6 WITHIN-YEAR (SEASONAL) RELEASE CONTROL

A reservoir works with a *within-year* (*seasonal*) *cycle* if it is able to distribute the discharges to cover the required withdrawal within a year, i.e., if the mean withdrawal is less than the mean discharge in the driest years.

This definition explains the essence of within-year release control, it is, however, not completely accurate. In the introduction to Chapter 5, within-year release control is explained as a special case of over-year control, when the probability of the occurrence of years with a mean discharge $Q_r < \bar{O}_p$ is very small. It is then possible to

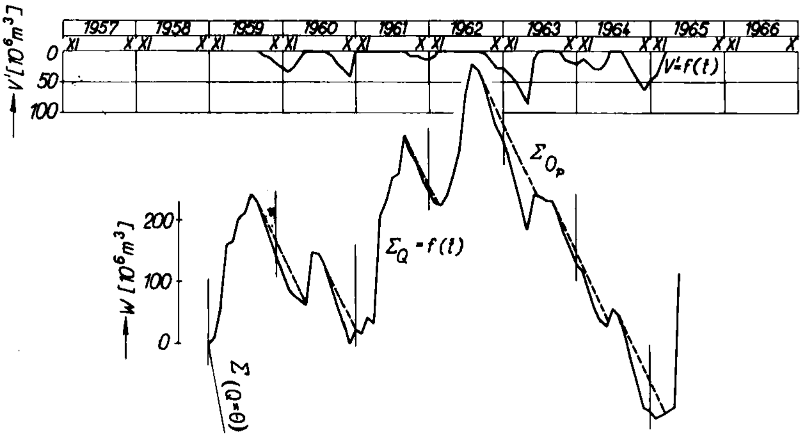

Fig. 6.1 Work regime of a reservoir with within-year release control for a constant reliable yield (withdrawal) O_p (in mass curves $\sum_Q, \sum_{O_p}$)

neglect the influence of these years on the reservoir regime without making the results less accurate. We actually have to neglect this infl… as there are no available data for its quantitative expression. This approach is significant from the technical point of view as the method for calculating the within-year release control can be derived from the methods of over-year release control.

In Figure 6.1, a time curve of the filling (emptying) of the storage capacity derived, e.g., from the graphical solution in mass curves of inflow ($\sum_Q$) and withdrawal ($\sum_{O_p}$), illustrates the regime of a reservoir with within-year release control in a ten-year period. Inflow to a reservoir is identical with the case in Fig. 5.1; presuming a constant safe yield $O_p = 12\,m^3\,s^{-1}$ ($\alpha \doteq 0.4$). The reservoir's working cycle is in no case longer than one year. The beginning, termination and duration of low-flow periods are very variable, which is typical for many rivers. The same applies to a quick refilling of the storage capacity. In view of the not very high relative yield (even if it is close to the upper limit for within-year release control), the probability of the occurrence of years in which the inflow to a reservoir does not drop below the value of the required withdrawal and a reservoir does not exert its influnce, is relatively high. In the ten-year period in Fig. 6.1 the probability of a full reservoir (in terms of duration) is ~64% (for the over-year release control illustrated in Fig. 5.1 it was only 31%).

The annual cycle of a reservoir is not identical with the water year (November – October) nor with the calendar year (January – December). For rivers with a simple hydrological regime, the so-called *water-management year* can easily be defined; its beginning coincides, e.g., with the beginning of the wet period. For irregular regimes this term is less strictly defined: usually the only rule is that the reservoir cycle should be completed within one water management year.

The term *within-year release control* refers to the annual discharge cycle which, in spite of the differences in the respective years, is a general phenomenon with a genetic justification. The equivalent *seasonal release control* is derived from the seasonal character of water withdrawal (e.g., for irrigation, hydro-power, food industry, etc.).

In the framework of an annual cycle much shorter release control can also be applied, e.g., daily or weekly (if the reservoir also serves as a storage or balancing reservoir for peak load or pumped-storage hydro-power plants), which might affect the size of the storage volume; however, these calculations can be carried out separately.

In view of the random discharge distribution in the respective years, probability methods are also used for within-year release control.

One possibility is statistically to process significant factors of the annual discharge cycle, e.g., beginning of low-flow periods, duration and depth of discharge depressions, analogous signs of wet periods, etc., and to create an unreal hypothetical design year. This process, which is suitable for rivers with a simple discharge pattern, cannot be applied to complicated hydrological conditions (Votruba and Broža, 1966). In this case, statistical methods should be used only after gaining further results in real series (necessary storage capacities in the respective years or regulated discharges). Stochastic discharge series can be used similarly as for over-year release control.

6.1 STORAGE CAPACITY DETERMINED WITH THE HELP OF EXCEEDANCE PROBABILITY CURVES OF NECESSARY VOLUMES

Here we apply the method described in Section 5.1.2 in its general formulation for over-year release control, using the basis of water years. With given withdrawal values O_p and with a design reliability P_o (occurrence-based), the theoretical storage capacity $V_z(P_o)$ is sought.

In within-year release control, the relationship $Q_r \geqq O_p$ holds for all the years of the real series. (If one or two years with $Q_r < O_p$ occur in the series, they can be neglected or the method for over-year release control can be applied.) In every year the respective parts of the storage capacity *init* ΔV_z, *end* ΔV_z and *mid* ΔV_z are then determined by the same method as the respective parts of the seasonal component—Section 5.1.2, equation (5.22) to (5.24)—and after adding the value of *end* ΔV_z of one year (t) and *init* ΔV_z of the following year ($t + 1$), an "empirical" probability curve $V_z(1) = f(p)$ is constructed and then a probability curve *mid* $\Delta V_z = f(p)$, which is the component of the size of the storage capacity (Fig. 6.2).

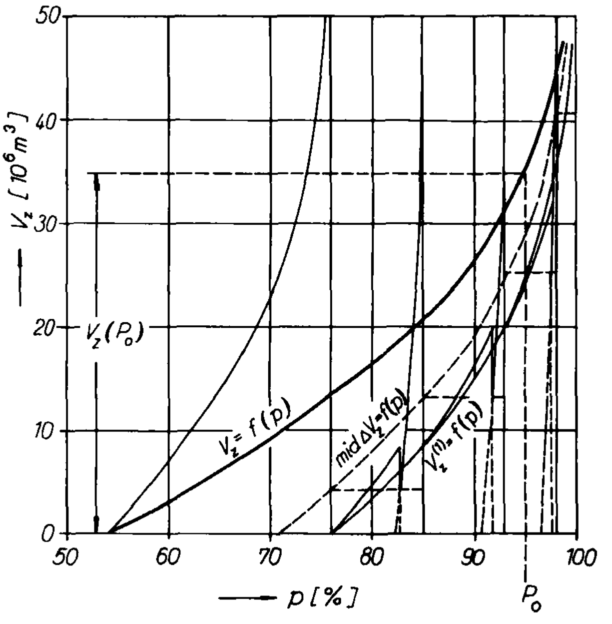

Fig. 6.2 Construction of probability curve of necessary storage volumes $V_z = f(p)$

Over-year low-flow periods do not have to be taken into consideration (the probability curve $V_z^v = f(p)$ is zero, therefore the method is greatly simplified. It only remains to select the significant values $V_z(1)$ and *mid* ΔV_z (see Fig. 5.17), the result of which is the *probability curve of the needed storage capacity* $V_z = f(p)$, from which we obtain, for the design realibility P_o, the resultant size of the storage capacity $V_z(P_o)$ (Fig. 6.2).

This method can also be applied if we look for the yield (withdrawal) with a given size of storage capacity. We select several O_p values (all within the seasonal release control), repeat the calculations, construct the relationship $V_z = f(O_p)$ valid for the design reliability P_o, and from that we determine the withdrawal O_p for the given size V_z.

Similarly as for over-year release control, calculations can be simplified by *V. G. Andreianov's method*, however, in this case without any detriment to accuracy.

The size of the volume necessary to ensure a withdrawal O_p is determined for every water management year by direct calculations. After arranging the values V_z in order of increasing magnitude, whereby a certain number of necéssary volumes equal zero (in relation to the relative yield α), the probability curve $V_z = f(p)$ is constructed, giving the resultant storage capacity $V_z(P_o)$ for the given reliability P_o.

6.2 DETERMINATION OF THE YIELD (RELEASE, WITHDRAWAL) FROM A RESERVOIR USING FITTED THEORETICAL CURVES

The method presumes a given size of storage volume and the quantity to be determined is the augmented release from a reservoir.

In every water management year of the real hydrological series, the theoretically possible withdrawal is determined; this is possible by distributing the discharge to be ensured by the given storage capacity. The basic relationship is simple:

$$O_{p,t} = Q_{lf} + \frac{V_z}{\tau_{lf}} \tag{6.1}$$

where Q_{lf} is the mean discharge in the low-flow period $[m^3\,s^{-1}]$, V_z – the size of the storage capacity $[m^3]$, τ_{lf} – duration of low-flow period $[s]$.

The term *low-flow (dry) period* in a year is a relative term, referring to the mean discharges in the year. In more complicated cases, where the duration of a low-flow period cannot be clearly estimated, it is indispensible to make the calculations for several estimated periods and to select the one with the smallest $O_{p,t}$ value. A mass discharge curve greatly facilitates the selection of the most critical low-flow period. The $O_{p,t}$ value can be determined with the help of a computer, but as all possible alternatives must be systematically tested, this is time consuming.

A statistical population of theoretically possible $O_{p,t}$ withdrawals in which, as compared to Andreianov's method, all members are non-zero, is arranged in order of decreasing magnitude; then the basic statistical characteristics and the curve of exceeding $O_{p,t} = f(p)$ are ascertained, from which we determine the safe O_p (P_o) yield corresponding to the required reliability P_o.

The author of this method Liapichov (1955) states that the types currently used in statistical evaluations of discharges can be used for curves of exceedance and statistical characteristics of possible $O_{p,t}$ withdrawals. The skewness coefficient can be the same as for mean discharges in low-flow periods (this refers to rivers with a simple hydrological regime), or mean annual discharges. More suitable is a graphical—numerical method using quantiles (Fig. 6.3).

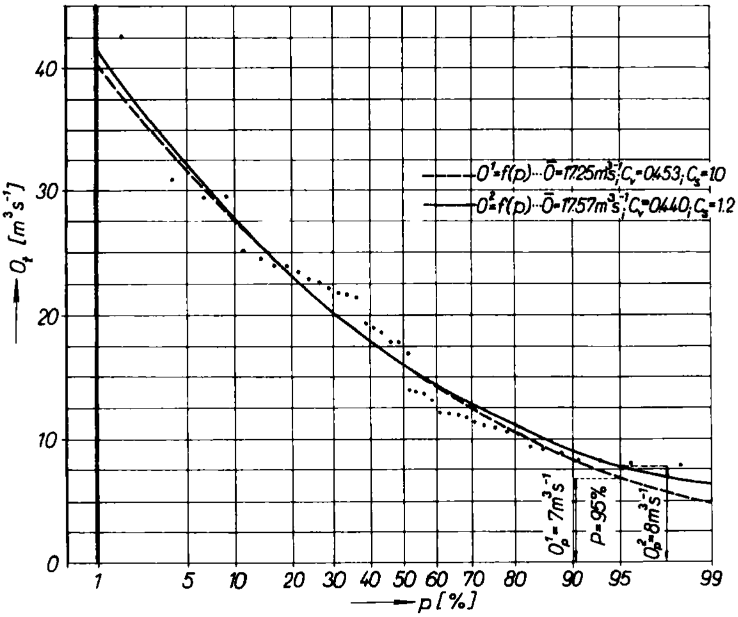

Fig. 6.3 Exceedance curve of theoretical withdrawals with a given size of storage capacity (Liapichov's method)

In Fig. 6.3 one can also see the shortcomings of Liapichov's method. The dotted curve of exceedance fits the sample of empirical points as well as the full curve; the most significant differences are in the interval of high P values (due to the different skewness coefficients), which are usually design values. The dotted curve of exceedance leads with $p = 95\%$ to an O_p value which is 10% lower and with $p = 99\%$ more than 30% lower as compared with the original curve.

6.3 CALCULATIONS OF WITHIN-YEAR RELEASE CONTROL IN SYNTHETIC DISCHARGE SERIES

Synthetic discharge series is justified for within-year release control mainly in the boundary regions between seasonal and over-year release control and also for complicated release control pattern from a reservoir, especially in real-time reservoir operation (see Chap. 4). The same applies to reservoirs with an annual cycle, which are important parts of a more complicated water resources system (e.g., to raise the yield by transbasin water diversion).

Mostly synthetic series of mean monthly discharges are used, even though they supply only approximate data for seasonal control. The modelling of series of, e.g., mean ten-day discharges must have many input constants ($3 \cdot 36$ statistical characteristics, $36 \cdot 36$ members of correlation matrix, etc.), including the risks they reflect (e.g., the errors in estimation of sample characteristics will increase). An experiment with synthetic series of mean daily discharges (Water Resources Development and Construction Institute, Prague, 1970), showed that such series should be used only for some special calculations.

Solutions in synthetic series for within-year release control are identical with the algorithm in Section 5.2, equations (5.29) to (5.35). By repeated calculations for several suitably selected sizes of storage capacity V_z', with a given value of withdrawal O_p, the relationship $V_z' = f(p)$ is obtained (Fig. 5.22), where the desired size of storage capacity $V_z(P)$ for the design reliability P can also be found.

For within-year release control it is also possible to apply in random series some of the statistical methods originally meant for real series (e.g., Andreianov's method) as a suitable means to verify the results.

6.4 ACCURACY OF RESULTS IN WITHIN-YEAR RELEASE CONTROL

6.4.1 Error in the size of the storage capacity resulting from the application of series of mean monthly discharges

In annual reservoir cycles mean monthly discharges are a rough schematization of the continuous time function of the discharge $Q = f(t)$, especially with a low level of yield α, so that they can cause great errors in the determination of the release control parameters (α, β_z, P). Bratránek (1939) compared the results of real *series of mean daily and mean monthly discharges.* Presuming that at the beginning or at the end of the "design" low-flow period a month occurs in which the mean discharge is influenced by a flood, Bratránek derived a relationship for the estimation of the error in the size of the storage capacity when using mean monthly discharges

$$E(\beta_z) = 0.08(\alpha - 0.1) \qquad (6.2)$$

The *probability method for release control* was studied at the Technical University in Prague (1976) to supply information about the influence of errors caused by the use of mean monthly discharges to determine the storage capacity with the help of the probability curve of necessary volumes (Andreianov's method). In several gauging sites in the Labe catchment, calculations were made for the period 1931 to 1970 in mean daily discharge series and in mean monthly discharge series for $\alpha = 0.2$; 0.3; 0.4, and over. Probability curves of the necessary volumes were constructured and deviations ΔV_z were evaluated in per cent of volumes resulting from mean monthly discharge series (Fig. 6.4).

However, no general conclusions can be drawn from these calculations. Clearly as the result of random influences on the pattern of the probability curves of necessary volumes, it is often difficult, to construct the relationship ΔV_z [%] $= f(\alpha)$ as a continuous declining curve, as had been expected.

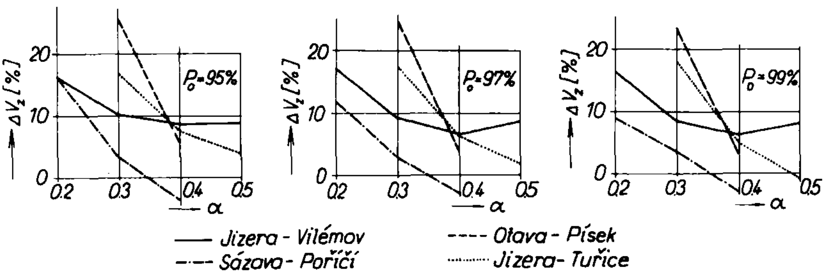

Fig. 6.4 Errors in determining the size of the storage volume using mean monthly discharge series

Of note is the relationship between the errors ΔV_z [%] and reliability P_o [%]. In most cases the values ΔV_z [%] decrease with increasing reliability. The reason most probably is that the increments of ΔV_z (absolute) are independent of the values of V_z (month). If the probability of the occurrence of certain absolute increments ΔV_z is approximately the same for any V_z value (month) a decrease of the relative error ΔV_z with increasing reliability (and therefore with increasing V_z) is a logical consequence. As the probability curves of necessary volumes are usually constructed from a small number of "empirical" points, another random factor is introduced which distorts the results. A great number of hydrological series will have to be processed in order to generalize the results.

It also follows from the analysis that the size of the errors resulting from the application of mean monthly discharges must be evaluated from the point of view of the method that was used. For example, when using Liapichov's method the values of the theoretically possible withdrawals in the respective years will be lower when using mean daily discharges than when using mean monthly discharges. In this case, too it can be expected that the deviations $\Delta O_{p,t}$ (absolute) are independent of the values O_p.

The method using synthetic series of mean monthly discharges is essentially the same as when using probability curves of necessary volumes for the design of the storage capacity. A correction can therefore be made of the results gained from synthetic series according to the relationship between the "daily" and "monthly" quantities resulting from the real series. A theoretically more correct procedure would be to determine in the real series the deviation ΔV_z (absolute) from calculations in daily and monthly discharges; a probability curve $\Delta V_z = f(p)$ is constructed which is then combined with the probability curve $V_z = f(p)$ gained from repeated calculations in synthetic series of mean monthly discharges (for various V_z values with same O_p).

6.4.2 Influence of the input real series on the characteristics of release control in an annual cycle

When using statistical methods for within-year release control, the influence of the input real discharge series on the results of the solution can also be observed.

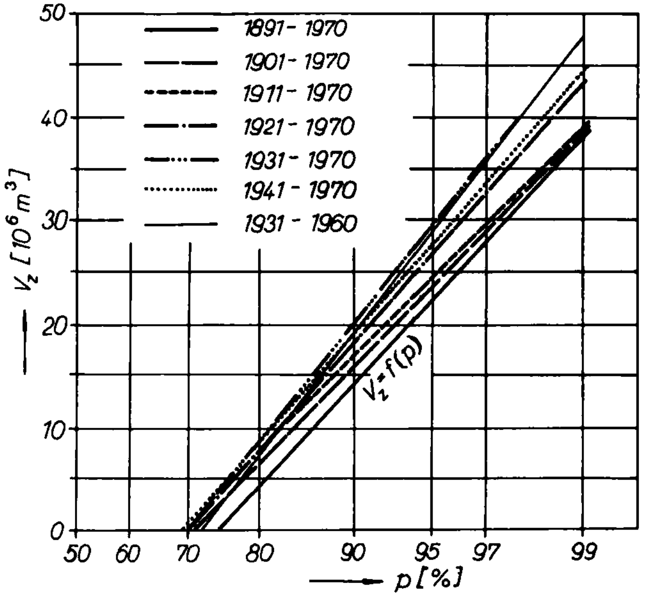

Fig. 6.5 Variability of the probability curves of necessary storage volumes (Andreianov's method) in relation to the input observation period (the river Berounka – Křivoklát)

Figure 6.5 shows a probability paper with plotted probability curves of necessary storage capacity (from mean monthly discharges) in the Křivoklát site on the Berounka, presuming a withdrawal of $O_p = 8\ m^3\ s^{-1}$ ($\alpha \doteq 0.25$) for an 80-year period from 1891 to 1970 and for several other selected periods. The differences are relatively large; e.g., the storage capacity V_z with $P_0 = 95\%$ for the period 1931 to 1970 is 34% greater than the respective value from the 80-year series. The possibility of such great differences is in agreement with the results gained from the study of synthetic series, where approximately the same differences of the α values regardless of the size β_z or of the β_z values, regardless of the size of α could be observed (Fig. 5.30, Section 5.3).

In seasonal release control the risk of deviations (errors) in design values $V_z(P_o)$ or $O_p(P_o)$ has been generally considered to be much smaller than in over-year control. We have proved that in spite of using statistical methods and after correcting the results of calculations with series of mean monthly discharges, the reliability in determining the characteristics of within-year release control is approximately the same as for over-year control.

6.4.3 Corrections of the storage capacity with regard to evaporation losses

Evaporation losses can be calculated approximately without affecting the accuracy. The duration of a low-flow period typical for the given degree of discharge regulation, its time in the year, total evaporation depth $\sum H_E$ [m] and the average water level in a reservoir $\bar{F}$ [m^2] for this period must be determined. Then the water volume lost by evaporation from the water level Z_v [m^3] is given by the relationship

$$Z_v = \bar{F} \sum H_E \tag{6.3}$$

The extent of evaporation should be determined for several years which have had the highest claim on the size of the storage capacity; of particular significance are the summer and autumn low-flow periods. An inundated area related to three-quarters of the depth of the storage capacity can be considered as a reliable estimate of $\bar{F}$.

The volume that should be added to the theoretical V_z size to cover evaporation losses is, in annual control, usually only a few per cent of the V_z value.

6.4.4 Water-management plan for reservoirs with power plants

If reservoirs which regulate discharges for peak-load hydro-power plants work in an annual cycle, a low-flow year (approximately the "design" year, or even a failure year), an average year, or a high-flow year can be selected in the real discharge series. Direct calculations are then carried out, including the time pattern of the filling of a reservoir, tailwater and headwater, the head and mean power-plant output.

Figure 6.6 shows a low-flow year (the storage volume empties without causing any failure) and an average year. In order to illustrate this, a graphical method was used. In winter (November – February) release is 50% higher than in the rest of the year.

From direct graphical calculations on mass curves of $\sum_Q$ and $\sum_O$, the time pattern of filling $V = f(t)$ can be obtained by plotting the vertical distances between them from the horizontal base. With the help of volume-depth curves $V = \Phi(h)$ and the secant under a 45% angle, we obtain the time behaviour of the fluctuations of the level of the headwater $h = f(t)$.

Presuming that the tailwater level is constant (e.g., the mean level of balancing reservoir), we obtain the head curve $H = f(t)$ simply by shifting the scale of the ordinates.

With a known release O (Fig. 6.6a) and gross head H (Fig. 6.6d), the time pattern of mean outputs can be calculated from

$$\bar{P} = 9.81\eta OH$$

which is plotted in Fig. 6.6e.

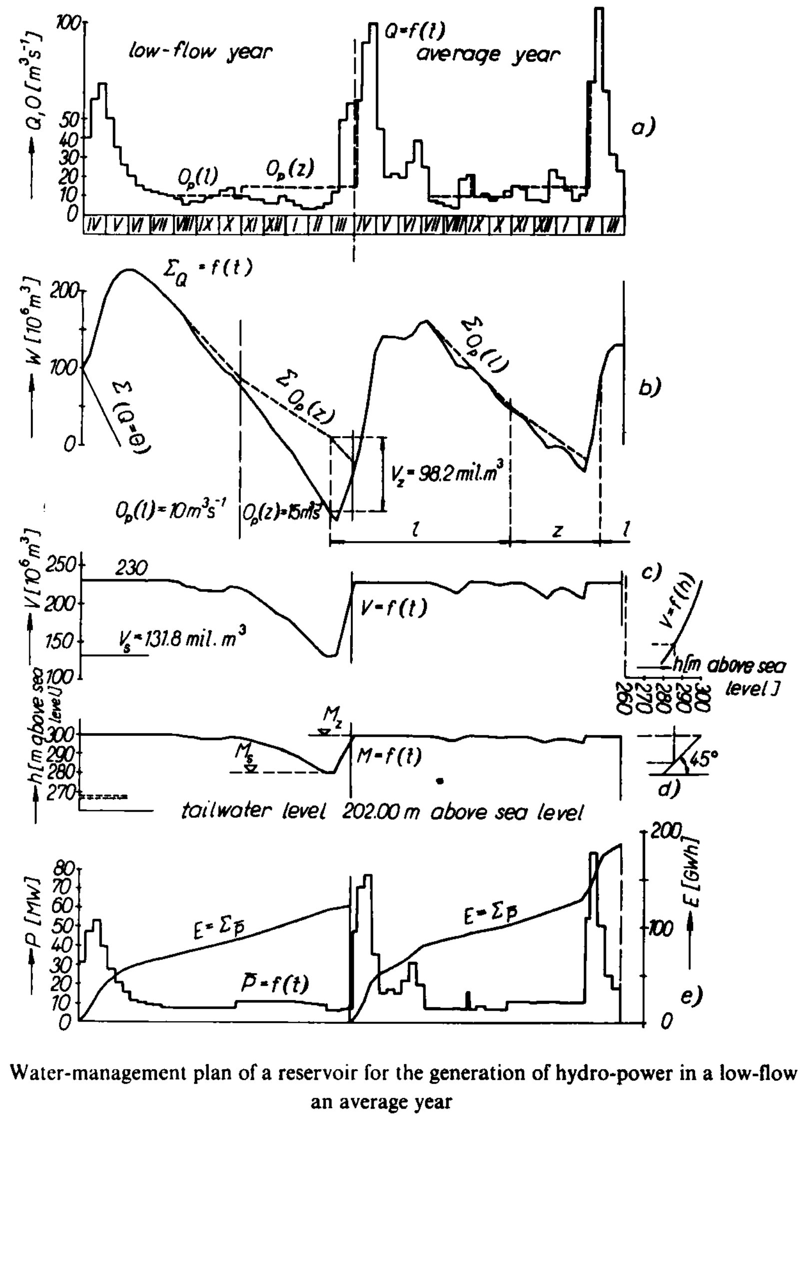

Fig. 6.6 Water-management plan of a reservoir for the generation of hydro-power in a low-flow and an average year

On the curve of mean outputs $\bar{P} = f(t)$ a mass curve $E = \sum_{\bar{P}}$ is constructed, the ordinates of which give us the annual production of electrical power.

Calculations for three suitably selected years provide basic information about the electrical power parameters of a reservoir. More extensive information is obtained from calculations of the whole observation period (real hydrological series) and statistical evaluations of the reliability of outputs and power production in the respective years. This applies all the more to over-year release control of reservoirs for hydro-power stations.

6.4.5 Within-year release control using curves of exceeding mean daily discharges

For small reservoirs with a direct supply function for various needs, which are mostly found on small streams for which there are no discharge observations available, the curves of exceeding mean daily discharges are sufficient as a basis for the estimation of the size of the storage capacity.

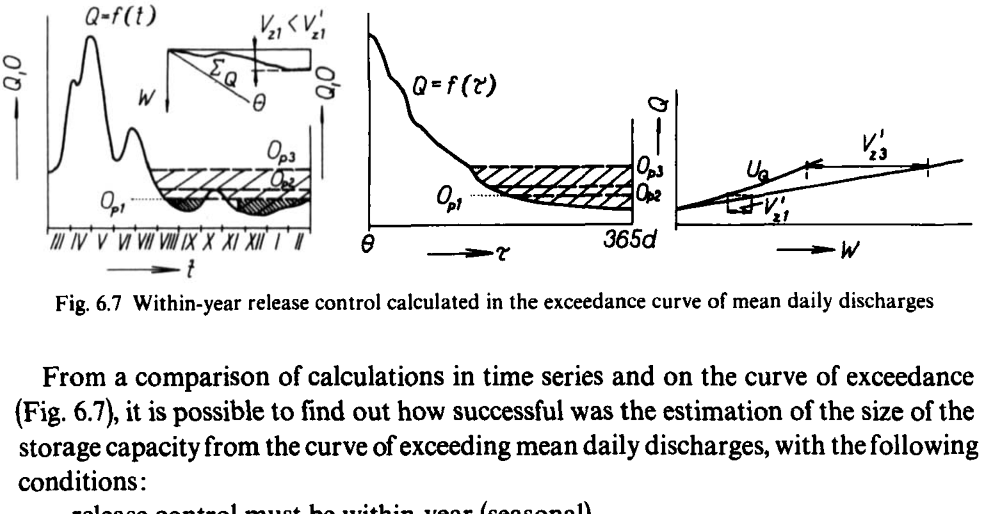

Fig. 6.7 Within-year release control calculated in the exceedance curve of mean daily discharges

From a comparison of calculations in time series and on the curve of exceedance (Fig. 6.7), it is possible to find out how successful was the estimation of the size of the storage capacity from the curve of exceeding mean daily discharges, with the following conditions:

- release control must be within-year (seasonal),
- water withdrawal is constant,
- the period of augmented discharge is continuous, or interrupted only by insignificant discharge peaks.

The size of the volume $V_z(\tau)$ determined by the curve of exceedance equals, or is greater than, the volume $V_z(t)$ ascertained on the time curve. Differences can vary from negligible values up to tens of per cent, depending on the discharge fluctuations (Votruba and Broža, 1966).

It can be presumed that in low-flow years with continuous discharge depressions, the storage capacity will not be over-estimated by more than 20 to 30% when using curves of exceedance.

An important problem is the definition of the "design" curve of exceeding mean daily discharges and its characteristics. So-called mean exceedance curves naturally cannot be used to estimate the size of the storage capacity. Much better from the point of view of low-flow periods is the so-called minimum exceedance curve (Hydrometeorological Institute, Prague, 1970), even though even this curve has no direct relationship to the specific low-flow years.

Due to the above-mentioned unclarity, which continues to increase when introducing the rate of reliability of water supply in the solutions, it is better to use suitable estimated flows based on measured flows making it possible to work with time discharge series; shortcomings in hydrological data must be balanced by a greater "safety margin" in the calculations.