7 SHORT-TERM RELEASE CONTROL

In short-term release control the cycle of filling and emptying a reservoir is of the order of days; in *periodical release control* the cycle is regularly repeated (usually with a one-day or weekly periodicity), in *non-periodical release control* a reservoir is filled and emptied irregularly, according to hydrological conditions or according to needs.

Periodical control serves to meet the periodical variability of water demand during 24 hours or during the seven days of a week, if the water demand is not the same for all the days of the week.

An example of a *non-periodical short-term control* is the accumulation of water from a small resource for short intensive irrigation, for additional re-regulation of the controlled discharge from reservoirs upstream, etc.

7.1 DAILY RELEASE CONTROL

Daily release control is applied when the periodically repeated reservoir cycle lasts for one day (24 hours). An example could be a water tank, a balancing reservoir for a peak-load hydro-power plant, reservoirs for pumped-storage hydro-power plants, etc.

7.1.1 Capacity of a water tank

The water demands of public water supply vary greatly during the day. This must be taken into consideration when assessing the yield of the water resource and in determining the parameters of the waterworks facilities, such as the pipelines, water tanks, etc. Fluctuations of water demand depend on the character of the community. If no more detailed data are available, then Table 7.1 can be used as a basis. The table also shows the distribution of water demand in Prague on June 12, 1964. From the values in Table 7.1 we can determine the necessary storage capacity (water tank) to meet the variable withdrawal, if we know the behaviour of the inflow to the water tank as a percentage of the water demand throughout one day. Thus we ascertain the size of the necessary storage as a percentage of the water demand in one day.

Figure 7.1 gives a graphical solution for a water tank for a housing estate. The mass demand curve $\sum_O$ and the mass pumping curves $\sum_P^1$ from 10 p.m. till 6 a.m.

Table 7.1 Hourly water demand as a percentage of daily demand

Hour	For coefficient k_h 1.8	For coefficient k_h 2.1	Prague 12th June 1964	Hour	For coefficient k_h 1.8	For coefficient k_h 2.1	Prague 12th June 1964
24– 1	1.0	1.6	2.4	12–13	5.0	4.6	5.0
1– 2	0.7	1.5	2.9	13–14	5.0	4.8	3.9
2– 3	0.7	1.5	2.4	14–15	4.0	4.6	6.0
3– 4	0.7	1.5	2.3	15–16	5.0	4.6	4.0
4– 5	2.0	3.0	2.7	16–17	5.0	4.6	5.7
5– 6	3.0	4.2	3.0	17–18	6.0	5.0	5.3
6– 7	5.0	5.0	6.3	18–19	6.5	6.5	3.9
7– 8	6.4	5.0	1.3	19–20	7.5	8.8	6.1
8– 9	4.5	5.0	4.9	20–21	5.0	5.0	4.9
9–10	5.5	4.6	4.8	21–22	5.0	4.6	4.5
10–11	5.5	4.2	6.0	22–23	4.0	3.2	4.0
11–12	5.5	4.6	4.7	23–24	1.5	2.0	3.0
				total	100.0	100.0	100.0
				ratio max : min	10.7	5.87	4.85

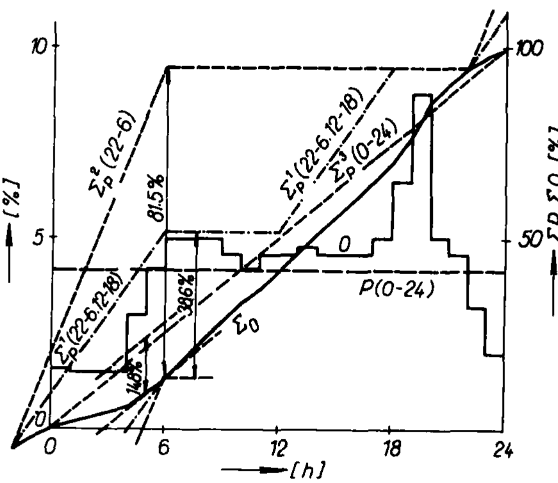

Fig. 7.1 Calculation of the volume of a water supply tank for a housing estate with different times of pumping

and from 12 a.m. till 6 p.m., $\sum_P^2$ for pumping only from 10 p.m. till 6 a.m. and $\sum_P^3$ for pumping throughout the day are plotted. It can be seen that in the first case the necessary storage capacity is 38.6%, in the second case 81.5% and in the third case 14.8% of the demand in one day. The way water is pumped to the water tank greatly influences its size. If we want to limit pumping to night time, the volumes of the water tanks and the output of the pumps and engines must be much greater.

When pumping proceeds throughout the day or when the inflow to a water tanks is uniform and if the all-day inflow and withdrawal are equal, 4.16% of the all-day demand flows into a water tank per hour and the necessary storage, in terms of Fig. 7.1, is 14.8%.

A uniform inflow to a water tank is used mainly for filling without pumping, in which case the minimum yield of the resource must be verified; very frequently it is slightly more than the water demand. Under these circumstances the water tank volume can be much smaller (Volejník, 1959). If the minimum yield of the resource exceeds the maximum daily water demand by 40 to 60%, there is no need for a water tank.

7.1.2 Daily release control for hydro-power generation

Figure 7.2 shows the load distribution of the electric power system of Czechoslovakia in the four seasons of 1975, and the changes of position, depth and duration of the peeks during a year can be seen.

The load variability during a day is reflected in the daily release control in several ways:

(a) *In reservoirs with within-year or over-year release control* a daily cycle is reflected only by small fluctuations of the water level so it can be disregarded when judging the work of a reservoir and power plant. The influence of great and sudden withdrawals causing currents of water in the reservoir which affect the quality characteristics of the water in reservoir and the water flowing out of it has not yet been determined.

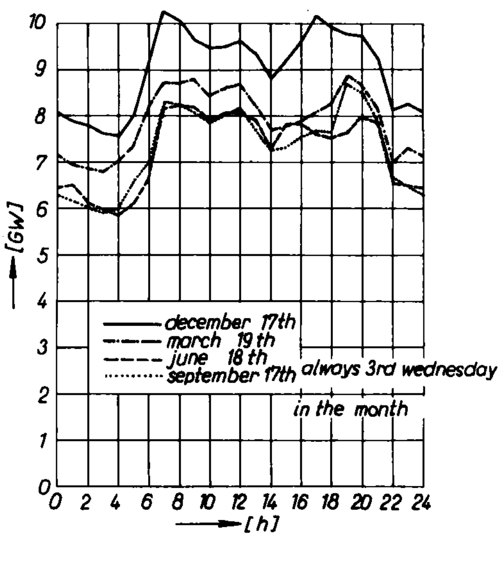

Fig. 7.2 Daily load of the power system in Czechoslovakia in 1975

(b) *In the balancing reservoir* of a peak-load hydro-power plant the inflow is given indirectly by the load of the plant. When the fluctuations of the head and the efficiency during the day are negligible, then the shape of the output diagram is identical to the shape of the inflow curve to the balancing reservoir, if the scale of ordinates is changed according to the relationship

$$P = 9.81\eta QH = KQ \tag{7.1}$$

where P is the hydro-power plant output at the turbine shaft [kW],
η – effectiveness of the turbine,
Q – discharge through the turbines [$m^3 s^{-1}$],
H – hydro-power plant head [m].

An analysis of the work of the balancing reservoir of a peak-load hydro-power plant can be found in Fig. 7.3. A diagram of the load of a power system receiving its power from thermal-power plants (*TPP*) and hydro-power plants (*HPP*) is also plotted in Fig. 7.3. The insufficient output and production is to be augmented from the newly designed HPP_2, which can store the necessary amount of water and can therefore be used to cover peak loads up to the 30% deficits of the total maximum load of the system.

A summation curve $E = f(P)$ can be used for an analysis of how to cover the load diagram—Fig. 7.3b. In point *1* the vertical (at the level of 70% of the maximum load) marks the value $P_p = 11.6\%$ on the line of mean peak outputs. The same value can be found between points *3* and *4*; point *3* is the point of intersection of parallels *1*, *3* to the straight line of mean peak (or basic) outputs, with the vertical drawn through the end point of the summation curve. The summation curve defines that HPP_2 is to supply 14.5% of the total production in the system, which must be met by the power resource with the required rate of reliability.

In Fig. 7.3c the load diagram of HPP_2 takes the shape of two trapezoids (dot-and-dash curve); attached to it, on the left, is a scale of P in kW. Presuming that in equation (7.1) the value $9.81\eta = 8.5$ and the head $H = 50$ m (i.e., constant with a negligible fluctuation $\pm 10\%$), then the load diagram can be considered to be the discharge curve through the turbines and therefore the inflow curve to the balancing reservoir of a peak-load hydro-power plant, with the scale

$$P = 9.81\eta HQ = 425Q \tag{7.2}$$

i.e., 425 kW corresponds to 1 $m^3 s^{-1}$, or 100 MW ... 235 $m^3 s^{-1}$.

In the same way, it is possible also to attach to the summation curve in Fig. 7.3d the power scale E [GWh] and the scale of the water volume, from the relationship 1 cm = 1 GWh = 100 000 kW · 10 h = $8.46 \cdot 10^6$ m^3, i.e., $10 \cdot 10^6$ m^3 = 1.18 cm. The peak of 300 MW in the summation curve corresponds to the production of $E =$ = 3.06 GWh d^{-1} and the necessary amount of water $25.9 \cdot 10^6$ m^3.

According to the summation curve E, about 1.1 GWh (i.e., $9.3 \cdot 10^6\ m^3$) are needed to distribute the flow to reach the mean value. However, as the diagram has two peaks, divided by a trough that is greater than P_p, these values are slightly higher than the accurate values that are absolutely necessary. These accurate values can be found from the summation curve $\sum_Q \equiv E$ in Fig. 7.3e, drawn with a pole distance of $f = 2.5$ cm, for the scale of the mass curve to be the same as the scale of the summation curve. The size of the storage capacity needed to balance the inflow to meet a constant release is $V_z = 8 \cdot 10^6\ m^3$, which is the volume of the storage capacity of the balancing reservoir.

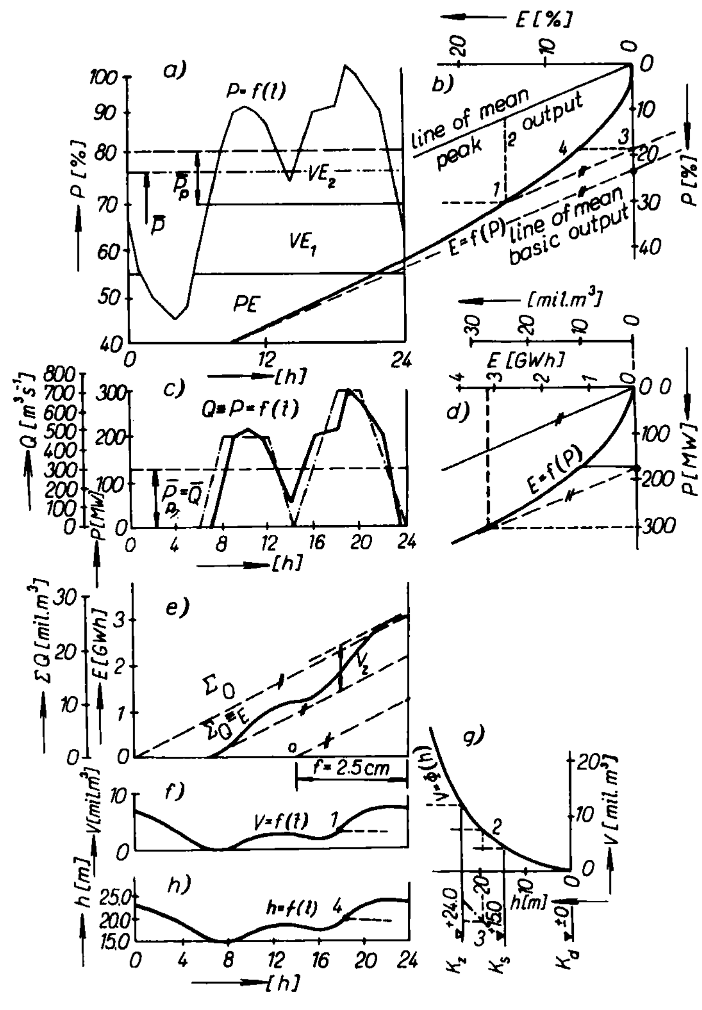

Fig. 7.3 Design and operation of balancing reservoir downstream of a peak-load hydro-power plant H = const.

From the relationship between the curves for mass inflow $\sum_Q$ and release $\sum_O$ from the balancing reservoir (Fig. 7.3e), the curve of the filling and releasing of the balancing reservoir $V = f(t)$ can be transferred to Fig. 7.3f.

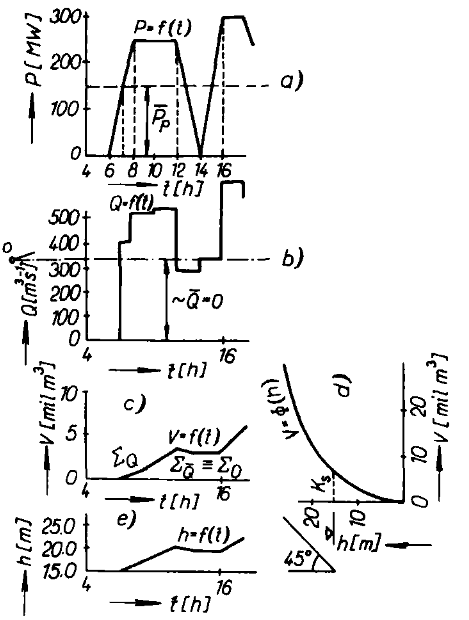

Fig. 7.4. Graphical-numerical solution of a balancing reservoir downstream of a peak-load hydro-power plant, taking into account the variability of its head

If the depth-volume curve of the balancing reservoir $V = \Phi(h)$—Fig. 7.3g—is suitably joined to the curve of the filling and releasing, it is possible to draw over this curve, at a secant of a 45° angle, the curve of the fluctuation of the level $h = f(t)$; the method is determined by points *2*, *3* and *4*. The level fluctuates from evaluation 15 to 24. In view of the head of the peak-load *HPP* ($H = 50$ m), fluctuations are rather extensive and can influence the volume of the balancing reservoir and the shape of curves $V = f(t)$ and $h = f(t)$. However, it can be expected that the influence is not of greater order than that of the schematization of the base curves Q and P (Fig. 7.3c).

For a precise solution it would not be possible to have the curves Q and P in Fig. 7.3c identical, but we would have to start with the given curve $P = f(t)$ and look for the curve $Q = f(t)$, e.g., using the graphical-numerical method shown in Fig. 7.4 and in Table 7.2.

From Fig. 7.3c, e we first of all determine the value $\bar{P}_p$, $\bar{Q}$ and A_z. In Fig. 7.4a we find the moment for which we know the position of the water level in a reservoir; the best moment is when the reservoir is empty and is beginning to be filled; at that moment (7 a.m. o'clock) we start calculations. We solve the problem in intervals (1 or 2 hours) and the initial as well as the calculated, or graphically determined, values are then written down in Table 7.2 and plotted in Fig. 7.4.

Table 7.2 Balancing reservoir considering the variability of the head of a peak-load hydro-power plant

Hour	Elevation main	Elevation balancing	Head H (m)	Output P (MW)	$Q = \frac{P}{8.5H}$ [$m^3 s^{-1}$]	Note
7.00 a.m.	70.00	15.00	55.0	200	427.5	balancing
8.00 a.m.	70.00	16.00	54.0	250	545	reservoir
10.00 a.m.	70.00	18.00	52.0	250	565	empty
12.00 a.m.	70.00	20.00	50.0	125	294	
2.00 p.m.	70.00	19.00	51.0	150	346	
4.00 p.m.	70.00	19.00	51.0	300	691	
6.00 p.m.	70.00	22.00	48.0	–	–	
–	–	–	–	–	–	
–	–	–	–	–	–	
–	–	–	–	–	–	

We consider the state of the level (70.0) in the main reservoir to be constant throughout the day. At 7 a.m. the balancing reservoir is empty, the level is at the elevation of dead storage $M_s = 15.00$. The head is therefore 55 m which we apply to the first interval from 7 to 8 a.m.; a certain inaccuracy arises from the fact that the initial state of the head is used for all the following intervals.

From Fig. 7.4a we read the mean output of the interval (200 MW) and calculate the corresponding discharge $Q = P/8.5H = 427.5\ m^3 s^{-1}$.

To obtain the changes in the filling of the balancing reservoir, we draw the mass inflow curve $\sum_Q$ and the mass release curve $\sum_O$ from pole o at the height $\bar{Q}$. Then the mass curve $\sum_O$ is a horizontal straight line, which at the same time is the axis for the curve of filling $V = f(t)$, which is given by the vertical distance between the two mass curves.

From the curve of filling and releasing and the depth-volume curve of the balancing reservoir $V = \Phi(H)$ and a secant under a 45° angle, we obtain the curve of the state of the levels in the balancing reservoir $h = f(t)$, from which we start to solve the next interval.

As we must know the state of the level in the reservoir for the further calculations, we write it down in the table—at 8 a.m. it is 16.0 m—and we calculate the head $H =$ $= 54$ m for the next interval 8 till 10 a.m. with an output of 250 MW and a calculated discharge of $Q = 545\ m^3 s^{-1}$. We draw the next section of the mass curve $\sum_Q$ within the limits of this interval and we transfer the filling at the end of this interval (about $1.7 \cdot 10^6\ m^3$) to the state of the level (about 18.0 m), whereby we obtain, for the next interval 10 till 12 a.m., a head of $H = 52$ m, etc. For a real project, larger scales of all curves should be used to make the values more accurate.

Water-resources engineering also makes use of the opposite function of a reservoir with daily release control, i.e., to divide the uniform inflow to serve a non-uniform release. The reservoirs are called distribution reservoirs. A water tank with a constant inflow has a similar "distribution" function.

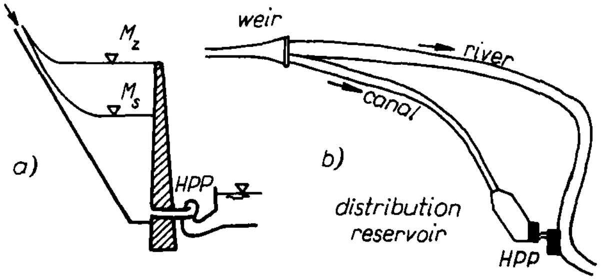

Fig. 7.5 Diagram of utilizing hydro-power from the distribution reservoir
(*a*) power plant by the impounding structure; (*b*) on the derivation canal

This can be the case of a peak-load hydro-power plant with an impounding structure forming a small reservoir, the volume of which is only large enough for daily or weekly release control (Fig. 7.5a). Inflow to the reservoir is considered to be constant and release according to the character of the structure and the needs of the power system.

It can also be a case of utilization of hydro-power with a long derivation canal with a free water level and a peak-load hydro-power plant. Here the conduit is usually designed for peak discharges. The conduit is cheaper if designed only for a mean daily discharges which can be the case when there are suitable conditions at the end of the conduit for a distribution reservoir (Fig. 7.5b). In both cases the pressure pipeline (penstock) to the power plant must be able to meet a peak discharge. It must be considered from the economic point of view which of the alternatives is more suitable.

A general solution for the capacity of a distribution reservoir is given in Fig. 7.6. Calculations were made on summation curves *E* and *U*, although it was a case of daily discharges with two peaks.

Figure 7.3 shows how to determine accurately the necessary storage capacity V_z of a balancing reservoir on mass curves of $\sum_Q$ and $\sum_O$. We shall explain how we can find the correct V_z value using only summation curves, without having to draw mass curves.

From the chronological curve $P \equiv O = f(t)$ we draw the duration curve $P_\tau \equiv O_\tau$ and from it the summation curve $E \equiv U_o$ from pole o'. The horizontal distance of the summation curve from the straight line of mean basic withdrawal determines, for any value O_i, how much water is needed to reach the amount $\Delta U_i = O_i \cdot 24 \cdot 3600$ [m^3]. On the level of O_{max} this shortage is expressed in the scale of the sum-

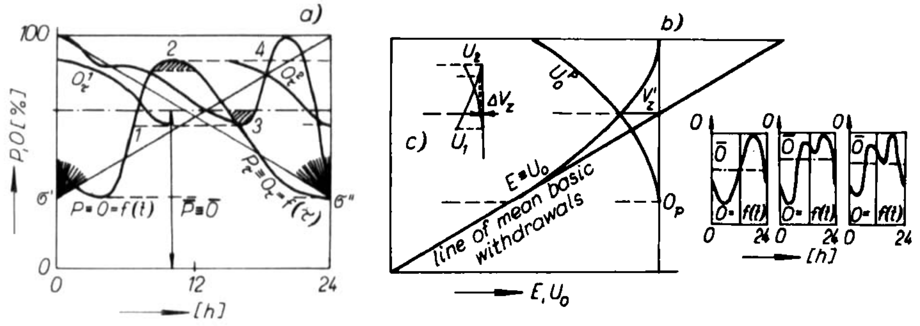

Fig. 7.6 Analysis of a distribution reservoir in summation curves

mation curve by the abscissa ΔU_{max}. On the level of $\bar{O}$, this shortage equals the excess water during withdrawal peaks above this level. This value in the case of one or two peaks with a slight trough (where O'_{min} between the two peaks $\geqq \bar{O}$) equals the storage capacity necessary for the distribution of a constant inflow $P = f(t) = \text{const} = \bar{O}$ for the non-uniform withdrawal of $O = f(t)$; in Fig. 7.6d there are three cases in which this simple solution was used to determine the correct volume of a distribution reservoir.

An analysis of the distribution function of a reservoir can be shown graphically if we draw a summation curve U_O^P of the above-mentioned water shortage into ΔU_i. We draw this curve from pole o'' to the duration curve O_τ, starting from point O_p. It follows that its distance from the vertical must be, at the same level, of the same size as the horizontal distance of the summation curve U_O from the straight line of mean basic withdrawals; it can therefore be constructed also in this simple way. The two curves U_O and U_O^P intersect at the level $\bar{O}$ and the distance of this point of intersection from the vertical drawn through the end ordinate of the summation curve U_O gives us the volume of the distribution reservoir, with only a slight inaccuracy caused by the two peaks.

The way to determine the precise V_z value of a distribution reservoir for withdrawal with two pronounced peaks, using summation curves, is shown in Fig. 7.6a, b, c. It is clear that the necessary V_z must be smaller than the V_z' value in Fig. 7.6b by the volume shown in Fig. 7.6a by the respective area of the trough of the curve O below the value P between both peaks. In Fig. 7.6c it is therefore sufficient to draw the summation curve U_2 to the trough (*2, 3, 4*) transferred into the duration curve O_τ^2. On the level of $P = \bar{O}$, the horizontal distance U_2 from the vertical drawn through the initial point of the trough gives us the volume ΔV_z, by which V_z' must be decreased to obtain the correct value V_z. If all the summation curves are drawn at the same scale (with the same pole distance), it is sufficient to subtract the abscissae, i.e., $V_z = V_z' - \Delta V_z$ to determine V_z.

To determine which withdrawn amount has to be replaced (hatched area at the top *2* of the curve $O = f(t)$), we draw the summation curve U_1 to the peak (*1, 2, 3*) which we previously transferred to the duration curve O_t^1.

The same method that has been explained for a distribution reservoir can also be used for a balancing reservoir; however, denotations P and O have to be exchanged.

A summation curve makes it possible to analyse mainly those cases where the reservoir capacity is not large enough for complete balancing (Votruba and Broža, 1966).

With daily release control for power plants, the problem is more complicated. In peak-load power plants great outputs start or stop within a few minutes. There is unsteady flow and the water level fluctuates in waves, which mostly affect low-pressure plants with small reservoirs and diversion canals of power plants, where the conduit also serves as a capacity able to balance sudden changes in withdrawals. This changes the head of the power plant, which in turn changes the discharges. It is therefore not sufficient to simply determine only the reservoir volume, but the hydraulic regime in the upper and lower reservoir basin and its effect on the work of the hydro-power plants and on the function of reservoirs.

A balancing reservoir downstream of a peak-load hydro-power plant sometimes also serves to pump water to a main reservoir or to a special storage reservoir. A case of this kind requiring increase of capacity is outlined in Fig. 7.7. The main reservoir regulates the discharge in the river to the yield $Q_r = 20\ m^3\ s^{-1} = 1\ 728\ 000\ m^3\ day^{-1}$. In the pumped-storage power plant there are turbines with design flow $400\ m^3\ s^{-1}$ through which $5\ 040\ 000\ m^3\ day^{-1}$ flow during a 3.5 hour rectangular peak.

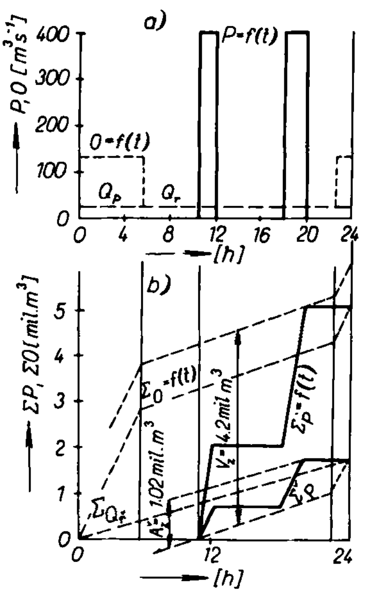

Fig. 7.7 Analysis of a balancing reservoir with the function of a reservoir downstream of a pumped-storage hydro-power plant

$5\,040\,000 - 1\,728\,000 = 3\,312\,000\ \mathrm{m^3\,day^{-1}}$; i.e., during 7 hours of pumping about $130\ \mathrm{m^3\,s^{-1}}$ have to be pumped back to the main reservoir.

These values are plotted in base curves in Fig. 7.7a; the amount pumped should be considered as a withdrawal from the balancing reservoir, so that we add it to the yield Q_r. Mass curves in Fig. 7.7b solve the size of the balancing reservoir, $V_z = 4.2 \cdot 10^6\ \mathrm{m^3}$. To give an idea of the influence of re-pumping on the balancing reservoir capacity, the volume of a balancing reservoir without re-pumping is shown in the same figure. The all-day augmented release of $1\,728\,000\ \mathrm{m^3}$ is processed into two peaks of the same duration, $1.5 + 2.0 = 3.5$ h. In this case, the volume of the balancing reservoir is $V_z = 1.02 \cdot 10^6\ \mathrm{m^3}$. It can be seen that re-pumping increased the volume of the balancing reservoir about four-fold.

Power plants using tidal energy also work on a daily cycle; a description can be found in the book by Votruba and Broža (1966, p. 159).

7.1.3 Daily release control for irrigation

For the irrigation, daily release control need not by typical. Conditions for a daily cycle are given, e.g., where land is irrigated only during the day. If, for such irrigation, water is withdrawn continuously and without storage, it is not used at night, and can even cause harm to land on lowest irrigated levels. This shortcoming can be avoided when reservoirs with daily release control are introduced. When placed at the end of a long canal, these reservoirs work as distribution reservoirs. The canal can then be designed only for mean daily and not for peak water demand and it helps to regulate the amount of water used.

With a uniform inflow P to a reservoir throughout a day T and with a balanced withdrawal O for part of a day t, the necessary distributing reservoir volume V_z can be determined in the following way:

$$V_z = (O - P)\,t \quad \text{or} \quad V_z = (T - t)\,P = \left(1 - \frac{t}{T}\right) Ot \tag{7.3}$$

For example, for an area of 1000 hectares with $P = 0.4\ \mathrm{l\,s^{-1}}$ per 1 hectare and $t = 10$ h, the reservoir storage capacity would be $V_z = 20\,000\ \mathrm{m^3}$.

The balance should also include evaporation and seepage losses from the reservoir.

Daily discharge can also be controlled by a reservoir placed at the inflow to a canal. This enables better use of the water resource; however, the canal must have the correct dimensions for peak water demand. Certain difficulties of withdrawal control are caused by the time the water needs to flow from the inflow to the conduit to the place of withdrawal, because discharge in the network of canals is unsteady and complicated which can be investigated in operation.

Short-term release control without a precise cycle duration can also be used for irrigation. If, for example, the yield of the water resource is small, a certain water volume has to be stored in a reservoir to start with. If the power resource is unsteady (e.g., by a wind-driven engine), a certain water volume must also be stored. However, the most important factor for irrigation is seasonal and over-year release control.

Daily release control is also used to increase the discharge for a few hours a day for floating timber. The reservoir volume is relatively small, about 85 to 90% of the daily release. A disadvantage of this method is that the wave reaches more distant places only at night, which causes difficulties for floating timber; much water is wasted by filling the empty parts of the stream channel, and the wave flattens quickly, which means an unfavourable discharge increase and a rise in the water level just downstream of the dam.

Buffer-storage reservoirs with a daily periodical function can also have a daily cycle in river flow regulation. The difference in their function is that they must coordinate the inflow from an interbasin and the release of water from a distant reservoir upstream and regulate this inflow to meet the demands of non-uniform withdrawal. The simulation of the inflow regime to a reservoir is more difficult than the reservoir design.

7.2 WEEKLY RELEASE CONTROL

A weekly cycle is introduced if the water demand in the region (or power from the hydro-power plants) differs in the respective days of the week. In this case, the reservoirs are usually distribution reservoirs. Figure 7.8 shows a general weekly load or

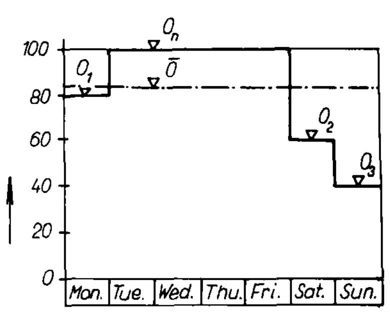

Fig. 7.8 Weekly withdrawal diagram

water demand diagram with mean daily values. The whole weekly demand $\sum_O$ is calculated from the sum of demands on the respective days:

$$\sum_O = \sum_{1}^{m} \Omega_i + (7 - m)\,\Omega_n \tag{7.4}$$

where Ω is the demand of one whole day [$m^3\,d^{-1}$] from among the working days (index n) and on the days with smaller demands (index $i = 1, \ldots, m$).

The mean daily demand will be

$$\bar{\Omega} = \frac{\sum_{1}^{m}\Omega_i + (7 - m)\,\Omega_n}{7} \tag{7.5}$$

If the mean daily demand during the week $\bar{\Omega}$ is greater than the greatest of the decreased daily demands Ω_1 to Ω_m, then the reservoir volume at the inflow will be $P = \bar{O} = \text{const}$

$$V_z = (\Omega_n - \bar{\Omega})(7 - m) \tag{7.6}$$

However, neither the water nor the energy demand is the same during the whole day. Figure 7.9 gives a diagram of a reservoir volume with regard to weekly and daily release control. Numerically the curve $O' = f(t)$ reads

$$\sum_{1}^{7}{}_{O} = 6.5\Omega_n; \qquad \bar{\Omega} = \frac{6.5}{7}\Omega_n; \qquad V_z = \left(\frac{6.5}{7} - 0.5\right)\Omega_n$$

These values were also determined graphically. A graphical method was also used to determine the storage capacity V_z^+ for a weekly discharge distribution according to the detailed curve $O'' = f(t)$, which also reflects the daily variability of water

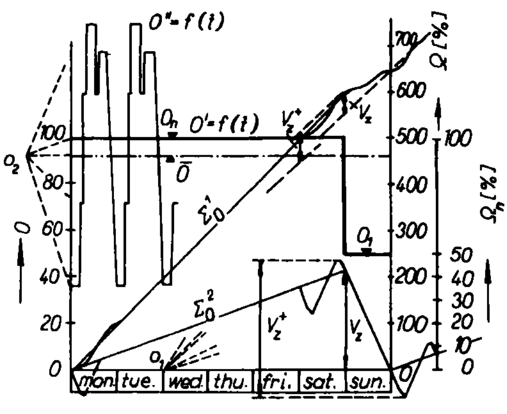

Fig. 7.9 Diagram showing weekly release control

withdrawal, i.e., $V_z^+ = 0.59\Omega_n$ which is larger than V_z by the value 27.5%. It can be seen that calculations to determine the storage capacity for weekly release control cannot generally be limited to uniform daily discharges, but that discharge fluctuations within one day must also be taken into account.

Note: The graphical solution in Fig. 7.9 uses a mass curve $\sum_O^1$ drawn from pole o_1 and mass curve $\sum_O^2$ drawn from the raised pole o_2. It can be seen that in the given case only the raising of the pole, by which the scale of the mass curve could be enlarged by five times, made it possible to read the value V_z in the mass curves accurately (with an accuracy of $0.01\Omega_n$).

A *balancing reservoir* can also work on a weekly cycle. At weekends and holidays the discharge downstream of the balancing reservoir does not then drop to a harmfully low value. It is, however, possible that the volume of a balancing reservoir with a daily cycle calculated for one specific day will also be satisfactory for a weekly cycle of a low-flow period, when the danger of a harmfully low release is the greatest.

Of constantly greater importance in Czechoslovakia will be peak-load hydro-power plants, the output of which will be used 8 to 11 h day^{-1} and 2000 to 2500 h yr^{-1} (Laudát, 1976). Pumped-storage hydro-power plants to be constructed in the future will no longer serve only 4 to 6 h day^{-1} and 1000 to 1500 h yr^{-1} as was previously the case. Weekly control cycles for pumped-storage hydro-power plants are one way

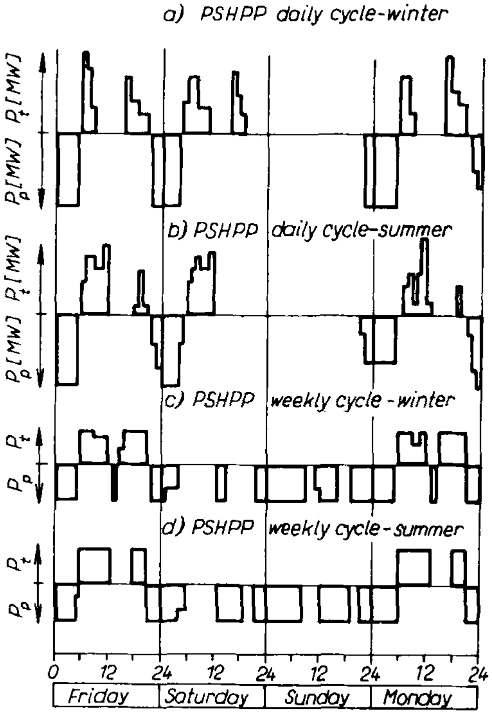

Fig. 7.10 Operations of a pumped-storage hydro-power plant (PSHPP) with a daily and weekly cycle from Monday to Friday and at weekends in December and June (Laudát, 1976), P_t – output with full turbine operations (MW), P_c – input with full pumping operations (MW)

of covering the growing needs of the power system. The volumes of the upper and lower reservoir of such power plants with a weekly cycle are about 4 to 5 times greater than for daily cycles. The difference between the function of pumped-storage hydro-power plants (PSHPP) with a daily and weekly cycle can be seen from Fig. 7.10. With a weekly cycle the upper and lower reservoir must be large enough for three-days of pumping, i.e., from Friday night to Monday morning.

If we use the maximum efficiency obtained from pumped-storage hydro-power plants in Vianden, Luxembourg for 1964 ($H = 292$ m, $P = 900$ MW), i.e., pumping operations 85.7% and total effectiveness of re-pumping 77%, we can write

$$P_p \doteq 11.4 Q_p H \tag{7.7}$$

$$P_t \doteq 8.8 Q_t H \tag{7.8}$$

The volume of the upper reservoir, with a rectangular peak and daily re-pumping cycle, is

$$V_{z,d} = Q_p t_p = Q_t t_t \tag{7.9}$$

where

P_p – input during pumping operations
P_t – output during turbine operations
Q_p (Q_t) – discharge during pumping (turbine) operations
t_p (t_t) – time of the day of pumping (turbine) operations
H – mean head of pumped-storage hydro-power plant.

From equations (7.7) to (7.9) it follows that

$$\frac{t_t}{t_p} = \frac{Q_p}{Q_t} = \frac{8.8 P_p}{11.4 P_t} \tag{7.10}$$

For $P_p = P_t$ and for $(t_t + t_p) = 24$ h, $t_t = 10.5$ h and $t_p = 13.5$ h. Under the above conditions a reservoir volume $V_{z,d}$ can ensure an output of turbine operations P_t for 10.5 hours.

In Fig. 7.11 the function of the upper reservoir of a pumped-storage hydro-power plant with a weekly cycle of 12 hours pumping on all days and of a 12-hour rectangular peak on work days is plotted in mass curves (for other pumping conditions the method is the same). Reservoir volume $V_{z,t} = 100\%$. Under these conditions, the pumped daily volume is $W_{p,d} = Q_p t_p = \frac{1}{3} V_{z,t}$ and the daily water volume for turbine operations is $W_{t,d} = Q_t t_t = \frac{7}{15} V_{z,t}$.

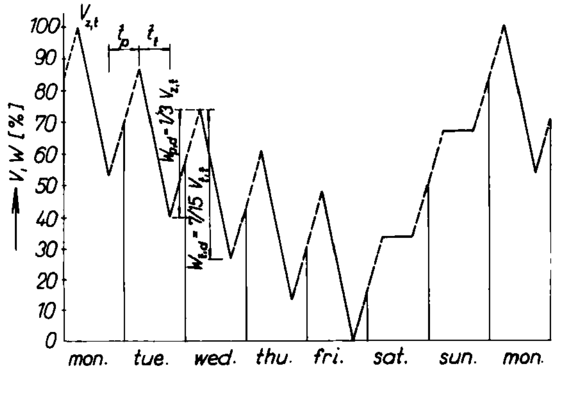

Fig. 7.11 Function of the upper reservoir of a pumped-storage hydro-power plant with a weekly cycle ($t_t = t_p = 12$ h)

With these relationships any parameter can be calculated. For example, for the required turbine output P_t we can calculate from equation (7.8) the discharge Q_t for turbine operations and from this the necessary volume of the upper reservoir $V_{z,t} = \frac{15}{7} Q_t t_t$, etc. A detailed comparison of a daily and weekly cycle of a pumped-storage hydro-power plant was described by Laudát (1976).

7.3 SHORT-TERM NON-PERIODICAL RELEASE CONTROL

This type of short-term release control is applied when the cycle of the reservoir function is not repeated in regular intervals and when the duration of the cycle is never more than one week.

A typical case is the *floating of timber*, when the discharge in the river is not sufficient to store water in a reservoir in one day to create a wave that would last at least three hours. In calculating the volume of a reservoir, we consider the inflow to be constant; however, release must be regulated according to the conditions (depth, duration of augmented water stages) which we wish to create in the river up to a distance of about 20 km downstream of the dam. We must therefore also calculate the transformation of the discharge wave in the stream channel.

A *discharge wave* is typical for short-term release control as such, however, it also has other aspects (flood routing in the stream channel, daily release control in some hydro-power plants, a wave caused by the bursting of a dam, etc.). Several methods have been elaborated, but it is difficult to obtain accurate results due to the complicated conditions in nature, and therefore simplified presumptions with an acceptable reliability are frequently used.

Short-term non-periodical release control is used wherever water management is connected with the *exploitation of the power of the wind*, which has short-term non-periodical characteristics (pumping water to a tank by wind engine). The best use of wind is made when wind-powered plants and hydro-power plants with storage reservoirs cooperate. As the output of wind-powered plants is never constant, the cooperating power plants must have a short-term, non-periodical control. This example can be applied to any power resource which does not have a constant and reliable output.

Non-periodical, short-term changes can also occur with so-called *buffer release control*. If the river-flow is regulated by a reservoir far upstream from the place of withdrawal, reservoir operations cannot meet the withdrawal changes, as the change of release from the reservoir is reflected in the place of withdrawal only after a certain period; tributaries on the way cause the discrepancies between the discharges in both the sites, etc. These discrepancies must be balanced by a reservoir with a smaller volume in the place of withdrawal; the main reservoir upstream carries out only rough release control and the "buffer" reservoir more sensitive regulation.

In a *cascade of power plants*, which essentially have a regular work cycle, an in-between reservoir can help to regulate the non-periodical changes of inflow from the upstream power plant.

Non-periodical short-term release control for the *irrigation* was dealt with in Section 7.1.3. With small irrigated areas and resources with a small yield, water must be accumulated for several days (according to the present yield of the resource), to create a supply for 1 to 2 days of irrigation.

Agricultural reservoirs placed in a *network of canals* also have short-term non-periodical characteristics; they mainly balance the inflow (e.g., by pumping) and withdrawal, but can also serve as settling tanks, to warm cold water from wells, etc. (Cablík, 1960).

Supply, fire control, etc., reservoirs, as well as cisterns, frequently have non-periodical operations. The volume of these reservoirs is mostly determined by withdrawal demands and less frequently by inflow conditions.

Flood-control of release (Chap. 11 and 12), for which flood-control reservoirs, drainage ponds, pondage and flood control storage capacities of multi-purpose reservoirs are built, also has short-term, non-periodical characteristics.