natural stream. Navigation may be obstructed by dams built for other purposes, like irrigation and hydropower. On the other hand, large reservoirs provide new navigation opportunities.

Transport on inland waterways also represents a considerable source of water pollution. This is caused by the boat traffic itself, but more the risk of accidents and the release of hazardous substances from the transported goods.

10 WATER IN RECREATION

Unspoiled rivers and lakes are of invaluable importance for recreation and tourism. Recreational activities connected to nearby water, like swimming, rowing, sailing, and fishing, are essential to many people. The scenic views of waterfalls, like the Victoria Falls in Africa, the Niagara Falls in North America, and the Angel Falls in South America, are spectacular and constitute natural resources of unique value.

Building of dams, the drying out of rivers and waterfalls caused by other water uses, have often had negative consequences on tourism. The most serious threat, however, may be the increased pollution in many rivers, which is a result of untreated wastes from agriculture, industry or other of man's activities. The water quality may be so bad that it is a health risk to take a swim.

However, in many areas tourism itself undeniably contributes to pollution of inland waters in various ways. One example is dropping rubbish in the water. Much more serious is the often untreated wastewater from tourist resort centres. Such pollution is primarily caused by inadequate investments in infrastructure or lack of control over effluents.

11 CONTAMINATED RIVERS AND LAKES - CAN THEY BE CLEANED?

As has been noted in the previous sections, a large number of rivers and lakes in the world are polluted to such a degree that the ecological balance has been completely changed and the water is unfit for most human use. Is it possible to reverse the trend and return the quality of the water to acceptable standard? In some cases, like the Aral Sea (Section 5.3), the situation seems hopeless. The ecological degradation process may have reached a "point of no return" such that it cannot be reversed.

However, encouraging examples are also found, especially in catchments of limited size and where the problems more easily manageable. The measures often combine preventive legislation, and proper treatment of wastewater. In the big rivers and lakes, a return to complete natural conditions may not be possible, nor adviseable. But great improvements can be achieved, as illustrated by the experiences from the Great Lake Basin in USA/Canada and the River Rhine in Europe, to be further referred to in the following. In both cases, the ecosystem approach (Section 2.3) has been applied with considerable success.

The Great Lake Basin, USA/Canada

The five great lakes, Lake Superior, Lake Michigan, Lake Huron, Lake Erie and Lake Ontario drain an area of 766 000 km^2 with a population of 34 million people. Large urban centres have developed and some of the world's largest concentrations of industrial capacity are located in the Great Lake Region. There is also considerable agricultural production.

Man's activities in the last hundred years have caused major changes to the Great Lakes Basin ecosystem. Agricultural and logging activities have increased erosion and increased the sediment transport in the rivers. In the 1970s, the pollution of the Lakes, including eutrophication, increased at an alarming rate and a number of pollution investigations were carried out. Their major findings were that the Lakes ecosystem was subject to:

* excessive inflow of phosphorous and chemical load from agricultural land-use
* increasing eutrophication and declining content of oxygen in the water
* increasing inflow of toxic chemicals from improper disposal and storage of hazardous waste
* industrial and urban pollution, including heavy metals
* acid rain, with pollutants such as phosphorous and toxic chemicals
* declining fish population, and a reduced fish health
* indications of adverse effects on human health

Through intensive collaboration between the two countries involved, a number of initiatives were taken to reduce pollution, including legislative measures and strict pollution control.

An enormous amount of money has been spent on building and upgrading municipal sewage treatment plants.

In the period 1972 to 1987, the situation improved considerably. A dramatic reduction of phosphorous inputs to Lakes Erie and Ontario is observed, reducing the rate of eutrophication. There is also a major decline in several toxic chemicals.

The struggle to reduce the pollution of the Lake ecosystem continues. The most difficult problems will be how to address atmospheric deposition, contaminated groundwater, and contaminated sediments. Adapting an ecosystem management control means more than pollution control and other restricting measures. It also means changing the way things are done, and the attitude of people. In the Great Lake's area such a change of attitude may be underway. The following points are considered important:

- local planning must take into account long term impact on local waters;
- remedial measures for specific problems must not compromise other beneficial water uses of the area;
- specific clean up activities should not proceed until all active sources causing that specific problem are under control.

The River Rhine, Europe

The River Rhine is called Europe's most important river, flowing through several countries, and with a catchment of 180 000 km^2. The river is channelized in the lower 800 km, and the waterflow in many tributaries is regulated by dams.

The catchment is populated by some 50 million people, partly concentrated in large cities on the river bank. The river provides drinking water for about 20 million people. Important industries, including chemical, are located along the river. Furthermore, it is a vital shipping route with a fleet of almost 12000 freight vessels. The river is also used for fishing, leisure and recreation.

In the 1960s and 1970s the Rhine was strongly contaminated with toxic material and untreated sewage, and the oxygen concentrations were low.

Since the Rhine is an international river, a comprehensive cooperation between the countries has been initiated, starting with the International Commission for the Protection of the Rhine against Pollution in 1950. The Rhine Action Programme was started in 1987.

In the past few years, important progress has been made in improving the quality of the Rhine water, due to high investments into sewage treatment plants and other measures to reduce the input of harmful substances. It is verified that since 1971:

* The load of biodegradable substances is reduced by more than 50%

* The average concentration of ammonia, mercury, and cadmium has been reduced to acceptable levels

* The content of heavy metals has decreased considerably, see Fig. 11.1

* The oxygen concentration is close to saturation point (which is positive)

* The chloride load is stabilized, but at too high a level

* The abundance of species has been risen sharply.

It is expected that further improvements will take place in the 1990s.

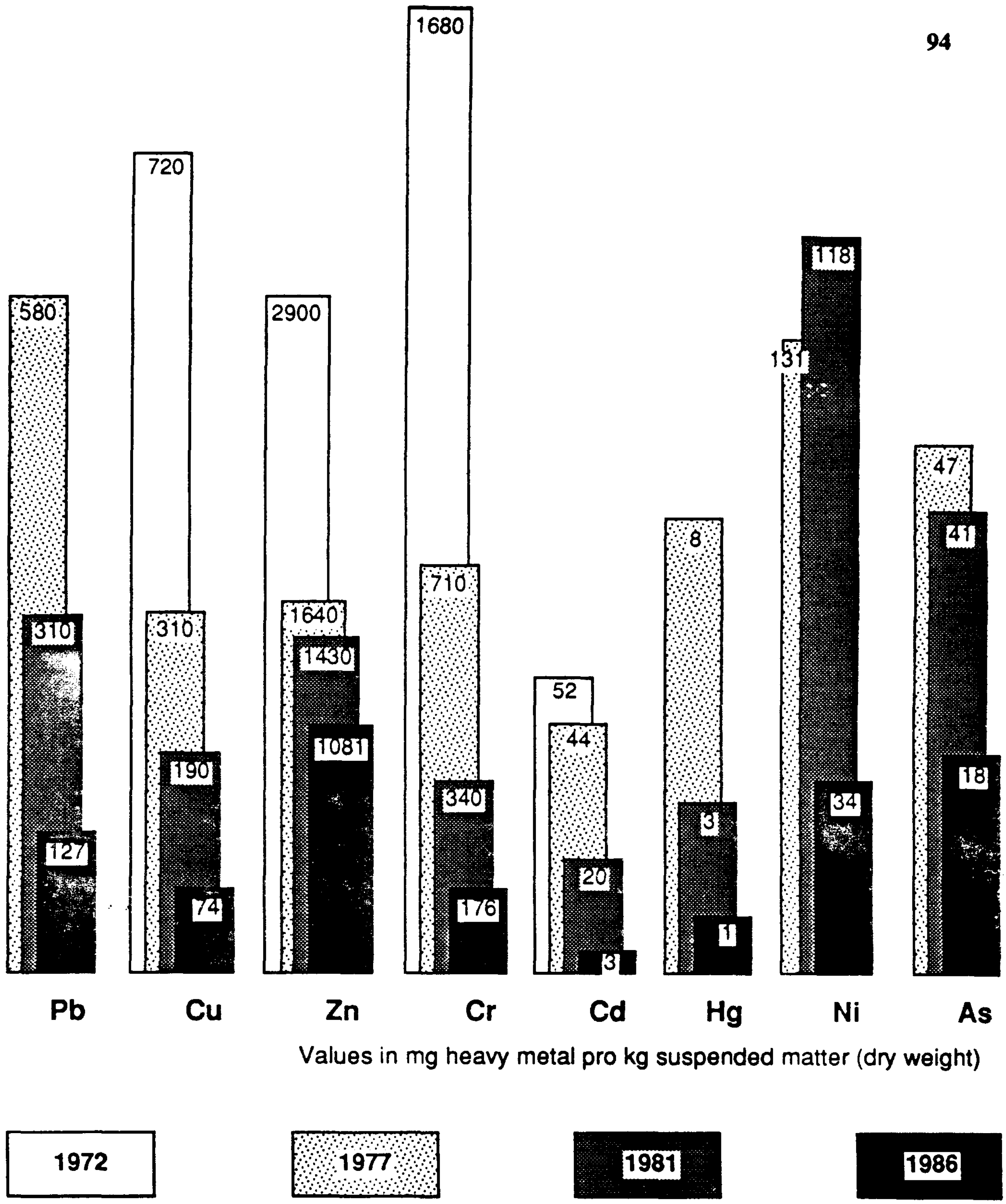


Fig. 11.1 Mean annual concentration of heavy metals in suspended matter in the Rhine at Bimmen-Lobith [5].

12 WATER RESOURCES MANAGEMENT AND LEGISLATION

As has been demonstrated in the preceding Chapters, the demand for water is increasing rapidly all over the world and we are confronting serious environmental (and economic) implications of water scarcity and water pollution. The situation in many countries is already critical. Of particular concern is the rapid growth of population in conjunction with the uncontrolled development of urban, industrial and agricultural activities. To meet this challenge, both globally and locally, a sound water resources management is a must, and it should be based on an equally sound legislation.

Water resources management may be defined to comprise the totality of tasks required to provide water of acceptable quantity and quality to satisfy the demand of all users, in an environmentally and economically sustainable manner.

In Section 2.3 the ecosystem approach was defined and recommended as the basic concept in dealing with water resources. This also applies to water resources management and legislation implying an integrated set of policies and managerial practices that relate people to the ecosystem of which they are part. Another important principle following the ecosystem approach is that the public should take part in decision-making (See also Section 4.4). This participation should reflect the diversity of interests involved, and thereby provide valuable experience and also responsibility among water users.

An important consequence of the ecosystem approach is that water management within one sector, say agriculture, cannot be isolated from other sectors. Integrated management is required, giving balanced attention to all sectors and interests combined with a holistic environmental view.

In many countries this approach may be difficult to achieve due to, historically, one user being particularly strong and having a dominating influence. The other users are then considered secondary and it becomes difficult to balance the interests. Navigation on the lower River Rhine may serve as an example of such a strong user. In dry areas of the world, access to water for irrigation is of vital significance and often dominates management practice. A conservative bureaucracy based on equally conservative legislation can often stop a new approach to management [41].

A major obstacle to integrated management in many countries is the division of responsibility for water use between different ministries and also between different public agencies. This causes lack of coordination, and often disagreements develop between the different bodies. A destructive competition as to who is the responsible agency is frequently observed. These problems are of a political nature, and should be solved by politicians.

There are in the world hundreds of international rivers where the water is shared by different countries. 214 rivers have been registered by UN as major international rivers. About 40% of the world's population live in these river basins shared by two or more countries. It is estimated that by the year 2000, the Ganges basin will have more than 500 million people living in it. In Asia there are 12 and in Asia 5 river basins shared by four or more countries. It is evident that conflicts easily develop when pressures on water resources increase. A common reason for such conflicts arises when an upstream country regulates or, pollutes the water causing adverse effects for a downstream country. Examples are the disputes between India and Bangladesh over the Ganges River, between Argentina and Brazil over the Rio de la Plata, and the conflict between Turkey, Syria, and Iraq over the Euphrates. The Indus Basin Settlement between India and Pakistan is considered a successful conflict resolution.

The sharing of groundwater basins may also create conflicts as have been reported from Egypt, Sudan, Chad, and from the Arabian Peninsula.

There exists today no effective international legislation on the use of rivers shared by several countries. What exists is a variety of international documents, declarations and treaties. Still about one third of the 214 major international rivers are not covered by any international treaty, and less than 30 have a cooperative institutional arrangement like joint river authorities.

However, we find examples of cooperative bodies which are functioning reasonably well, like on the River Rhine and the Great Lakes, as described in Chapter 11.

A major challenge for the future will be to include the ecosystem principles in national legislation. Change of legislation is normally a very slow process and conflicting economic interests may complicate the process. However, in Europe several countries have invested much time and effort in preparing and implementing laws to be more in line with the new principles. In some countries, like Canada and the Netherlands, specific reference to protection of ecosystems is made in the water legislation, or is underway.

Form and content of water legislation will vary with the conditions in each country, but some kind of well-defined framework is essential as a base for efficient management.

General environmental legislation has been implemented in most countries, and laws and regulations exist on the protection of water resources. There is, however, often a considerable gap between the official law and the actual practice. In many developing countries, the institutional framework is too weak for effective follow-up. Lack of trained personnel is often another main constraint. In Indonesia, for example, the existing legislation on water pollution is considered to be adequate, but lack of funds, laboratories and trained staff prevents proper implementation.

13 WATER RESOURCES IN ENVIRONMENTAL EDUCATION

As has been demonstrated in the preceding Chapters of this report, water is, in some way or the other, part of all man's activities. It is therefore of fundamental importance to provide, through environmental education and communication, the necessary knowledge and awareness of the complex relation that exists between water and environment. Environmental education is of basic importance in awakening attitudes in the society which are positive to the execution of responsible water resources management, based on a holistic ecosystem approach.

The environmental impacts are of global, regional and local nature. The global and regional aspects should not be underestimated, but in environmental education at secondary level examples from the country itself and the nearby neighbourhood should always be emphasized.

The priority given to the various water-and-environment issues will differ from country to country, and also differ between the different climatic zones. Questions connected to water supply and sanitation will be important in most countries, though the infectious water-related diseases are mainly limited to the tropical regions, in both rural and urban areas. However, water pollution caused by agricultural and/or industrial activities is a problem in nearly all countries.

The inclusion of environmental education in existing curricula can be approached in different ways [22]:

1. *The separate subject approach* is now gradually gaining ground in many countries. Since the water-and-environment issue should be treated as a separate identifiable unit and is dependent on interdisciplinary teaching, this approach is clearly favourable. Water-and-environment will then form a natural part of the total environment education, and the advantages of the ecosystem method are easily explained and understood.

2. *The integrated approach* involves a systematic integration of water-and-environment in the relevant science and social subjects. This method should be considered complementary to the separate subject approach. All curricula of selected subjects are revised to allow for inclusion of the issue. It is also a way of breaking down the barriers of the disciplines. The subject selected could be geography, biology, chemistry, physiology and hygiene, physics, etc.

3. *The infusion approach* is the simpler ad-hoc expanding of existing curricula to include the water- and environment issue, for example by substituting examples into already existing materials.

With the separate subject approach, the new main subject could be entitled "Human Influence on Ecosystems", with one unit focusing on water. As previously emphasized, examples from real-life situations are important, as well as study visits to nearby localities. This will encourage pupils/students to develop and apply knowledge they have obtained to real water-and-environment issues. The most important considerations in connection with existing problems will of course be the discussion of possible mitigation measures to be taken. The chain: knowledge - awareness - proposed actions, is then completed.

Environmental Impact Assessment is a very useful method in environmental education. An environmental impact assessment, EIA, is a method used to identify a project's probable impacts on the environment. EIA is also carried out in order to influence project design and the choice of project alternatives [39]. An example of procedure for EIA is given in Annex A. Through an EIA, the objective is to call attention to all impacts, both the positive and the negative impacts, at an early stage in a planning process. It may have the effect of changing the project itself, and propose mitigation measures. The reversed approach can be used for completed projects as a way of linking impact to its causes. Questions like those presented in Annex A are phrased to apply to new proposed activities. However, by changing "will the project cause" into "has the project caused", the method can also be applied to existing activities and completed projects.

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ANNEX A

EXAMPLE OF ENVIRONMENTAL IMPACT ASSESSMENT PROCEDURE

A great number of procedures for the accomplishment of EIA exist. In the following, some examples from the procedure recommended by the Norwegian Agency for Development Cooperation, NORAD, are presented [39]. This procedure includes check lists for initial screening of projects. If the answer is yes to one or more questions in the initial checklist, or insufficient information is available, the project should be submitted to a more detailed assessment. For projects within water supply/irrigation and hydropower the questions posed by the check list are

* Water Supply/Irrigation

  Will the project:

  1. Lead to tapping of groundwater in such quantities that there is a danger for permanently lowering of the groundwater-table?
  2. Flood areas which are of great local importance because of human settlements, agriculture, animal husbandry, or similar?
  3. Flood areas which support animal or plant life worthy of protection or especially vulnerable eco-systems?
  4. Flood areas which contains historic remains or landscape elements which are important to the population?
  5. Cause a noticeable reduction in the flow of nutrient elements or fish production?
  6. Lead to substantial waterlogging or salinization of cultivated or cultivable land?
  7. Create pollution problems?
  8. Create a risk for increased spread of water-borne diseases?
  9. Change the way of life of the local population in such a way that it leads to considerably increased pressure on the natural resource base?
  10. Lead to major conflicts with regard to existing land use and ownership of land?
  11. Obstruct, or lead to substantial changes in, the local populations exploitation or use of natural resources or land other than those directly affected by the project?

* Hydropower Projects

Will the project:

1. Flood areas which are of major significance for human settlement, agriculture, animal husbandry, or similar?

2. Flood areas which support animal or plant life worthy of protection or especially vulnerable eco-system?

3. Flood areas which contain historic remains or landscape elements which are of importance to the local population?

4. Drain rivers or change the flow of water in such a way that it creates considerable changes for the environment and the utilization of natural resources?

5. Cause substantial changes in the flow of nutrient elements and fish production?

6. Create a risk for increased spread of water-borne diseases?

7. Change the way of life of the local population in such a way that it leads to considerably increased pressure on the natural resource base?

8. Obstruct, or lead to substantial changes in, the local populations exploitation or use of natural resource other than those directly affected by the project?

The check lists are designed as a first step, to establish whether a proposed project is likely to have negative impacts on the environment. The next step will be a more detailed screening with a new check list, like the one for hydropower quoted in the following.

Will the project:

1. Affect areas important for settlement or utilization of natural resources?

   - Will it be constructed a reservoir of such a size that it might affect the local climate?

   - What types of areas (existing land use, types of vegetation etc) will be submerged?

   - How many people will have to be moved because of inundation or other physical encroachments that which destroys settlement areas or areas important for production activities? Will they be able to continue their traditional resource-utilization in new areas?

   - Will new activities or development of infrastructure hinder or alter the existing land use, or will new possibilities arise?

- Will the establishment of a reservoir create possibilities for other forms of utilization of the water resources, e.g. fishing, irrigation, water supply, recreation, tourism etc.? Which environmental impacts can be expected from these new activities?

2. Affect areas with animal or plant life worthy of protection?

   - Will inundation, altered water flow or ground-water level harm important habitats or vital functions for conservation-worthy animal or plant life?

   - Will the dam, roads or power lines create barriers for wildlife?

   - Will the construction work affect or include areas with valuable or conservation-worthy animal or plant life?

3. Affect areas which contain conservation-worthy cultural relics, landscapes etc.?

   - Will cultural relics or other objects/areas of importance for the local population's cultural activities be submerged or affected by other construction work?

   - Will physical encroachments affect especially beautiful or unique sections of the watercourse or drastically change the water flow?

4. Change the water flow or other hydrological features?

   - Will the project increase or decrease the risk of flood damage as compared to the present situation? Can these changes be quantified in terms of number of people in flood-threatened settlement areas, size of flood-threatened farmland etc.?

   - Is the reservoir situated in an area exposed to earthquakes, resulting in greater risk of a breach in the dam? What will be the impacts of a breach?

   - Can one expect a reduction of the total water flow due to increased evaporation?

   - Will reductions in water flow or changed patterns in water flow change the accessibility to water for drinking, irrigation, animal husbandry, wildlife etc.?

   - If the regulation leads to a changed level of ground water, which impacts can e expected on natural vegetation, water supply, agriculture etc.? The areas surrounding the reservoir as well as the areas along the watercourses will have to be assessed.

   - Is there a risk of a permanent periodical reduction of the water quality due to reduced water flow and consequently increased concentration or pollution?

   - Is there a risk of particular pollution problems during the construction period as a consequence of tunnelling, digging etc.?

5. Change the nutrient and sediment transport and the conditions for fish production?

- Are the soil conditions in the planned reservoir area and the watercourse vulnerable to erosion? Will the project increase erosion?

- Will the construction of reservoirs trap transported sediments and nutrients in the watercourse? To what extent will this affect the lifetime of the reservoir?

- Will a build-up of sediments in the reservoirs cause increased erosion downstream?

- Is there a risk that an increased concentration of nutrients in the watercourse can result in uncontrolled eutrophication and unwanted aqua-vegetation in the reservoir?

- Will the trapping of sediments and nutrients lead to decreased productivity in agriculture and fishing downstream?

- Will possible changes, in the volume and pattern of water flow, flood possibilities etc. have any consequences for fish production and fishing possibilities in the watercourse and the sea areas beyond?

- Are there valuable species of fish in the watercourse dependent on migration for nourishment or spawning? To what extent will technical installations or regulations obstruct migration and/or spawning? Will this affect the quantity or the production of important fish resources or fish worthy of conservation?

6. Change the risk of spreading diseases?

- Will the establishment of a reservoir or changed water flow in a regulated watercourse change the conditions of life for disease-spreading organisms?

- Will the project lead to a population concentration or pattern of settlement which increases the risk of infection? Is there a risk that the reservoir will be used both as a source of drinking water and as a recipient of sewage?

7. Change the way of life of the local population?

- Is it possible that the project may cause a sizeable increase in the population in the area? Is there a risk of potential conflicts between the new population groups and the original inhabitants due to scramble for limited resources, different cultural backgrounds, lifestyles, changed power-structures etc.?

- Will traditional and well-adjusted ways of life be endangered because of changes in natural environment, changes in production or influence from new population groups?

8. Influence the utilization of other natural resources?

- Will the establishment of a reservoir or connected activities force other activities (agriculture, animal husbandry etc.) to locate in other areas that are more ecologically vulnerable?

- Is the natural resource base sufficiently suited and stable to receive an increased population? Will the ecological carrying capacity be threatened?

- Will the construction work and any new activities place demands on water and fuelwood in areas where these resources are limited?

- Will increased accessibility due to development of infrastructure lead to the establishment of new activities like agriculture, forestry, industry etc.? To what extent will these activities affect the environment? (C.f. Checklists for initial screening or initial assessment of these project categories.)

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