4 RELEASE (WITHDRAWAL) FROM A RESERVOIR

Besides inflow, the law of outflow from a reservoir is the most important factor in its design. *Outflow* is the water volume that leaves a reservoir per second by outlets, spillways or withdrawal; *withdrawal* is the water volume that leaves a reservoir per second only when it is specifically withdrawn.

Outflow from a reservoir is determined by a *reservoir release schedule*, i.e. a set of principles, rules and directives, approved by water-management authorities. Surcharge over a spillway depends on the water level; the other components of outflow are regulated by various devices and can be adjusted to meet the given demands. The reservoir release schedule includes data about the maintained minimum outflow, i.e., the smallest outflow from a reservoir to a stream must be preserved to meet the demands of other users downstream of it, for sanitary reasons, etc.

Withdrawal of water is given by the need for water, i.e., the sum of water demands from a reservoir with their time pattern and reliability of water supply. Outflow from a reservoir not used for the purpose for which the reservoir was built is called *excess outflow*.

According to the function and control cycle (Table 3.8) withdrawal and controlled outflow can be

- deterministic or stochastic,
- constant or variable.

In designing the storage volume of a reservoir, *water losses* must be taken into account, i.e., the amount of water escaping by seepage, evaporation, etc.

4.1 USERS' WATER DEMAND

To determine the design water demands for the solution of the *storage capacity of a reservoir* is one of the most complicated problems. It must respect the following principles:

- bear in mind the needs of the region and determine all the various demands,
- consider the order of importance of the respective demands,
- consider not only the quantity of water, but also its quality,
- select economically justified time levels for meeting the water demand,
- determine a justified measure of the reliability of the water supply,
- optimize the design by alternative solutions,

- select a justified maintained minimum flow downstream of the reservoir,
- consider cooperation with other reservoirs in the system,
- consider the influence of the environment on the reservoir and its influence on the environment.

Every user has demands as to the time pattern of water supply: water supply for households and industry is relatively balanced throughout the year; irrigation needs are concentrated in the vegetation period; power resources needs are usually concentrated in the winter months.

The designer of a reservoir cannot decide by himself the amount and quality of water for the various users. This is a problem in which many various branches of industry are involved; however, the water-management experts always hold a control and coordinating position.

It is also necessary, although difficult, to determine the future withdrawal. In Czechoslovakia, the following forecasting methods are used:

- analytical smoothing and extrapolation of past time series,
- direct investigations in the most important enterprises, factories, etc.,
- determination of the total demands of the respective production branches,
- application of prospective standards of water needs and demand,
- estimation of the total water demand with respect to the number of people.

All these methods serve extensive more than intensive uses of water resources. They do not incorporate the water price adjustment, which is reflected in an increasing demand for new water resources.

In the nineteen-seventies the term *demand* has been introduced in forecasts of water needs. The future rate of water demand gives more reliable data for the planning of future capital investments for the exploitation of water resources. How these aspects will be applied in future constructions depends on the level of the exploitation of water resources and on the economic system of the country.

The International Institute for Applied System Analysis (IIASA) is preparing, together with the member countries, an extensive *Survey on Methods for Eastimating Water Demands and Waste Water Discharges*. In January 1977 a discussion was held on *Modelling of Water Demands*; further discussions will be organized.

The IIASA considers two approaches to the problem of lack of water:

- gaining new resources (extensive method),
- more efficient utilization of the existing resources (intensive method).

Stress is being put on the second method, which so far has been applied only to a limited extent, as water was always considered a free or reasonably princed "commodity". Fees for water supply and fines for water wastage are not effective enough. If they are low, their influence is very small, if they are high, they are unfavourably reflected in the final product, which in turn affects the consumer.

Thompson and Young (1973) stressed the significance of the forecasting of the "law of demand" for water as:

- enabling alternative proposals for the utilization of water as the factors influencing water demand changes,

- supplying data for the evaluation of whether capital investments for flow regulation or water diversion between catchments are justified.

For economic solutions of the questions of utilization of water and treatment of waste water, analytical methods (Thompson and Young, 1973) or programming methods (Calloway *et al.*, 1974) can be used.

4.1.1 Requirements of public water supply

Supplying households with drinking water is an important task in Czechoslovakia, as it greatly effects the living standards of the people. The greater part of the population receives its water from public water mains (in 1985 it was 76.2%, in the year 2000 it is presumed that it will be 90%). To rationalize the use of water, regional water mains and water mains systems are being built and are supplied from reservoirs.

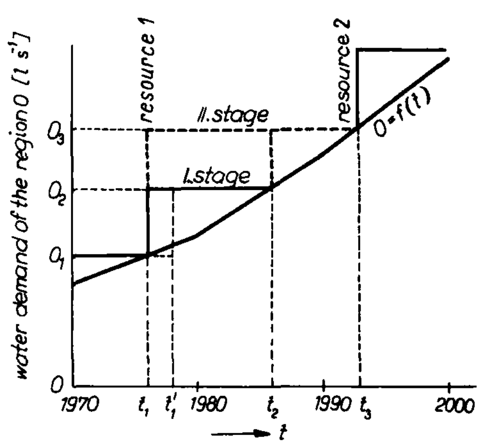

Fig. 4.1 Exploitation of a new water resource in time

The need for a new water source must be determined well in advance, leaving sufficient time for the design and construction. For this, a forecast of the water need in a given area is indispensable (Fig. 4.1).

To take a hypothetical case, the yield of an existing resource will be depleted in 1986 and a new resource *1* should take its place. This is to be a large over-year reservoir which will take ten years to be designed and built. Work on the reservoir should, therefore, have been started in 1976.

The problem of the first filling of a reservoir has to be analysed carefully, as it is only when the reservoir is full that it can carry out its complete function.

The following must be taken into consideration:

- whether the reservoir could start to be filled already during its construction (which depends, among other things, on the type of dam),
- the need for a full output right from the beginning.

It is usually not required that a waterworks reservoir starts full operations right from the first years, and it will only be used completely after several years. Such reservoirs can also be built in stages.

According to Fig. 4.1 the yield of resource *1* is depleted in time t_3 (1993), when the water need will rise to O_3. By building the reservoir in stages, stage *I* could supply a yield of $O_2 - O_1$, which will be depleted in time t_2 (1986); then stage *II* could be build. However, building in stages requires greater capital investment and must therefore be considered carefully. In our hypothetical case, construction would be stopped from 1976 to 1983.

However, the new resource might be put into operation in time t'_1 instead of t_1. At the time between t_1 and t'_1 the lack of water is balanced by measures designed to economize on water. These limiting measures can be mitigated by a more extensive use of other resources, which can be replenished when resource *1* has been completed. This means a depletion of storage volume in other reservoirs, mainly in over-year reservoirs.

Studies of water needs in the region at various time levels help to determine the water demand increase. The storage capacity of new reservoirs is determined by methods corresponding to the respective outflow control (Chaps. 5 to 10). It is usually designed for a constant withdrawal according to the given reliability, which for drinking water is rather high (Section 4.4). Drinking water is largely returned to the stream (about 70%) after treatment in a sewage-treatment plant.

4.1.2 Demands on water for industry

Every branch of industry has its own specific demands as to the amount and quality of water. Only very few technological products need less technological water than their own weight; some need many thousand times more than the weight of the products. In 1985, the water demand in industry was five times higher than for households; of this amount, 12% was for consumption.

The greatest amount of water is needed for power production. Hydro-power plants only make use of the mechanical energy of water; they do not consume water and do not change its quality, but only re-distribute the discharges. Steam power plants need water mainly for cooling purposes and for the transport of slag and ash. The demand for water is very high, especially if no recycling of water is used. In Czechoslovakia, withdrawal of water for the production of heat and electrical power came to $1700 \cdot 10^6\ m^3$ in 1985.

Other large groups of water users in industry are fuel production, products from coal and oil, the chemical industry and the paper and cellulose industry, which in 1970 needed more than $1000 \cdot 10^6\ m^3$ of water. Metallurgy, machinery and the metal-working industries required more than $380 \cdot 10^6\ m^3$ of water.

Even though about 90% of the water used by industry is returned to the streams, industry is still a very demanding consumer as to amount and negative impact on the quality of the returned water.

Industry is not always seriously effected if the supply of water is temporarily decreased. However, in designing new water resources for industry, a large enough reliability of the yield must be ensured. It is possible to use two values of reliabilities: a high value for the supply of water for technological purposes and a lower one for the total demand.

4.1.3 Demands on water for agriculture

Agriculture needs water for irrigation and for livestock. Water demand for agriculture in Czechoslovakia amounted to $225 \cdot 10^6\,\mathrm{m}^3$ in 1985, though only one fifth came from public water mains.

Water demand for irrigation is increasing and the water is almost 100% consumed. The amount in 1970 was $79 \cdot 10^6\,\mathrm{m}^3$, and about $176 \cdot 10^6\,\mathrm{m}^3$ in 1985. Water demand changes greatly according to weather conditions and the amount and distribution of precipitation in time during the vegetation period. This is why the water demands also differ greatly.

When designing the storage capacity of a reservoir for irrigation, the size of the area irrigated must be determined as well as the amount of irrigation water and its distribution in time. If no reliable data are available, the water demand in a so-called *design dry year* is used as a basis.

4.1.4 Demands on water for hydro-power production

Hydro-power systems must consider two aspects in their water demand:

- power production, i.e., the needs of the electric power system,
- water management, i.e., the needs of the other water users.

Different types of hydro-power plants affect the interests of water management in different ways:

(a) *Run-of-the-river hydro-power plants* do not change the flow regime, nor the characteristics of the water so that they affect other users only by a raised water level and any investments that have to be made to ensure navigation, etc.

(b) *Peak-load hydro-power plants incorporated in or adjacent to dams* greatly influence the flow regime of the river without, however, changing the amount or quality (except for changes caused by the very existence of the reservoir). Any unfavourable changes of the discharge downstream of the power plant can be regulated by a daily or weekly storage reservoir.

(c) *Peak-load hydro-power plants on diversion canal* have a similar effect on the flow regime as in (b). If the water is withdrawn from one stream and let out into another, the flow regime of both rivers changes essentially.

(d) *Pumped-storage hydro-power plants* do not as a rule limit other users, except for losses from the upper and lower reservoirs.

Run-of-the-river hydro-power plants do not work with accumulated storage water and can therefore best be designed with the help of flow-duration curves. The volumes of the upper and lower reservoirs of pumped-storage power plants are determined by the demands of the power system, making the solution of water management issues rather simple.

The design of a reservoir with a large share of peak-load power production is rather complicated. The parameters of the reservoir depend on the local conditions and must take into account other water users and also bear in mind the place it occupies in the power system. The reservoirs are usually of the over-year control type. The released water volume is larger in winter than in summer. Besides covering the peak-load parts of the daily diagram, these power plants ensure further services and needs of the power system.

4.1.5 Water demands of other users

Navigation may need a controlled increase of discharge from a reservoir to make a river navigable or to supply water to a canal. For the controlled increase of river stages to be effective, the storage capacity of the reservoir must be large. The economic efficiency of navigation must therefore be considered from the point of view of the total optimal utilization of the water resource.

Navigation on rivers can also make use of the controlled discharge from reservoirs for other purposes, e.g., power production or flood control. Navigation uses water, but does not consume it. It can, however, in certain cases increase the pollution of the river.

A reservoir or a river downstream of a reservoir can be used for *recreation purposes*. Recreation has its demands as to the amount and quality of water. The water level in a reservoir should not change greatly and the banks should be firm. At the time that a river is used for recreation the flow should be large enough to ensure good water quality. This concerns the discharge during dry periods, when it is almost minimum. Summer recreation downstream of a reservoir is unfavourably affected by cold water released from a reservoir, and this influence can be observed up to some dozen kilometres away. The quality of water in a stream can be improved by an occasional flushing of the stream channel by an increased discharge.

Water sports can also be performed on reservoirs and streams. Controlled increase of discharge in the dry summer months is of help. Competitions on "wild" water in the upper sections of rivers usually have to wait for a long discharge wave from a reservoir.

Fish and poultry farming has its specific demands on water management. These can best be met by reservoirs (ponds) constructed for this purpose. Large reservoirs offer suitable conditions for fishing, if the water is clean enough. If, under certain conditions, zones with a low oxygen content appear in the lower levels of a reservoir, incorrect manipulation might cause large numbers of fish to perish.

4.2 HOW TO MEET THE WATER DEMAND

When deciding about how to meet the water demands of a certain region, the demands must be compared with the water resources both as to amount and quality. The results of this comparison supply the most important data for decisions concerning the measures that must be introduced for using the existing water resources and for introducing new ones.

The solution is based on the water-management balance of the past period, the present balance and the forecast balance, for 5 years or up to the years 2000 and 2015. The design of a new reservoir must be based on the study of its function in the whole system and an analysis of its relationship with the environment. Optimization of the design is usually a complex technico-economic and social problem.

Method for determining new resources for drinking-water demands within the framework of regional waterworks

1. Definition of the system and its environment

The final scope of the system (e.g., up to the year 2015) must be determined according to the water plan and natural conditions (water resources, morphology of the territory) and according to the location of villages, industry and agricultural production. The environment of the system is defined and its interactions with the system too.

2. Meeting the needs of industry and agriculture

The system of water supply for a region is divided into sub-systems according to their purpose, e.g., waterworks sub-system, industrial water, water for agriculture, flood control, pollution control, etc. The water demands of these sub-systems must be assessed as well as their links with the waterworks system.

3. Assessment of the present state of drinking-water supply to the region

The present state is described and analysed, including ground and surface water, water users and facilities for the treatment and transport of water. The present operations must be judged as well as all possibilities of a rational utilization of the present resources, e.g., by increasing the capacity of the water mains, a more systematic exploitation of the advantages of systems, etc.

4. Demographic prognosis

With the help of existing data, the future number of people living in the respective parts and communities of a region must be determined to serve as a basis for the calculation of the drinking-water demand in the whole region and its respective parts.

5. Future drinking-water demand

The drinking-water demand is determined according to various spans of time, e.g., up to the years 2000 and 2015. The specific water demands according to the size of the community and the coefficients of unequal demands are determined according to water-management plans. The growing number of people supplied by public water mains must be taken into consideration. Drinking water for industry and agriculture must be determined separately.

6. Balance of demands and resources

For every balance unit the demands and local resources must be compared. From these the demands on the central resources can be determined. The capacity of the existing central resources is assessed with the help of the most recent hydrological data, progressive methods, etc.

7. Drinking-water deficits

Drinking-water deficits are calculated to the given time levels in mean and maximum values and the amount to be covered by central resources is determined. This gives us the year in which a new central resource must be operated.

8. Analyses of potential drinking-water resources

Both ground and surface water is taken into consideration. The most promising resources are considered together with any possible further impacts. Water-management development plans in the given area and its surroundings are taken into consideration.

9. Basic demands on a new water resource (reservoir)

The design of a new reservoir must meet all the aims it is to serve (or the priorities should be stated), e.g., withdrawal of as large as possible an amount of drinking water, improved water quality in a stream for other water withdrawals, improved flood control, ensured recreation facilities, etc.

10. Forecast of the quality of withdrawn water and consequences of reservoir operations

The present and future quality of the water flowing into a reservoir and changes in the quality as a result of water storage in a reservoir must be judged. Protective zones are designed as well as other measures to ensure a good quality in the stream and tributaries. A forecast of the effect of waves on the reservoir banks, the effects of periodical emptying and filling of a reservoir, any possible eutrophication of a reservoir, the winter regime, etc., must be determined. Figure 4.2 shows the time-related lowering of the water level in a reservoir which, if the banks are not under water for any length of time can lead to overgrowing of a reservoir banks by vegetation and the deterioration of water quality (Kubín, 1976).

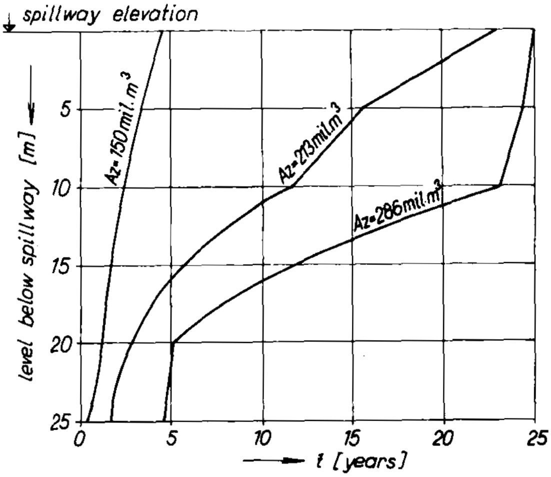

Fig. 4.2 Continuous depression of the level below the spillway elevation in relation to the storage volume A_z

11. Determination of reservoir parameters

The parameters of a reservoir which form the basis of the conception and dimensions of the project are determined by a technico-economic evaluation of alternatives.

4.3 WATER LOSSES FROM RESERVOIRS

A reservoir changes the runoff from an inundated area as a result of evaporation, infiltration, formation of ice and changes in the water storage (ground water, snow, etc.).

Changes in the runoff as a result of *evaporation* are caused by changes from the land surface to water surface. The difference in the water balance E caused by evaporation and changes in the water storage can be expressed by the relationship

$$E = E_v - E_p \pm \Delta W \tag{4.1}$$

where E_v is evaporation from the water level,

E_p – the total evaporation from the territory prior to inundation (from the soil and transpiration),

ΔW – change in the water storage.

ΔW can influence the water balance of short seasons. Mean annual water storage does not change essentially, so that one can write

$$\bar{E} = \bar{E}_v - \bar{E}_p \tag{4.2}$$

Evaporation $\bar{E}_p$ can be expressed as the difference between precipitations $\bar{X}$ and runoff $\bar{Y}$ from the inundated area, therefore

$$\bar{E}_p = \bar{X} - \bar{Y} \tag{4.3}$$

so that

$$\bar{E} = \bar{E}_v - (\bar{X} - \bar{Y}) \tag{4.4}$$

If, in the time interval Δt [s], E is given in metres, and if the increase in the water level caused by a reservoir is denoted by ΔF [m^2], the mean change per second of the water balance (by evaporation losses) q [m^3 s^{-1}] in interval Δt can be written as

$$q = \frac{E\,\Delta F}{\Delta t} \tag{4.5}$$

whereby ΔF changes according to the state of the water level in a reservoir.

J. Váša (Váša and Wurm, 1975) calculated the evaporation from a pan 5 m in diameter at Hlasivo (547 m above sea level) with an average temperature slightly higher than the long-term average for the period from 1957 to 1974. Table 4.1 gives the values supplemented by measurements with a Wild atmometer in the winter months (November till March).

Table 4.1 Evaporation distribution during the year (J. Váša)

Month		1	2	3	4	5	6
Mean daily	[mm d^{-1}]	(0.2)	(0.3)	(0.7)	1.5	2.2	3.0
evaporation	[%]	1.19	1.54	4.35	8.70	12.70	16.97
Max. daily evaporation	[mm d^{-1}]	(1.9)	(3.1)	(3.8)	5.7	7.0	7.1

Month		7	8	9	10	11	12
Mean daily	[mm d^{-1}]	2.9	2.8	1.9	1.0	(0.4)	(0.4)
evaporation	[%]	17.16	16.39	10.72	5.80	2.41	2.09
Max. daily evaporation	[mm d^{-1}]	7.8	6.5	5.3	5.1	(3.0)	(2.6)

The mean annual evaporation was 528 mm (1.45 mm day^{-1}), the mean evaporation during the vegetation period (April – September) was 436 mm, mean evaporation during summer (June – August) was 267 mm (50% of the annual evaporation).

P. Petrovič elaborated a nomograph to determine the mean daily evaporation from the water level according to the mean (monthly) pressure of water vapour in the air and according to the mean air temperature (Fig. 4.3).

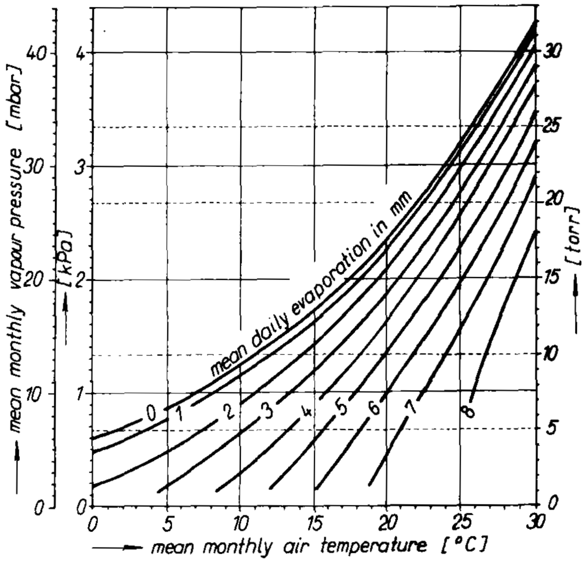

Fig. 4.3 Determination of the mean daily evaporation from a free water level by means of a nomograph

If the influence of evaporation on a reservoir is small, it is sufficient to include in the design the mean annual evaporation; if the influence is greater, a more detailed analysis must be worked out (Section 2.1.2). If the evaporation in the low-period is large, evaporation losses are included in the design with a certain probability

$$p' = 100 - p \tag{4.6}$$

where p is the design reliability of water supply.

Seepage can be just as important for the design of a reservoir as evaporation. Water can escape through the banks or bottom of a reservoir, the dam or other functional structures (bad sealing, etc.). When including seepage losses in the design it must be decided whether the water escapes to another valley or whether it returns to the river downstream of the dam, and whether water is withdrawn from a reservoir or from the river downstream of a reservoir. In the first years seepage is rather extensive, later it usually decreases.

The extent of seepage through the dam and subsoil can in simple cases be calculated or assessed by suitable analogues.

Table 4.2 Leakage in Czechoslovak reservoirs (M. Šimek)

Type of dam	Number of reservoirs with leakage ($l\,s^{-1}$) less than 5	 $5 \div 20$	 more than 20
earth	17	6	2
rockfill with earth sealing	4	1	1
earth and rockfill with concrete, asphalt-concrete sealing, PVC foil	2	2	1
concrete and masonry gravity	with some exceptions less than $0.15\,l\,s^{-1}$ per $1000\,m^2$ of wetted area, only exceptionally more than $2\,l\,s^{-1}$		

Note: With half the depth of backwater, leakage drops below 20% of the values of the full depth of backwater.

Losses caused by bad sealing, can be determined by using the type of equipment described in the literature or from data supplied by manufacturers.

Table 4.2 shows seepage through the dams of Czechoslovakia.

Water losses caused by ice cover have a greater impact only in reservoirs with flat banks, which have a great drop in their water level in winter, when the ice cover rests on the banks and temporarily (until it melts or until the water rises again) decreases the available water volume in a reservoir. If the mean width of the ice resting on the banks is h and the water level at the beginning of the winter is F_b and at the end of the winter F_e, the water losses caused by ice are

$$\Delta V = 0.9h(F_b - F_e) \tag{4.7}$$

4.4 RELIABILITY OF WATER SUPPLY FROM RESERVOIRS

From the economic point of view it is indispensable to introduce the rate of reliability into the solution of technical and economic problems. It is a very important question, as only a small change in the value of the rate of reliability leads to an essential change in the basic parameters of a reservoir. Although the determination of an optimal rate of reliability of water supply for any purpose is mainly an economic problem, it also has its non-economic impact.

Definition of the basic terms of reliability

Reliability of water supply from a reservoir (or energy from a hydro-power plant) is the probability that the ensured parameter of water supply (or energy) will not drop below the given value. The parameter can be the amount per year, the amount per second, output, etc.

More generally, the *design reliability of a reservoir* (hydro-power plant) can be defined as the probability that the users will receive the full amount of water (energy), needed for their most expedient operations.

Quantitatively the design reliability can be expressed

(a) as the ratio (percentage) of the number of years in which the ensured supply of water (energy) is not limited, to the whole period in question—occurrence-based reliability P_o;

(b) as the ratio of the duration of water (energy) supply without any breakdowns to the total duration of the period in question—time-based reliability P_t;

(c) as the ratio of the actually supplied water (or energy) to the value of the demand on water (energy) supply during the period in question—quantity-based reliability P_d.

In all three cases the rate of reliability of water or energy supply from a given reservoir is expressed as a percentage P of the value of the full amount meeting the needs during the period in question.

The *total deficit of water* (energy) $\Delta \sum O_p$ during the given period is the total amount of water (energy) in m^3 (kW h) that is lacking, during low-flow periods, to ensure the volume of water (energy) that is to be supplied.

The *relative deficit of water* (energy) is the ratio of the total deficit to the demanded quantity of supply during the whole period in question, expressed as a percentage $(1 - P_d)$.

Mean annual deficit of water (energy) is the share of the total deficit of water during the given period and the number of years.

For *flood control*, the term reliability reflects the average time (number of years) in which the design value of non-damaging flow (the so-called recurrence interval of floods) is not exceeded.

However, it is no longer only the quantity, but mainly the quality that has to be taken into consideration. Regulated flow in streams helps to dilute waste waters and to increase the water quality, relationships between the discharge and the water quality are not simple and are being studied further. Water also changes its quality in reservoirs, sometimes to its detriment. In determining the optimal reliability of water supply, we must always bear in mind not only the quantity, but also the quality, which can have direct economic and non-economic consequences.

Economic aspects must be considered from the economic and not only from the technical point of view. Methods using economic parameters are less reliable than those using technical parameters, as the availability of statistical and economic data is limited. Difficulties arise as it is almost impossible to assess exactly the economic consequences of a limited supply of water and it is also most difficult to evaluate the impacts caused by deficits of drinking water objectively, by maintaining the minimum flow in the river etc.

Water balances incorporate the meeting of water demand with various degrees of reliability for various users, depending on the consequences caused by incomplete water supplies. The rate of reliability of a full supply of water is given by a *standard of design reliability*, determined on the basis of the occurrence of unfavourable hydrological conditions in long-term perspectives.

In hydrological series of several decades, the period of a minimum discharge corresponds to a reliability of 95 to 99%. This reliability has become the standard for important consumers. Where a decreased supply does not cause any great damage, failures are admitted to occur once every five to ten years, i.e., 80 to 90% probability of years without any failure. Sometimes two standards of reliability for two withdrawal values are given: a lower one for the full standard of needs, a higher one for a reduced minimum.

Supplies ($P = 97$ to 99%) must be ensured for industries and housing estates. Supplies can be decreased for navigation, irrigation and hydro-power plants in large power systems with base-load thermal power-plants.

The higher the standard of the design reliability, the smaller the losses caused by deficits of water, but the higher the capital investments that have to be put into the water resource. By comparing the two consequences, an economic optimum for the meeting of the demands of the respective users is found. As it is very difficult to solve these problems, the design standard is determined on the basis of experience from design and operation practice.

In compiling a balance, the standards of the design reliability $P_{0\,\mathrm{des.}}$ are usually given as a share [%] of years, in which water is supplied without any failure.
The values usually are:

	[%]
(a) supplies for households and industry	95–99
(b) irrigation (for the growing season)	90–95
(c) livestock farming	95–97
(d) hydro-power production	80–95
(e) navigation	90–95
(f) maintained minimum discharge in streams	95–99

Over-year release control must have a higher design reliability than seasonal control. If water is withdrawn from a stream without a reservoir, the design reliability $P_{t\,\mathrm{des.}}$ can be given as the share of the duration of time in which the supply is fully guaranteed.

More accurate standards than $P_{0\,\mathrm{des.}}$ should be used in those cases where they convincingly express the economic consequences of deficits of water.

4.5 LOCATION OF THE ACTIVE STORAGE CAPACITY IN A RESERVOIR

The *total storage capacity of a reservoir* A_c with a volume V_c, confined by the bottom and sides of a reservoir, by the dam (or weir) and the maximum water level, is usually divided into smaller areas, according to the purpose of the reservoir (Fig. 4.4).

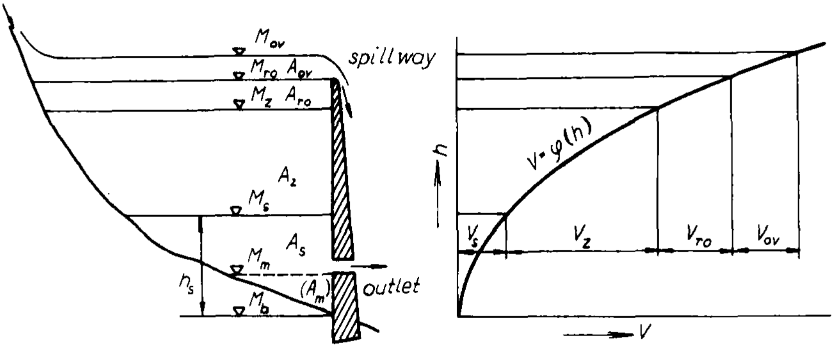

Fig. 4.4 General scheme of the division of a reservoir storage capacity

(a) *dead storage capacity* A_s, which under normal conditions is not used for flow control, but for the settling of sediments, to ensure the required water quality, to create a head, to preserve a sufficient amount of water for fish when the higher regions of a reservoir are emptied in low-flow periods, etc.; a part of the permanent storage is the technological dead capacity below the lower outlets, which cannot be emptied without pumping,

(b) *active storage capacity* A_z, which helps to regulate the flow and withdrawals in low-flow periods,

(c) *flood control capacity* A_r, which catches the water from floods and transforms flood waves; it can be regulated (A_{ro}),

(d) or non-regulated (A_{rn}), called also *surcharge capacity* (A_{ov}), which is above the level of the overflow crest of an uncontrolled spillway or the overflow crest of a controlled spillway.

The sum of the volume V_z of the active storage capacity and the volume V_r of the flood control capacity gives us the volume of the regulation capacity.

The *size of dead storage* is usually given indirectly by the minimum permissible operation level of the active storage capacity; decisive therefore is its depth h_s and not its volume V_s, which we try to make as small as possible so as not to increase the total volume of a reservoir and thus its costs. This is also why we place the bottom outlets as low as possible to avoid any technological dead storage or making it only large enough for sediments to settle.

To ensure a *good quality of water* (especially in reservoirs for drinking water) the minimum level of the active storage capacity M_s should be relatively high above the bottom of a reservoir; usually 12 to 15 m. The reason is that water to be withdrawn should be out of the reach of any chemical or biological factors near the bottom and that an adequate depth of water is preserved above the place of withdrawal even at the time of the reservoir's lowest level (Fig. 4.5).

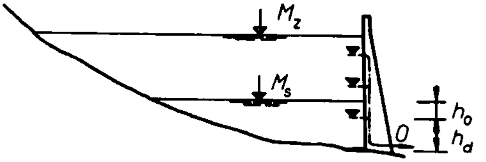

Fig. 4.5 Depth of dead storage level M_s corresponding to the lowest withdrawal level from a withdrawal device built in steps

From the point of view of the quality of water (especially its temperature), a great depth of the active storage capacity is important, as it enables withdrawals from various levels (or from several levels simultaneously), while preserving the quality of the withdrawn water.

A *suitable head* is most important for hydro-power plants. The various types of turbines used in hydro-power plants need a relatively steady head, which is reflected in a given minimum level of the storage capacity. Reservoirs with hydro-power plants therefore usually have a relatively large dead storage capacity (e.g., Orlík reservoir $A_s = 280 \cdot 10^6\,\mathrm{m}^3$ and $A_z = 364 \cdot 10^6\,\mathrm{m}^3$). The minimum head needed for water withdrawal by diversion canal (for water treatment plants, for irrigation, etc.) can also be one of the deciding factors in the selection of the water level.

In the interest of *preserving the natural environment*, the storage capacity should ensure that the flat muddy parts of the valley are under water level, even when a reservoir is being emptied; the water level should not change to any great extent when a reservoir is also used for recreation purposes.

The storage capacity on gravel-bearing streams has its specific characteristics. The forecast of the gradual *silting of a reservoir* with gravel influences not only the position

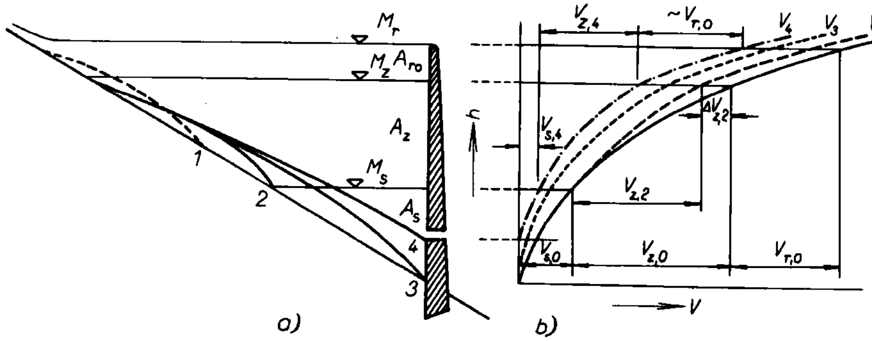

Fig. 4.6 Diagram of the silting of a reservoir and the corresponding elevation-storage curve
(*a*) change in the longitudinal profile due to silting; (*b*) corresponding change of elevation-storage curve

of the active storage capacity (dead storage serves to collect the sediments), but also its size (silting of a reservoir decreases its storage capacity). In Fig. 4.6, a cross-section of a reservoir shows the gradual filling with gross sediments: presuming that the flood control capacity A_{ro} is empty, it is the active storage capacity A_z that is the first to be filled. As sediments reach a reservoir mainly during flood flows, it is at that time that the flood-control capacity is filled (in Fig. 4.8 dotted, stage *1*); in view of the large inundated area, the decrease in size is relatively small.

In stage *2* the original active storage capacity decreases from the original $V_{z,o}$ by $\Delta V_{z,2}$ to the value $V_{z,2}$; the other capacities remain unchanged.

In stage *3* the sediments reach the foot of the dam, partly silting the dead storage capacity A_s and increasing the silting of the active storage capacity.

In stage *4* the dead technological capacity is completely silted, the volume of dead storage decreases from the original $V_{s,o}$ to $V_{s,4}$ and the active storage capacity decreases to the value $V_{z,4}$.

The whole silting process is, however, more complicated. Sediments have different grain size, from gravel to fine suspended particles. Gross sediments settle mainly at the end of the backwater due to the decreased carrying force, fine sediments usually go as far as the dam. Gross sediments shift constantly deeper into a reservoir as the result of the smaller depth of the stream channel due to silting, which again increases the flow rate and also as the result of the changes in the water level of a reservoir. Reservoirs are silted not only by sediments from the inflow, but also by abrasion of their banks caused by waves.

If the active storage capacity is used for flood control in connection with the forecasting service, a rapid decrease of the reservoir volume must be possible. The same applies to reservoirs which are built to solve difficult sanitary conditions or removal of ice downstream of a reservoir with the help of an artificial discharge wave.

If a reservoir does not have any flood control function, the level of the active storage capacity can be its maximum level. This solution allows for a sufficiently large gated spillway. If the spillway is not gated, there must always remain an uncontrolled capacity above the level of the active storage capacity, the depth of which is determined by the need to transfer the design flood over the spillway. If a reservoir also has a flood-control function, a flood-control capacity can usually be found above the active storage capacity (see Chap. 12).

Another way to solve the problem of special demands on the storage capacity is a *reserve capacity*, by which the design value V_z has to be increased.

The boundary between the dead storage and the active storage capacity and between the active storage and flood control capacity need not be fixed. The size of the storage capacity is designed with a water supply reliability $P < 100\%$. In a specially low-flow year, the storage capacity can be completely emptied and a deficit in the water supply can occur. At that time water from the dead storage capacity can be used.

The boundary between A_z and A_{ro} is less defined, if the active storage capacity is also used for flood control, either according to forecasts or after the partial or complete catching of a flood wave in the over-year storage capacity that has previously been slightly emptied.