WORLD METEOROLOGICAL ORGANIZATION

TECHNICAL REPORTS TO THE COMMISSION FOR HYDROLOGY – No. 19

HYDROLOGICAL FORECASTS FOR HYDROELECTRIC POWER PRODUCTION

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WMO/TD - No. 118

Secretariat of the World Meteorological Organization - Geneva - Switzerland

1. Introduction

The second half of the twentieth century is characterized by a continuous growth of water requirements owing to the intensive development of various branches of the economy in many countries. Hence a demand arose for a more efficient use of the water resources, primarily due to optimal streamflow control by large reservoirs. For this purpose, individual reservoirs and systems of reservoirs have been constructed on many large rivers of the world.

Most of large reservoirs are multi-purpose, i.e. they are used not only for one branch of the economy, but usually for a number of branches. The main branches are hydroenergetics, water management and reclamation.

The requirements of the various branches of the economy for streamflow control often do not coincide and sometimes are even conflicting.

For example, it is not in the interests of hydroelectric power generation, in the period of low flow on lowland rivers, to open the spillway since it is better to store the water and then work with higher head. However, for fisheries and agriculture it is necessary to create a flood of certain dimensions and shape below the power plant, which requires the opening of the spillway. In years with abundance of water the reservoir should be operated so that to avoid flooding of towns and settlements situated below the dam.

Efficient streamflow control and determination of the most advantageous for the economy of the country operation of both the reservoir and the hydroelectric plant require fairly reliable, timely information on the expected regime of the water bodies, i.e. hydrological forecasts.

This report discusses the problems of providing hydroelectric plants with inflow forecasts with different lead time. These problems are of great importance because in countries with a well developed hydroelectric plant system (USSR, USA, etc.) the correct use of forecasts makes it possible to increase substantially the hydroelectric power output.

The problems of providing hydroenergetics with hydrological forecasts are considered below on the basis of papers by specialists of different countries /1-17/.

In the paper particular emphasis is placed upon the following:

- The types and forms of hydrological forecasts issued for the purposes of hydroelectric power production;
- The value of hydrological forecasts for hydroelectric power production;
- The accuracy of forecasts of the inflow to hydroelectric plants.

2. Types of hydrological forecasts and their value for hydroelectric power production

The main types of forecasts issued for hydroelectric power production are now those of the inflow to hydroelectrical power plants (into the reservoir). These forecasts take the following forms:

(a) Seasonal inflow (covering the spring flood period and the winter and autumn-summer low-flow periods);

(b) Quarterly inflow;

(c) Monthly inflow;

(d) Ten- and five-day inflow;

(e) Daily inflow for a few days in advance.

The forecasts indicated under (a), (b) and (c) are issued for all most important hydroelectric power plants one to two months before the beginning of the spring flood period and five to six days before the beginning of the quarter or the month, respectively. The ten-, five- and one-day inflow forecasts are issued one to three days in advance. The lead time of daily inflow forecasts varies from 24 hours for the first day to five-six days for the last day.

Thus, in certain cases each hydroelectric power plant can receive the annual total of about 470 forecasts of the inflow to the reservoir, including 3-4 seasonal, 4 quaeterly, 12 monthly, 36 ten-day, 73 five-day and 365 daily forecasts.

However, in practice, each hydroelectric plant often is provided only with long-range forecasts (seasonal, quarterly and monthly), i.e. the total is not more than 20.

On the majority of rivers of the USSR and certain other northern countries the greatest part of the annual runoff is formed by melting of the snow cover accumulated in winter. 70-90% of the total annual runoff occurs in the spring flood period on lowland rivers and in the spring-summer flood period on mountain rivers. These are the periods when the streamflow is controlled to ensure its most rational use for hydroelectric power production. Because of this annual distribution of the runoff the most important forecasts for power production are long-range and short-range inflow forecasts for the periods of spring or spring-summer floods.

What is the value of these forecasts for hydroenergetics?

Forecasts of the volume of inflow during the flood period into an individual reservoir or a system of reservoirs with annual or long-term streamflow control make it possible for power plant managers to establish the optimal winter operating regime for the reservoir. When the inflow for the spring flood period is expected to be low, the power plant operation is limited in the preceding period in order to fill the reservoir during the high water period up to the design level. On the contrary, when the spring inflow is expected abundant, the capacity of the reservoir is released by increasing the discharge up to the dead storage.

On reservoirs with seasonal streamflow control the scheme for passing the spring (spring-summer) discharges is also established depending on the expected volume of the spring flood. In this case, the forecast of the spring flood volume makes it possible to use water resources for power production more economically, to improve the reliability of filling the reservoir up to normal back-water levels and to provide the planned water supply to various branches of the economy during the subsequent period.

Forecasts of the inflow to hydroelectric power plants are used for taking appropriate measures for water passes through the system during the spring flood period; for planning quarterly, monthly and weekly energy production and distribution; and for ensuring correct distribution of the power load among hydroelectric power plants and thermal power plants.

In planning energy generation those responsible for operating hydroelectric power plants are primarily concerned with the maximum possible guarantee of fulfilment of the plan.

Therefore they need the most reliable forecasts. However, it is not uncommon for forecasts to have substantial errors, whose values depend on the errors of precipitation forecasts for the lead time, the forecasting method and the initial hydrometeorological data (water equivalent of snow, moisture conditions in the basin, etc.).

Consequently, a hydrological forecast always is of a probabilistic nature, i.e. it is expressed by a number of values whose probability of occurrence in the given year is various.

In practice, forecasts of the inflow to reservoirs are usually issued in two forms. In the first case, they are expressed as a conventional distribution curve within the confidence limits from 10 to 90 percent. Usually, the user of such forecasts orients himself to an expected inflow the probability of which for that year is 50 percent.

Forecasts of the second type are expressed by two figures one of which shows the expected value the probability of which for that year is 50 percent and the second figure denotes the forecast probable error.

3. Cost-benefit of forecasts

The cost-benefic of inflow forecasts is determined by the following three main factors: the forecast accuracy, their lead time and the benefit resulting from their use in the power plant operations.

It is self-evident that the higher the accuracy of inflow forecasts, the more reliable the calculations used in the operation of power plants and energy generation. The principles of forecast evaluation are presented in /13/.

The forecast accuracy is characterized by two indices: the mean square error and the distribution of errors. Experience in developing forecast methods and the mass data on their reliability show that in the majority of cases the error distribution is close to normal.

The forecast mean square errors usually range as follows: for short-range forecasts for 1-5 days they range from 10 to 15 percent, for monthly and quarterly inflow forecasts, from 15 to 25 percent, for spring flood forecasts, from 15 to 20 percent of the actual inflow value. The experience shows that errors of calculations of water inflow to hydroelectric power plants are 5-15 percent. They depend to a great extent on the availabity of hydrometric data over catchment areas of the reservoirs /3/. Data available show that the accuracy of inflow forecasts in many cases is scarcely less than the accuracy of the determination of the actual inflow to hydroelectric power plants.

Figure 1, cited from /7/, gives a certain idea of accuracy of long-range forecasts. It presents the comparison between the observed and forecasted inflow in the second quarter of the year into reservoirs of 25 largest hydroelectric power plants in the USSR for the period of six years. Both observed and forecasted inflows are expressed in percent of the mean long-term values (norms). The coefficient of correlation of this relationship is fairly high (0.82). Figure 1 shows that more successful forecasts were in years of low flow. This is explained by the fact that in years with abundance of water, liquid precipitation usually plays a greater part in the formation of flood flow but up to the time when the forecast is compiled this precipitation is unknown and is assumed to be normal.

The above example and other results presented in /3,4, 8,12/ show, that the accuracy of forecasts of the inflow to reservoirs is fairly high. However, high accuracy in itself does not determine the forecast efficiency. They must, in addition, have a certain lead time.

The determination of the optimal lead time for forecasts of inflow to hydroelectric power plants is a very complicated task which can only be accomplished using economic calcula-

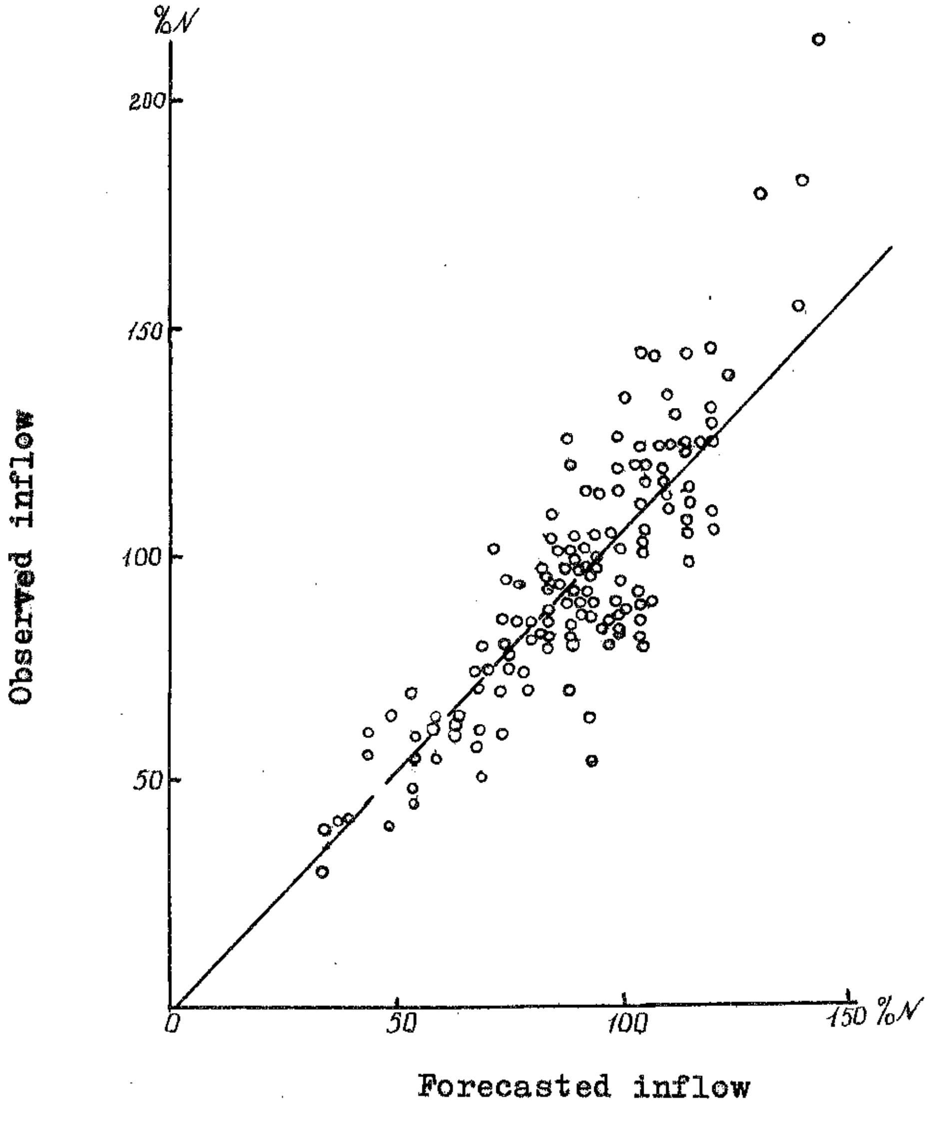

FIG. 1. Comparison of the observed and forecasted inflow into large reservoirs in the second quarter of the year (in % of the norm)

tions taking into account technical indices and the specific features of operation of each power plant. However, in practice, such calculations are not made and the real lead time of forecasts for each power plant is dictated by the possibilities of the forecasting method.

It should be pointed out here that, as a rule, the accuracy and lead time of forecasts are interrelated. A forecast with the short lead time is usually more accurate as compared to a forecast with the long lead time. The relationship between these two characteristics should be selected on the basis of the greatest benefit for the operation of the power plant. Consequently, a forecast method is usually developed for a forecast with the longest possible lead time, but the system of corrections is necessary as the forecasted hydrological phenomenon is occurring.

For example, a forecast of the inflow to a reservoir during the spring flood period compiled according to data on the water equivalent of snow cover in the basin and its absorption capacity is corrected using data on precipitation during the snowmelt and flood period, data on the runoff of small rivers and calculations of the amount of water in the stream network as well as calculations of the daily snowmelt. Thus, agencies engaged with the operation of power plants are steadily provided with information on the expected development of the phenomenon and can correct their decisions on the basis of more detailed and accurate calculations.

The third factor determining the efficiency of forecasts is the benefit from their use in the operation of a power plant. It is well known that in the absence of forecasts, particularly long-range forecasts, energy generation is planned according to the inflow with a given reliability or according to the norm. Often in the absence of short-range forecasts planning for 1-3 days in advance is made on the basis of the inflow value for the preceding 24 hours, i.e. the users utilize the so-called inertial forecasts. In all cases the forecast benefit can be defined only by comparison between the power plant operating levels with and without forecasts.

The first obvious advantage of using forecasts is that they make it possible to forsee various inflow values (including extreme or close to extreme ones) and, consequently, to take necessary measures in good time for more rational use of water. This is particulary important for power plants with long-term or seasonal streamflow control.

Figure 1 demonstrates how successfully deviations from the norm are predicted. However, a clearer assessment of the benefit of forecasts by comparison with using the norm can be derived from Figure 2 which is also cited from /7/. This figure shows the distribution of errors of a forecast of the inflow to reservoirs as compared with deviations from the norm (Figure 2 was prepared using the same initial data as Figure 1).

Figure 2 shows that in 80 percent of cases the forecasting error is less than 20 percent of the actual value, and in 90 percent of cases it is less that 25 percent. At the same time, the deviation from the norm for the same reliability (80 and 90 percent) is 70 and 130 percent of the observed value respectively, and the greatest deviations are 200-300 percent.

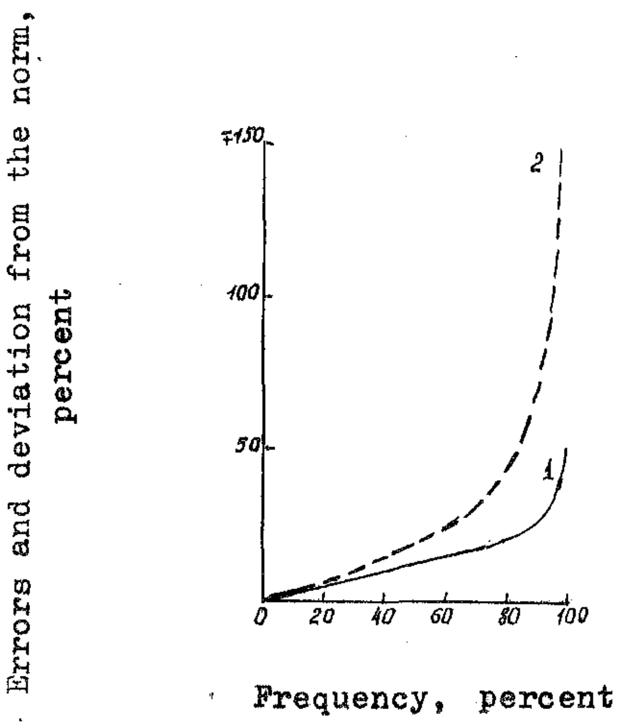

Fig. 2. Distribution of errors in a forecast of inflow to reservoirs in the second quarter of the year (1) and deviations from the norm (2) (errors and deviations from the norm are given in percent of the observed value)

Thus, the advantage of using forecasts as compared with assuming the expected value equal to the norm is considerable, and represents an extremely important index of the forecast benefit, i.e. their efficiency.

Forecasts of the inflow to reservoirs are considered more efficient (from the point of view of power generation), if they contribute to an increase in power generation or at least to its improved planning.

The use of forecasts makes it possible to generate more power either due to operating the hydroelectric plant with a higher head or due to reducing the opening of the spillway.

At hydroelectric plants with long-term regulation the spillways are open very seldom.

At such hydroelectric plants, some additional power can be generated through increasing the annual mean head due to the use of long-term inflow forecasts, particularly in years with low flow. In this case, low flow forecasts make it possible to reduce the decrease of storage during winter thus providing a higher spring flood level and, consequently, increased head at the plant during the rest of the hydrological year.

At hydroelectric plants with seasonal streamflow regulation, additional power can be generated both due to increased head when low flow is forecasted and due to reducing the opening of the spillway in case of high-water forecasts.

At hydroelectric plants with small storage and unstable spring-flood regime of water inflow, power output can be increased due to reducing the opening of spillways on the basis of short-range flood forecasts with the lead time ranging from 1-3 to 7-10 days.

This report is concerned with some results of calculations of additional power generation in years with low flow due to the use of forecasts of quaterly inflow to the Pybinsk and Mingechaur reservoirs on the Volga and the Kura respectively. These results are cited from /2/.

Calculations made in /2/ are based on the following principles.

- In the absence of inflow forecasts, the storage is decreased during the spring flood period up to the normal pre-flood level proceeding from the assumption that the expected flood volume is normal.

- When inflow forecasts are available, the storage is being decreased up to the level fixed taking into account a certain additional water volume W_{add} stored in the reservoir according to the forecast. It is expected that if the forecast proves successful the above value W_{add} will make it possible to fill the reservoir up to the normal affluent level in spring of a dry year.
- The value W_{add} is taken to be a measure of the forecast efficiency since it affects the water head and consequently, power generation.
- Actual values of W_{add} are determined taking into account the forecast errors and lead time.

Based on the above principles and simple formulas, the values of additional power generated at the Rybinsk hydroelectric plant for 11 dry years were calculated. Some results of calculations cited from /2/ are presented in Table 1.

The calculations have shown that the forecasts were efficient in 9 cases and in 2 cases they were not efficient due to forecast errors. The total additional power generated for 11 years amounted to 340 million kWh, i.e. nearly to 4 percent of the total power output of the Rybinsk Hydro for those years. It is also seen from the table that if a forecast is fully successful and its lead time is sufficient the additional power output can be 2 or 2.5 - times more, i.e. it can average 8 to 10 percent of the yearly power output.

Table 1

Years	Actual values of W_{add} with consideration of the forecast, km^3	Additional power generated with consideration of the forecast, million kWh	Additional power generated in case the forecast is fully successful, million kWh
1949	4.2	65	65
1950	2.3	40	64
1951	2.0	39	39
1952	0	0	85
1954	3.9	75	159
1960	-2.0	-32	62
1961	3.0	60	62
1963	2.9	43	104
1964	0.6	6	55
1965	1.2	14	41
1967	2.3	31	42
TOTAL	20.4	341	778

Similar studies of forecast efficiency in connection with extending their lead time were carried out for the Mingechaur reservoir. Extending the lead time of the spring-summer inflow forecast by a month was found to increase the power output by 25 percent.

Calculations show that the correct use of hydrological forecasts makes it possible to increase the power output of each hydroelectric plant by 2 percent on the average. Based on the above it is possible to evaluate approximately the annual benefit from hydrological forecasts for the national power industry. For example, the annual power output of all hydroelectric plants in the USSR is about 170 billion kWh /1/. Hence, the total economic effect of hydrological forecasts for national power industry is approximately equal to 3.0-3.5 billion kWh per year. This amount is usually generated by a hydroelectric plant with power of 700-800 megawatts.

Consequently the economic effect from hydrological forecasts in the USSR each year is equal to that from the operation of such a plant.

In conclusion , it should be pointed out that in developing forecast methods it is important to know and consider the specific operation of each power plant.

For example, for a hydroelectric plant with daily or weekly streamflow regulation, a forecast of the total inflow for an extended period is of less interest than that of the available inflow, i.e. the discharge minus that part of the water which is removed through the turbines of the power plant.

For a power plant with a small regulating storage the expected total inflow during the spring flood period is also not so important as the time of the beginning of the spring rise in the water level and the time when the inflow value exceeds the power plant design discharge, since these are the factors which determine the possibility of efficient decrease of water storage and the time for the hydroelectric plant to be operated at full power.

It is characteristic of the hydrological regime of large reservoirs to have considerable water losses through evaporation. For such reservoirs, it is necessary to have forecasts of the inflow minus the evaporation loss.

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