17 RESERVOIRS AND THE ENVIRONMENT

Every individual reservoir has an impact on its environment. Proportionally to its size and function, it influences the natural environment of the water course and the surrounding regions, the life of the inhabitants and the economic activities in the region.

A reservoir changes the physical and biological regime of a river, inundates territories, threatens its embankment by abrasion and landslides, affects the weather conditions. It helps to raise the living standard (Fig. 17.1).

In designing, constructing and operating reservoirs, the water-management engineer must maximize their favourable effects and minimize the negative con-

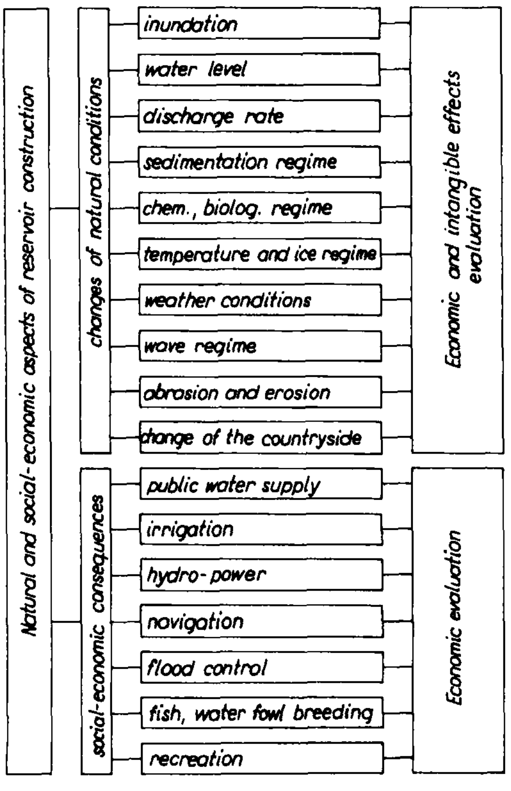

Fig. 17.1 Survey of natural and socio-economic aspects of reservoir construction

sequences of their construction on the environment. It is his social mission to control the change of the environment. In collaboration with other experts (biologists, etc.), he has to maintain the quality of the environment even though it changes due to economic activities and scientific-technological progress, and to intensify the utilization of water resources—an irreplaceable part of the other natural resources. The technical qualification of water-management engineers must help to implement the scientifically controlled changes that lead to such technical advances that are able to satisfy the main necessities of man.

Water does not know any frontiers and is therefore a subject of international interest. The European Charter on Water (1948) states that water is common property, the value of which must be recognized by everyone; it must be kept, protected and preserved; water quality must meet the standards of public health and water must be used effectively and reasonably.

Environmental problems are dealt with within the framework of the Council of Mutual Economic Assistance that established the solution of concrete tasks in the water-management branch at a Conference of Leading Authorities for Water Protection in the CMEA Countries.

The Water Act of 1973 declared surface and ground waters to be one of the principle raw-material resources, representing an important component of the human environment which ensures economic and other social requirements.

Every water reservoir is principally the reflection of the respective catchment area. If in the catchment area, soil management, agricultural activities and the settlement of the inhabitants are properly regulated, then the conditions of the reservoir, water quality and required service life of the reservoir are also favourable.

Scientific methods and technological solutions for the rational exploitation of water resources have already been elaborated. Less advanced is the understanding of the complex problem of the natural processes caused by the activities of man, undoubtedly because these processes are very complicated and dynamic, requiring long-term research. Scientific and technical experts in the field of water management should help to overcome this problem.

17.1 CONSEQUENCES FOR THE HUMAN ENVIRONMENT OF THE CONSTRUCTION OF RESERVOIRS

Reservoirs affect the environment during the years of their construction, and for the many decades of their service life a survey of the unfavourable effects and the measures taken to prevent them, is carried out (see Fig. 17.2).

The classification of the effects reservoirs have on the environment and the respective measures taken to counteract them lead to the conclusion that

– every research task concerning the construction and operation of a reservoir should be undertaken with a view to the relationship between the reservoir and the environment;

– every reservoir design should be undertaken with a view to the environment, with a separate section dealing with the utilization of natural resources and environmental protection.

The environment is an ever present factor of life. It is a feature of scientific studies, from theory in basic research up to the technological implementation in practice, and is the subject of studies in sociological, natural and technological sciences. Taking into account these fields of science, the position of the water-management branch should be determined in relation to the environment (Table 17.1).

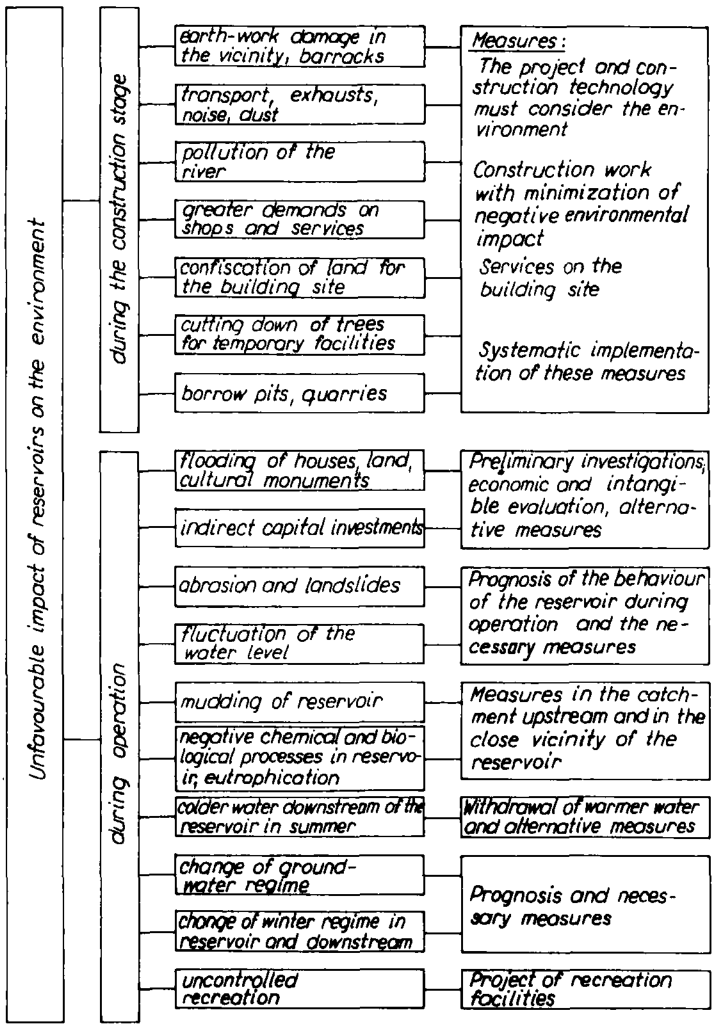

Fig. 17.2 Negative impacts of reservoirs on the environment during construction and operation

Table 17.1 Subjects studied by scientists relating to the human environment

Social sciences	Natural sciences	Technological sciences
Relationship between society and nature	Influence of production and technology on nature	The control of the relationship between production and environment
Impacts of the differences of regions	Stability and transformations of natural systems	Intensity of technological activities in the environment
Social and individual needs	Biological productivity of ecosystems	Technological improvements for the utilization of natural resources
Economical tools Legal measures	Biosphere and its natural components	Technology for pollution prevention
Control of the interaction between man and environment	Adaptability of organisms to changes in natural conditions	Procedures to reduce waste
	Effects on soil and occurrence of erosion	Production of equipment for waste treatment
	Effects on water resources, etc.	

From the table it is evident that the branch of water management and of water engineering takes its duties concerning environmental problems in the field of sociological and natural as well as technological sciences seriously. In the cycle: research → → development → design → production → operation, water engineering also plays a part in solving the problems of the environment as well as in all the other steps of the cycle. Thus, it can be concluded that the field of water engineering deals with all aspects of environmental problems.

The effects of reservoirs on the environment can be divided into physical and biological and effects on man (Cheret, 1973; Votruba, 1973).

17.1.1 Physical impacts of reservoirs on the environment

Physical impacts of reservoirs have to be considered from the beginning of the construction as they have a marked effect on the hydrological and sedimentary regime.

The *hydrological regime* is influenced mainly by the reservoir volume. Relatively small reservoirs have a smaller effect on the discharge conditions, whereas large ones, with long-term release control have a substantial effect on the discharge regime in the range of low, as well as flood discharges. The balancing effect of regulated discharges favourably influences the environment, since it reduces the flood damages and improves the general use and quality of the water by augmenting the discharges in periods of low water stages.

How the discharges are changed depends on the purpose for which the reservoir is used. A flood-control reservoir reduces floods, but does not regulate the low discharges. A conservation reservoir, in addition to its main function, improves the minimum maintained discharge which is higher than the natural discharge minima.

Peak operations of hydro-power plants have a negative effect on the discharge conditions. The rapid changes in the discharge have an adverse effect on the riverbed as well as on the biological function of the river. For this reason, if they do not operate in series, peak-power plants are usually accompanied by a balancing reservoir.

A similar effect is exhibited by river flow regulation during sudden changes in water withdrawal. This shortcoming can be removed by a buffer-storage reservoir whose volume is designed with a view to the permissible harmless gradient of discharge change.

A deterioration of discharge conditions can occur with relatively high consumptive withdrawal from a reservoir. For this reason a relatively high yield has to be included in the design, as well as a certain water volume for occasional flushing of the riverbed.

Reservoirs also alter the *groundwater regime*. If the water level reaches above the surrounding land, agricultural lands are threatened by water. On the other hand, excavations of the riverbed downstream of the dam can lower the groundwater table to a detrimental extent. Seepage from the reservoir can deteriorate groundwater used for drinking purposes. The surplus groundwater on the agricultural land can sometimes occur in the valley below the dam.

A significant seepage problem through the protective dykes arose due to the impounding of the water for 270 km, by damming the straights of Džerdap on the Danube (Mostarlic, 1973). The building of the reservoir led to the following adverse consequences: flooding of the valley due to the water impoundment, raising of the groundwater table, deposition of bedload, and changes in the ice mass.

The impounding endangered 200 km of old protective dams that protected over 90 000 ha of arable land and a large number of villages and towns with industrial plants against floods. These dams had to be reconstructed, i.e., they had to be raised and reinforced. A drainage system was constructed in the protective section. The dams were elevated by 0.70 m above the height of the end of the wind wave, counting on a high wind velocity with an occurrence probability of 1%.

The groundwater table was determined by agropedological criteria, separately for unmineralized groundwater that cannot cause salt contamination of agricultural land (depth during the growing season 0.90 m in very light soils and up to 1.30 m in heavy clayey soils) and for mineralized water that can cause salt contamination of the soil (depth in the growing season 1.00 to 2.00 m and outside the growing season 2.20 to 2.70 m). All measures taken in connection with the construction of the Džerpad water scheme, whose main function is power generation and navigation, were judged not only from the aspect of these main objectives, but also from broader social-economic aspects.

Present experience shows that the unfavourable effects of impoundments on groundwaters have to be overcome in time

- by geological and hydrogeological surveys,

– by predicting the changes in the groundwater regime after the filling of a reservoir,

– by proposing and executing the respective control measures,

– by careful maintenance, and investigation of the effectiveness of the measures carried out.

Siltating is one of the most imporant physical factors in reservoirs, since it reduces their volume and shortens their service life, which should be at least 250 to 300 years. Bulgarian engineers assume that the volume for siltating should be calculated for 100 to 200 years.

The speed and manner of siltating varies greatly in different watersheds and reservoirs. Bristol University has been collecting data on 130 reservoirs of various sizes in the USA, India and Cyprus, where the siltating amounted to 0.17 to 92.9% and the annual volume decrease was 0.02 to 14.3%. The Mangla reservoir in Pakistan is expected to lose $1.233 \cdot 10^9$ m^3, i.e., one-ninth of its total volume in 20 years.

In Lake Nasser, created by the Aswan Dam, a volume of $30 \cdot 10^9$ m^3 of the total volume of $164 \cdot 10^9$ m^3 is set aside for siltating; it is assumed that it will be silted up in 500 years, although only 12% of suspended solids are retained in the reservoir. Sediments contain mainly fine mineral material composed of:

fine sand	(0.2 ÷ 0.02 mm) : 30%
silt	(0.02 ÷ 0.002 mm) : 40%
clay	(< 0.002 mm) : 30%.

The loss of these suspended solids in the Nile water used for irrigation purposes had no effect on the crop yields. On the contrary, the yields are higher due to controlled irrigation and the addition of cheap fertilizers. However, downstream of the dam, the riverbed became deeper due to the passage of clean water, which disturbed the former equilibrium. The water level sank by 40 to 80 cm. This fact is being investigated by geological, topographical and hydrological surveys and control measures will be introduced (Kinawy *et al.*, 1973).

The volume loss of Czechoslovak reservoirs due to siltating is relatively small. The volume of the Kníničky reservoir on the river Svratka decreased by 3% during 30 years' operation and its service life under present conditions in the watershed is approximately 800 years (Kratochvíl, 1970). The conditions in many other Czechoslovak reservoirs are similar. However, greater difficulties due to siltating can arise at the inflows of rivers into reservoirs. Kališ *et al.* (1972) resolved the siltating in the inflow reaches of the rivers Dyje, Jihlava and Svratka into the Nové Mlýny reservoir on an air model and predicted the bottom deformation by bedload.

To retain coarse bedload before it reaches a reservoir, *retaining dams* are sometimes built on the tributaries. Their function is, as a rule, of short duration as they soon become clogged and can cause deterioration of the water quality. When the retaining dam is placed in the inundation of the reservoir, in the form of a "submerged" dam, it fulfils yet another function by controlling the fluctuation of the water level in shallow parts of the reservoir at the end of the backwater.

Some of the disadvantages of tipped rockfill retaining dams can be prevented by using coarse screens that are installed into the riverbed of the tributary at the end of the reservoir backwater (Priehradné dni – Dam Conference 1972, Loucký, p. 187).

They affect the discharge conditions to a lesser degree, retain mainly coarse bedload of plant origin and can be treated easily, thus prolonging their service life. A removable screen was installed on the main tributary to the reservoir e.g. near Ludkovice.

Although many methods for the solution of siltation problems have been developed, there remains much uncertainty in predicting the bedload movement and siltation due to the raising of the water level by a weir or dam. Experience gained all over the world was concentrated in questions No. 40 and 47 discussed at the XIth and XIIth International Congress on Large Dams (XIth Congress, 1973, XIIth Congress, 1976) and, together with Czechoslovak experience, they were also the subject of discussions at Přehradní dny (Dam Conference) 1972, 1973 and 1976 (see references).

The environmental impacts connected with the changes in reservoir topography are *bank abrasion and slides*. Bank abrasion is the result of wind waves, waves produced by vessesls, ice, water level fluctuations and man-made interventions. The extent to which the banks are changed depends on the nature of the banks along the reservoir shore line and on the magnitude of the influence. Even small changes are unfavourable from the environmental point of view. However, sometimes they reach significant or even catastrophic dimensions when great land slides into the reservoir occur.

Due to wave action and water-level fluctuations, the banks of the Orava reservoir (surface area 35 km^2) receded in some places by more than 45 m and abrasion palisades up to 20 m high were formed (Priehradné dni – Dam Conference 1972, Horský, p. 121). Abrasion and bank-slide material reduced the reservoirs volume. The original banks, with the slope of now-steadied bank-abrasion platforms, are practically unchanged. Steep slopes in Neocene and Quaternary sediments were very quickly transformed by abrasion. Experience gained is a valuable basis for the prediction of reservoir bank transformation. This prediction should be part of any reservoir design (Kachugin, 1955, Pyshkin, 1963).

Peter and Lukáč (Priehradné dny – Dam Conference 1972, p. 131) determined the extent of wave abrasion for the Orava and Velká Domaša reservoirs; as a relative criterion they introduced the so-called abrasion degrees I to V:

I: most intensive abrasion with great abrasion volume and velocity;
II: intensive abrasion in steep, easily decomposable banks;
III: slight abrasion with abrasion palisade heights of 0.5 to 1.0 m;
IV: very slight abrasion with abrasion palisade heights up to 0.5 m;
V: banks without abrasion.

The extent of the abrasion degrees is given in Table 17.2.

The greatest abrasions in Slovakia are encountered in flysch regions. Economic impacts are significant as the bank lengths of six reservoirs (Orava, Velká Domaša, Vihorlat, Nosice, Ružín and Lipt. Mara) are about 300 km and according to Table 17.2 about one-half of the bank lengths is affected by abrasion.

Bank slides due to impoundments can sometimes reach catastrophic dimensions. On the left bank of the Rumanian Izvorul Muntelui – Bistrita reservoir, several bank

Table 17.2 Abrasion in the Orava and Velká Domaša reservoirs

Abrasion degree	Length of reservoir banks			
	Orava		Velká Domaša	
	[km]	[%]	[km]	[%]
I most intense	6.60	9.56	2.70	6.74
II intense	6.30	9.13	4.87	12.17
III slight	15.40	22.32	3.83	9.58
IV very slight	11.90	17.25	6.91	17.28
V without abrasion	28.80	41.74	21.69	54.23
I–V total	69.00	100.00	40.00	100.00

slides occurred, the greatest of which was 250 m long and 350 m wide. On the right bank of the Pingarati – Bistrita reservoir, a bank slide on the interface of diluvium and rock occurred, having a width of about 300 m, a length of 150 m and a thickness of 3 to 6 m (XIth Congress, 1973, Q. 40, R. 31, Diacon *et al.*, p. 445). The landslide of Toc Mountain into the Vajont reservoir in northern Italy in 1963, where about $250 \cdot 10^6$ m^3 of rock material slid into the reservoir from the left side, forcing a water wave over the crest of the 261 m high arch dam, was catastrophic. The discharge wave demolished the village of Longarone in the Piave river valley near the mouth of the Vajont mountain stream and killed 2000 people.

In large reservoirs the *water quality* improves, undoubtedly due to physical sedimentation. However, as a rule, more complex physical, chemical and biological processes take place in reservoirs. The result of all these processes are changes in water properties that can vary greatly and to a large extent are dependent on the properties of the inflowing water.

Special problems arise during the building of reservoirs for fresh water in the vicinity of salty groundwater. Problems connected with the leakage of salt and fresh water require special research. In the seaside zone in Yugoslavia, this problem is further complicated by the presence of karst waters.

The effects of large reservoirs or reservoir systems on the *weather conditions* have been studied for a long time and have led to conflicting opinions. Posekaný (1969) reports the effect of the South-Bohemian ponds on the environment, especially on the microclimate. With a daily evaporation of 5 mm, 1500 m^3 of water passes from 1 ha of pond area into the atmosphere in one month, thus increasing the air humidity near the ground surface which can be carried by the wind to more distant regions.

The Swedish Meteorological and Hydrological Institute ascertained during 20 years of investigations that discharge control can alter the water temperature, whereas the air temperature is mostly unaffected. In spite of this, small changes in extreme daily temperatures were encountered near the banks of a new reservoir. In autumn and at the beginning of winter, fogs increased due to the higher water temperature.

Volta Lake in Ghana, with a volume of $165 \cdot 10^9$ m^3 and a surface area of 8730 km^2, exhibited a change in its precipitation regime. After the completion of the Lake in 1964, it seems that October was no longer the month for rains, but that July and August are now the rain months (XIth Congress, 1973, Kumi, p. 907).

One of the most marked effects of reservoirs on the surroundings is their impact on the *temperature and winter regime*. The temperature regime of a river changes in relation to the relative reservoir volume. Shallow or deep reservoirs, as well as relatively small or large reservoirs, create different temperature conditions. The most regular temperature conditions are in large and deep reservoirs with relatively small inflow and stready outflow. In such a reservoir a regular vertical stratification of water temperature is produced, similar to natural deep lakes. The temperature of the outflowing water is determined, not only by the temperature of the water in the reservoir, but also by the position of the outflow devices and by the magnitude and time pattern of the outflow.

Since water has its greatest density at 4 °C, in summer the water is coldest near the bottom, while in winter it is at its warmest near the bottom. The water leaving the reservoir through the bottom outlets or low-lying hydro-power plant intakes is therefore cooler in the summer than the water in the natural river and warmer in the winter. This affects the water course for tens of hundreds of km downstream of a reservoir. The fact that the water is cold in the summer is unfavourable for the natural environment. Proposed measures therefore plan for water withdrawals from the upper layers.

For the dam on the river Blanice near Husinec F. Čech designed a shutter intake with its lower edge supported by a float at a constant shallow depth below the water surface. For the Slapy and Orlík reservoirs it was suggested that an "apron" should be built at a certain distance from the dam that should close the total cross-section of the valley except for a few metres below the backwater level. L. Záruba prepared a design using plastic foil and L. Lískovec tested its effect on the temperature rise of the water flowing through turbines from a reservoir in the laboratory. The object was to improve the recreation conditions on the river Vltava by the outflow of warmer water in summer. The impact of the apron on the chemical and biological conditions of the water still has to be determined.

Summer water temperature stratification in a reservoir is called *direct stratification*, in winter *indirect stratification*. When direct stratification changes to indirect stratification (in autumn) and from indirect back to direct stratification (in spring), the reservoir exhibits homogeneity in temperature, i.e., the temperature in a vertical section from the bottom to the surface is the same. Especially in summer, when the temperature gradient in the vertical is usually not constant, there is a certain layer (about 5 to 15 m below the water level) where the temperature gradient is higher.

This thermocline is called the metalimnion, the area underneath it is the hypolimnion and above it the epilimnion.

The temperature conditions affect the biochemical processes and water characteristics. The hypolimnion is usually poor in dissolved oxygen and richer in iron and manganese.

In *shallow reservoirs*, isotherms are, as a rule, not horizontal, but inclined to the vertical and reflect, e.g., the gradual warming of the water in the direction towards the dam. Only in the case of small inflows can a vertical stratification also occur in a small reservoir. Ponds are typical shallow reservoirs. For fish-farming, which requires warm water, the warming of water is also supported by leading the water to the spill crest from the bottom at the deepest point of the pond.

Ice conditions are changed by reservoirs in the backwater reach to a certain distance upstream from the backwater end and in the reach downstream of the dam. As a rule, ice sheets form earlier on the backwater than on the river, are thicker and melt later. The ice sheet in a reservoir melts without the ice falling over the spillway as long as the velocity at the cross-section during ice motion is less than 0.4 to $0.5\,\mathrm{m\,s^{-1}}$.

At the end of the backwater and above it, the ice conditions deteriorate, especially when ice floes and frazil ice approach it (hummocks, ice clogging). Downstream of the dam, ice conditions improve again: no ice mass arrives from the upstream range and warm water released from the reservoir keeps part of the river free of ice (Kratochvíl *et al.*, 1965; Votruba, Patera, 1983). The water from the Slapy reservoir affects the temperature conditions in the river Vltava in Prague, i.e., at a distance of 40 km, although it passes the Štěchovice and Vrané reservoirs and has two large tributaries—the rivers Sázava and Berounka. Freeze-up in winter is reduced and recreation suffers due to the cold water in summer. At low discharges, the Nechranice reservoir affects the water temperature in the river Ohře to a distance of 100 km. By releasing water from the reservoir, the ice conditions on the river can be controlled.

Ice sheets act by their dynamic and static effects on the banks and structures and, together with frost, threaten the operability of the gates. Ice pressure endangers thin structures, concrete bank reinforcements, tower structures in reservoirs, etc. To counter this threat a number of effective measures have been introduced (heating of all kinds, disturbing the ice sheets near structures using compressed air, water from the deeper layers, etc.).

Seismic effects due to the filling of large reservoirs with water have been reported from several sites (Caribbean, Marckison, Volta). An increasing number of seismic vibrations in the vicinity of large reservoirs in the Sudan has been registered, but the question still remains of whether all these reported vibrations were really caused by the water load in reservoirs or whether they would have occurred anyway.

17.1.2 Biological and chemical impacts of reservoirs on the environment

Biological and chemical changes brought about by reservoirs are even more complicated than physical changes. To predict them and to design control measures, engineers have to cooperate with experts—chemists, biologists, and others. All these changes are caused by a multitude of factors and are extraordinarily complex: physico-chemical changes lead to changes in the microbiological composition which in turn affect plants and higher animals. Aquatic ecosystems that existed before a reservoir was built change gradually until, in the course of time, a new equilibrium is established and only then can the biological impact of the reservoir be judged with final validity.

The chemical composition of the reservoir waters changes, in consequence of the increased evaporation from the free water surface (increase of the relative mineral content), and due to biochemical processes taking place in the reservoirs. In a nutrient-rich reservoir (eutrophic) the oxygen balance changes to a great extent: the dissolved oxygen content decreases with the depth, to such an extent that mass fish deaths can occur when this water reaches the riverbed downstream of the reservoir or the following reservoirs of the reservoir cascades (Štěchovice, 1956, Slapy, winter 1962/1963, etc.).

During peak operation of the hydro-power plant, the Orava reservoir causes considerable biological disturbances in the river due to sudden changes in discharge, water velocity, temperatures, etc.

Degradation processes of organic matter in the hypolimnion of eutrophic reservoirs can exhaust the total dissolved oxygen in the summer stagnation period, increase the free carbon dioxide concentration, and result in the release of hydrogen sulphide. From his measurements on the Klíčava and Slapy reservoirs, Fiala (1961) revealed that the dissolved oxygen stratification is adversely affected by small dams built inside a reservoir; e.g., a temporary dam serving to by-pass the water from the dam building site during the construction period. Behind such a dam, the water stagnates, having a very low dissolved oxygen content. Similar conditions can be encountered when the water intake from the reservoirs is at a greater distance from the dam and the bottom outlets are closed. The outlets in the small dam are not sufficient to move the stagnating water.

The water quality in a reservoir is adversely affected by water bloom (algae) which negatively influences water treatment, recreation, etc. In addition, it also leads to secondary eutrophication of the hypolimnion, which in turn leads to a deterioration of the water quality in the reservoir and in the downstream river reaches. This secondary eutrophication can be prevented by water aeration (Fiala, 1972).

A very effective aeration of reservoir water can be achieved by introducing a water–air mixture below the water surface (Haindl, 1975). The water is pumped from the bottom layers of the reservoir and passes through an earation device operating on the principle of a ring jump. The ring jump produces a water–air mixture; due to the high turbulence behind the jump, an intensive oxygenation is attained that is in addition supported by the secondary flow and mixing in the reservoir.

Radical changes in water quality occur in tropical countries by the action of bacteria (XIth Congress, 1973, p. 523). Water can become undrinkable or corrosive to metal structures, as was shown by investigations on the Ayamé I reservoir, on the Ivory Coast, situated in wooded landscape. The investigations require long-term extensive measurements that must follow the vertical stratification and the effect of the annual discharge variations and water-level changes in the reservoir. Investigations in Cameroon and Gabon confirmed that the principal and permanent causes of microbial processes and the increased aggressivity of water in reservoirs result from the properties of the water that flows into reservoirs from the tropical woodland region.

The flooding of the biomass by water polluted during the first filling of the reservoir and with every following rise of the water level can lead to increased nitrogen and phosphorus concentrations and thus to the development of bacteria and then algae (phytoplankton and biotecton). The water has an unpleasant taste and appearance and is odorous, the oxygen concentration varies up to values inadmissible for fish and anaerobic conditions are encountered.

Sanitary measures combined with the construction of water-supply reservoirs are expensive. Often villages, churchyards, manure heaps, etc., must be demolished. However, the extent and manner of removal of vegetation from the inundated area has to be judged separately in each case. According to experience from the operation of Czechoslovak reservoirs, it is possible to leave tree stumps in the region of permanent inundation, since even in the course of decades they do not yield to fouling (experience with spruce stumps in the reservoirs of Sedlice and Souš after 40 to 60 years of operation). The mere ploughing of the natural vegetation cover is detrimental. Also the disturbance and incomplete exploitation of peat deposits in the inundation leads to a deterioration of the water quality in the reservoir due to increased eluation of humic acids (experience from the Lipno reservoir on the upper Vltava).

The algal concentration can be determined quantitatively in milligrams of chlorophyll per litre and its limit must be ascertained for each use. It is important that the daily, annual and long-term changes are predicted.

In one Dutch reservoir, very strong eutrophication phenomena due to the inflow of polluted water from the rivers Maas and Rhine have been observed. However, 40% of the product of algal decay settles on the bottom and thus flocculation and sedimentation maintain aerobic conditions.

In tropical regions, mass development of vegetation can obstruct navigation and fishing, can change the chemical composition of the water and produce conditions supporting the propagation of disease-carrying insects. In the zone of water level fluctuations in the reservoir, special vegetation can be found according to the extent and duration of the water level fluctuations; in the moderate and cool zone it is usually bare. However, in reservoirs with long-term control, where the emptying of the reservoir can last ten years or over, vegetation can develop in the moderate zone which can be very harmful for the water quality during the refilling of the reservoir.

The water quality in reservoirs is also affected by the activities of man in the entire watershed. Control measures should be introduced, mainly into the watershed of public water-supply reservoirs. These usually cause a certain limitation on agricultural production, due to the reduction of the use of industrial fertilizers and chemicals against weeds and insects, control measures introduced in the breeding of livestock, and the disposal of sludge. Crop spraying from aircraft in the vicinity of these reservoirs and water courses increases the danger of diffused pollution.

Those industrial processes that work with petroleum are especially dangerous. The strict adherence to sanitary measures is essential; otherwise the difficulties connected with the pollution of the inflowing water and with the low quality of the water withdrawn from the reservoir would surpass the acceptable limits.

Great care was taken with the water-supply reservoir near Švihov on the river Želivka, with a watershed covering an area of 1 178 km^2, 27% of which is covered by forests, and is inhabited by 60 000 people. From the inundated area and the hygienic protection zone I, 2166 inhabitants were evacuated and 710 buildings were demolished. The sources of pollution on the river Želivka were (Priehradné dni 1972, Dajbych–Lepka, p. 275):

	[%]
– sheet erosion and rainwash	49.6
– wastewaters from farms	8.7
– inhabitants	4.4
– industry	6.5
– other sources (fall-out, groundwater)	30.8

A study on the *Biotechnical Protection of the Švihov Reservoir*, prepared by the Comission for Water Management at the Czechoslovak Academy of Sciences, assumes the best protection against sheet erosion and rainwash from fields to be a zone of mixed deciduous and coniferous forest, 20 to 30 m broad, along the inflow reaches of significant tributaries. This was achieved by amelioration, using natural elements without grossly interfering with the natural environment. This necessitates an early analysis of the sources of pollution and the execution of the respective measures long before the reservoir is put into operation.

Of economical and ecological significance is the effect of a reservoir in fishing, which can be both favourable and unfavourable. The change of the flow velocity, water depth, temperature, and water-level variations considerably affect the fish-breeding conditions so that the composition of fish species can also vary. Pivnička and Holčík (Priehradné dni 1972, p. 219 and 225) reported on two stages of the reservoir operation from the ichthyological point of view:

– the first (initial) stage lasts until the maximum capacity of the ichthyomass is reached,

– the second (stabilization stage) following the termination of the first stage.

Table 17.3 shows the development of the ichthyomass and production (weight increase) in the reservoir on the river Kličava near Zbečno since 1957, i.e., two years after the filling of the reservoir.

At the beginning, the ichthyomass and production increases; however, in the stabilization period of the hydrological and biological regime in the reservoir these values decrease, as the fish find less nourishment. From Table 17.3 it is also evident that the change in the species composition of ichthyocoenoses is unsatisfactory; it is possible to derive that per 1000 fish about 50 kg of fish perish annually. It is therefore

Table 17.3 Ichthyomass values and fish production in the Kličava reservoir

Indicator [kg ha⁻¹]	1957	1964	1967	1968	1970
ichthyomass	59.1	97.4	194.6	161.3	122.9
production (weight increase)	154.1	971.5	512.6	402.0	285.4
biomass: pike	10.5	3.3	–	–	2.3
tench	4.1	1.4	–	–	0.6
roach	7.4	106.0	165.0	126.0	92.0
Most important species [number of fish per ha]					
roach	75	7471	1720	3450	918
porch	890	650	408	377	149
chufs	15	398	84	174	56
rudd	15	126	58	80	60
tench	6	3	2	2	2
pike	8	3	2	1	2

advisable to place predator fish (pike, pike-perch, trout, etc.) into these reservoirs and to forbid fishing for such species.

The use of impounding reservoirs for fish farming requires collaboration between water-management engineers and biologists. According to present experience, some measures could be taken that would contribute to the improvement of fisheries in reservoirs (adjustment of the bottom in sites of net fishing, damming up the tributaries entering the reservoir, preventation of the escape of fish from the reservoir, regulation of the water level, flunctuations, etc.).

In countries situated in the north (Sweden, Canada, the USA) where salmon-like fish are of great commercial and sporting significance, dams act unfavourably, since they hinder migration of fish. On the Saint John River in Canada three dams obstruct the migration path of salmon. The problem of migration was solved radically by transporting the fish over these obstacles in trucks. It is a system of sophisticated devices that serves to transport 10 to 20 thousand fish upstream yearly. About 1000 breeding fish produce approximately 500 000 young salmon that are again transported below the downstream dam (XIth Congress, 1973, O'Connor *et al.*, Q 40, R 47, p. 755).

Positive effects on fish farming, are caused by impounding the water by dams on the African continent (Cariba between Rhodesia and Zambia, Kainja in Nigeria, Ayamé and Kossou on the Ivory Coast, Volta in Ghana, etc.). In the Volta reservoir the quantity of fish catch increased from 10 000 t to 50 000 t annually. In the Cariba reservoir the annual production is about 17 000 t, i.e., 186 kg ha^{-1}, and might further increase. In the Nasser reservoir in Egypt, 3930 t of fish were caught prior to 1971, when the biological equilibrium was not yet established.

From these examples it can be seen that reservoirs can contribute to an increased fish production; it requires suitable exploitation of their possibilities and measures to control some adverse effects.

The effect of tropical reservoirs on the development of diseases of man and domesticated animal is important. This is manifested either directly by the change in the water regime upstream of the impounding structure, or indirectly by the construction of irrigation canals downstream of the dam. The most important diseases are malaria, bilharzia and onchocerciasis. To fight against them it is necessary to know exactly how they are transmitted. There are measures that reduce the risk, if they are introduced in time. The use of insecticides is not recommended, as they can be harmful to other organisms. Often it is considered more effective and cheaper to cure sick people than to destroy the carrier organism. It is essential to instruct people about the necessary sanitary measures and how to fight the diseases.

Even though certain biological effects of reservoirs are negative, they are not as great as the positive effects. It is the task of water-management engineers, in collaboration with the respective biologists, to overcome the adverse biological impacts.

A reservoir affects the water quality in a river to a great distance downstream of a dam. The problem is to control the water quality by controlling the release from the reservoir. By augmenting the discharge, only those water-quality indicators that have more favourable values in the water flowing out of the reservoir than in the water in the river downstream of the pollution source improve. It is not only a question of diluting wastewaters, but of changing the flow conditions, i.e., vertical and horizontal velocity components, their distribution in the cross-section and the fluctuations in the direction of the river.

Nejedlý (1975) demonstrated both in the laboratory and by measurements in nature that longitudinal dispersion affects the rate of the biochemical oxygen demand and that its velocity coefficient in the river is a relatively simple function of the coefficient of longitudinal dispersion; deoxygenation increases with increasing longitudinal dispersion. This law is valid in the discharge range in which the deoxygenation process is evident and hence measurable.

Figure 17.3 shows a diagram of a water-quality model in a polluted river reach expressed by the BOD_5 value. It consists of two parts. The dimensionless part B expresses the share of the pollution source considered, part A the share of the watershed—both in dependence on the exceedance of the discharge. For polluted river reaches (upstream of pollution sources or far downstream), part A is a complete model and can be constructed for any water-quality indicator.

The relation B has two marked minima, the left in the region of mean discharge $\bar{Q}$ and the right in the range of low discharges; both demarcate the range of the maximum effect of the deoxygenation process between the site considered and the site of the wastewater outfall. The magnitude and mutual position of the two minima often vary; the left is usually deeper, more extensive and simple, compared with the right one. A great discharge creates favourable conditions for a rapid course of the deoxygenation process; it has, however, only a short mean water detention time. With

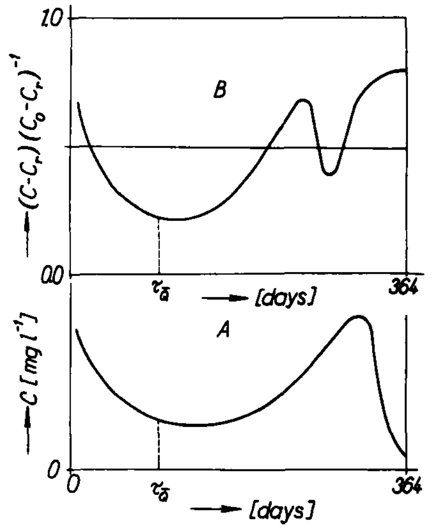

Fig. 17.3 Graphic illustration of a mathematical model of water quality expressed in BOD_5 values (Nejedlý, 1976): C – concentration of substances expressed as BOD_5 following the mean retention time t between the river site and the site of the waste water outfall; C_0 – ideal concentration of substances expressed as BOD_5 in the site of the waste-water outfall ($t = 0$); C_r – residual value to which quality C converges during the deoxygenation process in the river reaches downstream of the pollution source

low discharges the opposite holds true. With a certain ratio of the mean water detention time and flow conditions, the effect of the deoxygenation process is at maximum and the share of the pollution source in the considered river reaches the minimum.

Of considerable significance is the relatively narrow range of the right minimum, where the coefficient of longitudinal dispersion reaches a transitional maximum, and hence there are favourable flow conditions for the deoxygenation process. If the discharges are low, and hence the waste load in the river especially high, and if the water temperature is also high, the risk that will perish increases. A small increase of the discharge is sufficient to moderate the intensity of the deoxygenation process considerably, even at the expense of a deterioration of the water quality, which is slightly compensated by the greater dilution of the wastewaters.

The duration of the augmentation is limited by the water volume in the reservoir that can be released for the given purpose. Naturally, also another operation can be applied, i.e., to lower the discharge to shift it to the right of the right minimum of the pollution-source share and thus to attain again a reduction of the intensity of the deoxygenation process, even though it means a slight deterioration of the water quality in the river.

On the contrary, if the water temperature is lower and there is no risk of high dissolved oxygen deficits with mass fish deaths, it is advisable to control the flow so as to intensify the deoxygenation process as much as possible, i.e., to keep the discharge within the range of one of the two minima of the share of the pollution source and so to maximize the natural self-purification process of the river.

Knowledge of the correlation between the water properties and the discharge permits an effective management of the water in the reservoir, also from the aspect of the water quality in rivers. The relationships seem more complicated than was hitherto assumed, however, their significance for respecting the natural environment in the management of surface waters justified the continuation of this demanding research work.

17.1.3 Impact of reservoirs construction on man

That reservoirs can change the life of man in many respects can be seen from Figs. 17.1 and 17.2. The aim of this book is to show how reservoirs can be used rationally for the purposes for which they were built, i.e., to supply water, control floods and establish an aquatic environment. This is certainly advantageous to man; man must have sufficient water in order to live and to work and should not have to rely on the random character of the natural hydrological regime.

However, reservoirs also have adverse effects on man, some of which can be eliminated and others limited if suitable measures are introduced.

A building site is a source of noise, dust, smoke, and water turbidity. All this is to the detriment of man and the human environment, both in rural areas and densely populated regions. The surroundings are affected by the construction of new roads. Traffic on public roads is hindered by heavy vehicles. The workmen's barracks do not please the local people.

The noise of a building site disturbs the surroundings and is bad for the health of the people working on the dam's construction site. Blasting operations and production of aggregates is accompanied by much noise and dust. When the arch dam at Las Portas, in Spain, was built, over 5000 people were affected by the noise. This initiated studies to reduce this noise, in which engineers (measurements and control), physicians (traumas) and sociologists (changes observed in the people) participated. The noise intensity was determined [dB]: e.g., crushers (95), sorting plant (102), and concrete plant (89 dB). It is very difficult to reduce this noise; one way is to use the ground configuration as a natural screen.

Other measures can be:
- reduction of the intensity of the noise source,
- isolation of the noise source, if its intensity cannot be lowered,
- individual protection, if the first two measures are impracticable.

In the U.S., standards were issued by the Bureau of Reclamation (Environment Act, 1969) concerning exhaust fumes on building sites, dust from stone aggregates, cement and puccolane and waste water flowing from the building site.

Another environmental factor connected with a reservoir is the danger to the people living downstream of the dam. To rid the people living within the reach of a break wave of their fear, safety measures and a reliable alarm service must be introduced.

Actually, the risk of dam failures is very small; out of 10 000 reservoirs only 3 or 4 accidents occur annually and those are mostly caused by floods in regions with little hydrological information.

Most dangerous is the first filling of a reservoir. At that time detailed observations and measurings and their immediate estimation are indispensable.

To move people and industries from the inundation area of the future reservoir requires a very sensitive approach. To keep the people in the region, new houses have to be built and jobs found. Very important, but very costly, is the construction of new roads. One advantage is that these new facilities have a higher technical level, thus actually raising the living standard. In tropical regions, reservoirs and irrigation system even stop the migration of the population, which benefits their living conditions and health.

For the construction of the Keban Dam in East Anatolia, it was necessary to move 30 000 people; compensation for the expropriation exceeded the costs for the construction of the dam and power plant. Besides that, 300 km of roads, 48 km of railroads and a large factory had to be built. The building of the housing estates due to the construction of the Bigge dam in the river Ruhr basin took up two thirds of the overall costs.

In Czechoslovakia, the greatest number of people had to be moved from the area of the Liptovská Mara reservoir with an inundation area of 21.6 km^2. In all, 3400 people had to be evacuated from 30 villages; 17.5 km of railroads and more than 30 km of roads had to be moved (Priehradné dni 1972; Svetlík, p. 249; Macko, p. 257).

The construction of a large reservoir is accompanied by the construction of new villages, industrial plants, farming and tourism. There is the danger of an uncontrolled development of these projects with all of its negative effects on the environment, including water pollution. It is therefore essential to predict the development of the reservoir surroundings and to control it by a well-prepared plan.

New reservoirs often interfere with the scenic beauty of the countryside. In building them, often only their function and utility are considered and not how they fit into their surroundings. This is quite contradictory to ancient structures, such as aquaducts, bridges and dams, the creative beauty of which we still admire today. The simplicity of concrete dams, the simple arrangement of earthfill dams, and the harmony of the curves of arch dams can make a very pleasing scene.

A dam, as an essential part of a reservoir, changes the landscape, but this does not mean that it has to be ugly. However, the untouched nature has to be replaced sensitively by a combination of the landscape and the man-made element. Dams are usually built in beautiful and attractive areas and those who build them must see to it that the scenery does not deteriorate. There is no reason why a well-built dam should not even improve the landscape.

The water surface of a reservoir is always pleasing. A sensitive place is the shore line with possible abrasion pallisades and surfaces that are bared during fluctuations of the water level. Suitable measures help to minimize these negative consequences. When the construction is completed, good care should be taken to remove all the equipment no longer needed, and to leave the place tidy and pleasant.

The impression of a reservoir differs when viewed from a distance or from close to. The total view of the dam should exhibit aesthetic lines, surfaces and materials; the railings, entries, etc., which the public pass must be executed perfectly in suitable colours, materials and shapes. These details reflect the cultural standard of the whole project.

17.2 RESERVOIRS AS AN IMPORTANT ELEMENT OF ENVIRONMENTAL POLICY

A construction as a work by humans, and thus an artificial element, should form a harmonious entity with the surrounding countryside.

Large reservoirs have a rather complicated relationship vis à vis nature. This complexity arises from the functional structural relationship of an impounding reservoir and its environment (Fig. 17.4).

It is given by

– the large dimensions (of the order of tens of km),

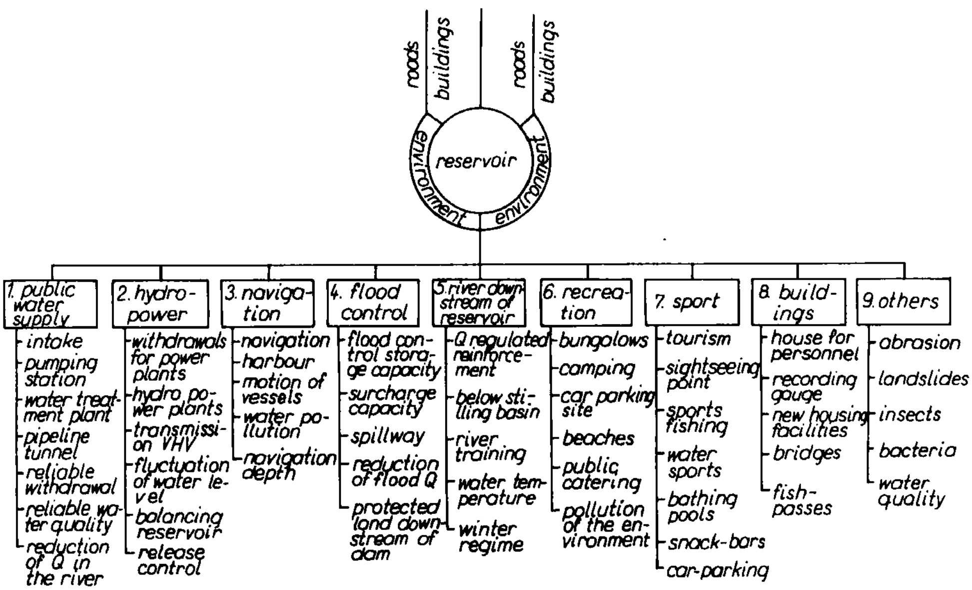

Fig. 17.4 Functional structural relationships of an impounding reservoir and its environment

– complicated relationships between the variable, often random quantities, when the change of one causes the change in others: hydrological regime, recreation and tourism.

With the exception of, e.g., recreation reservoirs, large reservoirs are as a rule built for economic reasons and not to improve the environment and therefore the whole project corresponds to these reasons.

Of special importance are small reservoirs, which can greatly contribute to the environment and are attractive recreational facilities as they can often be found in regions without any large rivers. In Czechoslovakia the density of dams exceeding 15 m is one of the highest in the world, as one reservoir can be found for every 1000 km^2.

A high dam changes the landscape to such an extent that it deserves a careful architectural approach. Masonry and concrete dams cannot be hidden in the landscape, but they should therefore become an integral part of it.

Dams of local material can be fitted to the slopes of the valley in such a way that only the horizontal line of the dam crest can be seen; the dam equipment (intake, outlets etc.) is usually submerged in the water and only the inflow from the lateral or side spillways sometimes outs obliquely into the side of the valley.

Not only is the architecture important for the appearance of a dam, but also the quality of the work, a smooth and even surface of the concrete, straight curbs, railings and breakwaters, even pavements, good-quality coatings, etc. A high standard of the finishing operations is of the utmost importance. Even if a very little is left undone, this can easily spoil the total impression.

The beauty of the water surface is spoilt by devastated banks and the uncontrolled erection of recreational facilities. From an analysis of the exceedance curves of the water level in the various seasons, a suitable vegetation cover of the banks and maintenance of the flat parts of the bottom under constant bakwater can be derived.

Reservoirs in Mariánské Lázně, Bedřichov and others prove how beautiful a reservoir can be if surrounded by forests.

Often the stream channel is affected just below the stilling basin. A proper balance between the absorption of kinetic energy of water in the stilling basin and the reinforcement of the channel below it must be found.

The beauty of a natural river can be spoilt by diverting part of the discharge through canals to power plants or by withdrawals for water supply. A maintained minimum discharge downstream of a dam and an occasional flushing of the stream channel is not only an economic problem, but also has its impact on sanitary and aesthetic conditions.

The construction of a reservoir can change the picture of the surrounding countryside either for the better or for the worse. An unfavourable impact is usually not caused by the construction of a reservoir itself, but is the result of badly carried out or incomplete work. Projects should include scientific prognoses that can eliminate any unfavourable consequences.

A price has to be paid to preserve the beauty of the environment, but even environmental protection has its limits; we cannot stop the construction or limit the main functions of a reservoir. Nature conservationists can ask for certain economic sacrifices and it is also their duty and their right to participate in the elaboration of projects, such as reservoirs that affect the environment extensively.

Water management engineers should be able, with high professional erudition and social responsibility, to understand the present and future needs of a society and to choose such solutions that would meet all demands in the proper proportions.