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FORECASTING ANALYSIS OF RUNOFF FOR RESERVOIR REGULATION OF DAMS AND WEIRS IN TERMS OF HYDRO POWER PLANT OPERATION

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Abstract

In order to meet the needs of Hydropower Plant (HPP) production new algorithms and software were developed for daily, seasonal, annual and long-term control of the runoff for the design of dam and weirs. This control is carried out for monitored periods from 20 to 50 years. The control depends on economic considerations, namely that the accepted probability of required water power is 90%, i.e. concerning the runoff and in this way for the useful volume of water dams. The research is accomplished by a design with the observations.

First the hydrometric stations are selected at the available analogy with the building project and then the correlative connection is found assessed by general and true correlative coefficients. The transferring to the project of the observations for the average annual and average monthly water discharges is made with the coefficient of the analogy. The theoretical probability curves are chosen with a minimum dispersion. By the last curves the average monthly distributions are settled with probability from 2% to 90% by statistical method.

During the investigated period of the regulation the volumes of discharge, overflow and shortage are calculated as and the determination for the accepted volume of the reservoir if the normative probability of the need is executed. As well the power output of the HPP and its participation in the coverage of the charge diagram on the peak load, under peak load, daily and nightly part are determined in separate observed or forecasting periods. The upper problems about the design and the operation of HPP, water output, reservoir volume and coverage of the charge diagram are solved by iterations. Practical examples are given for the runoff and for the time forecasting system.

Keywords: *HPP, algorithm, runoff, overflow, shortage, power output, forecasting.*

1 INTRODUCTION

The design of the building project demands a determination in the separate years and average power output of the HPP and the monthly share for the consumer need in peak load, under peak, day and night. The HPP is rational to share first of all for peak load but therefore the regulated volume is necessary to be created. For that purpose the monthly production is examined for 50 years in order to establish the

probabilities and monthly distributions in the interval from 2% to 90% (Nikolov, 2007; 32 IAHR Congress). The choice of the years with their probability in this interval becomes with the help of equal area below the differential curve of probability density function in the field of the final water discharges with probabilities 2% and 90% (Fig.1). Further for the observed water discharge in 12 months period and for the average monthly water discharge (Table 1) the probability density curves are found. Then by the 12 theoretical probability curves the monthly distributions for 50 years between 2% and 90% are established. Namely with these statistical curves, through an algorithm and software, the annual and monthly power output, the hour coverage of the charge diagram, the useful volume with standard probability are examined.

When the observed water discharges are with duration from 20 to 50 years the upper investigations about the distributions can be implemented directly by observations but their accuracy is smaller than the statistical distributions. If the observations are shorter than 20 years, the investigation must be implemented with statistical characteristics or forecasting analysis during 50 years.

The choice of the probability density (Fig.1) and the theoretical distributive curve (Fig.2) are computed by observations of the dam A - Table 1.

First the hydrometric stations are selected at an available analogy of the dam A and then the correlative dependence is found assessed by general and true correlative coefficients.

The transferring to the dam A for the average annual and average monthly water discharges becomes with the coefficient of analogy by means of the data given in Table 1.The option of the probability density function and the theoretical curve of distribution among a set of functions is given by minimum dispersion. The accepted probabilities are obtained in accordance to economic considerations for a minimum - 90% and 2% for a maximum average annual water discharge (Fig.1, Fig.2). The last probability 2% is found from the correspondence of the full long term cycle of the runoff of 50 years.

2 MONTHLY DISTRIBUTION

The 12 monthly distributions throughout the years is established by two methods:

a) Statistical characteristics in the course of 50 years.
b) Observations within a period from 20 to 50 years.

The monthly observations are ordered in descending series for 12 monthly observations and are calculated by empirical probabilities with the next formula $p = \dfrac{m - 0.25}{n + 0.50}$. The probability density of the separate 12 months and the theoretical curves of probability are computed and selected according to a minimum dispersion among the functions: Pearson III, II and I type, three parameter gamma, gamma or lognormal, exponential and Weibul. The chosen theoretical curve for the separate 12 months can be one type or other.

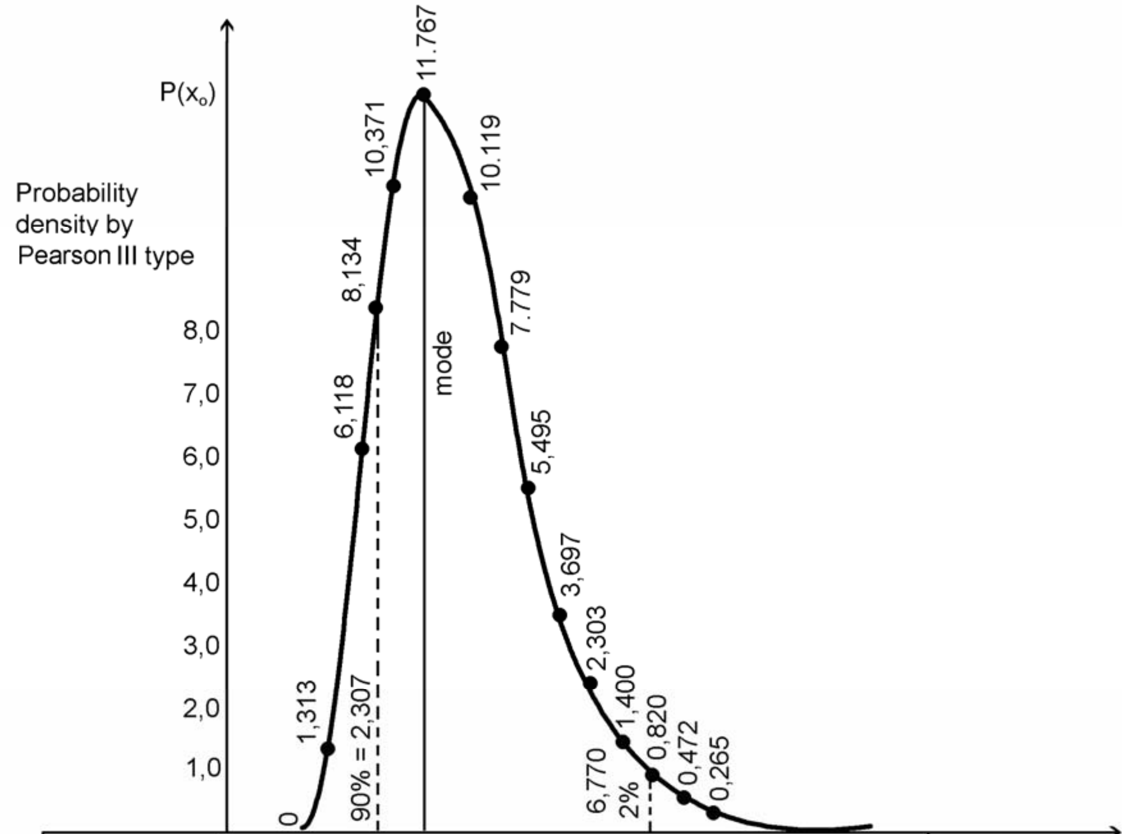
The monthly productions are examined for 50 years by the established probability monthly distributions in the interval from 2% to 90%. The realized test shows that the function Pearson III has a minimum dispersion. The parameters are given below.

Test Pearson III type with minimum dispersion for 12 months (Fig.1).
The mode of the function is:

$$P_o = \frac{n}{l_1} \frac{q^{q+1}}{e^q . \Gamma_{(q+1)}} \tag{1}$$

Probability density $P_{(x_o)}$ for x_o :

$$P_{(x_o)} = P_o (1 + \frac{x_o}{l_1})^q . e^{-\frac{q . x_o}{l_1}} \tag{2}$$



$x = \bar{Q}_A$	0	1,154	1,645	2,145	2,645	3,145	3,803	4,305	4,805	5,305	5,805	6,305	6,805	7,305	7,805	8,305	8,805	9,305	9,805	10,305
x_0 [m_3/sec]	-3,145	-1,991	-1,50	-1,00	-0,50	0	0,658	1,160	1,660	2,160	2,660	3,160	3,660	4,160	4,660	5,160	5,660	6,160	6,660	7,160
$k = \bar{Q}_A/\bar{Q}_0$		0,303	0,433	0,564	0,696	1	1,132	1,263	1,395	1,526	1,658	1,789	1,921	2,052	2,184	2,315	2,447	2,578	2,709	

Fig. 1. Differential curve of probability density – distribution of average annual water discharge $\bar{Q}_A$ by dam A

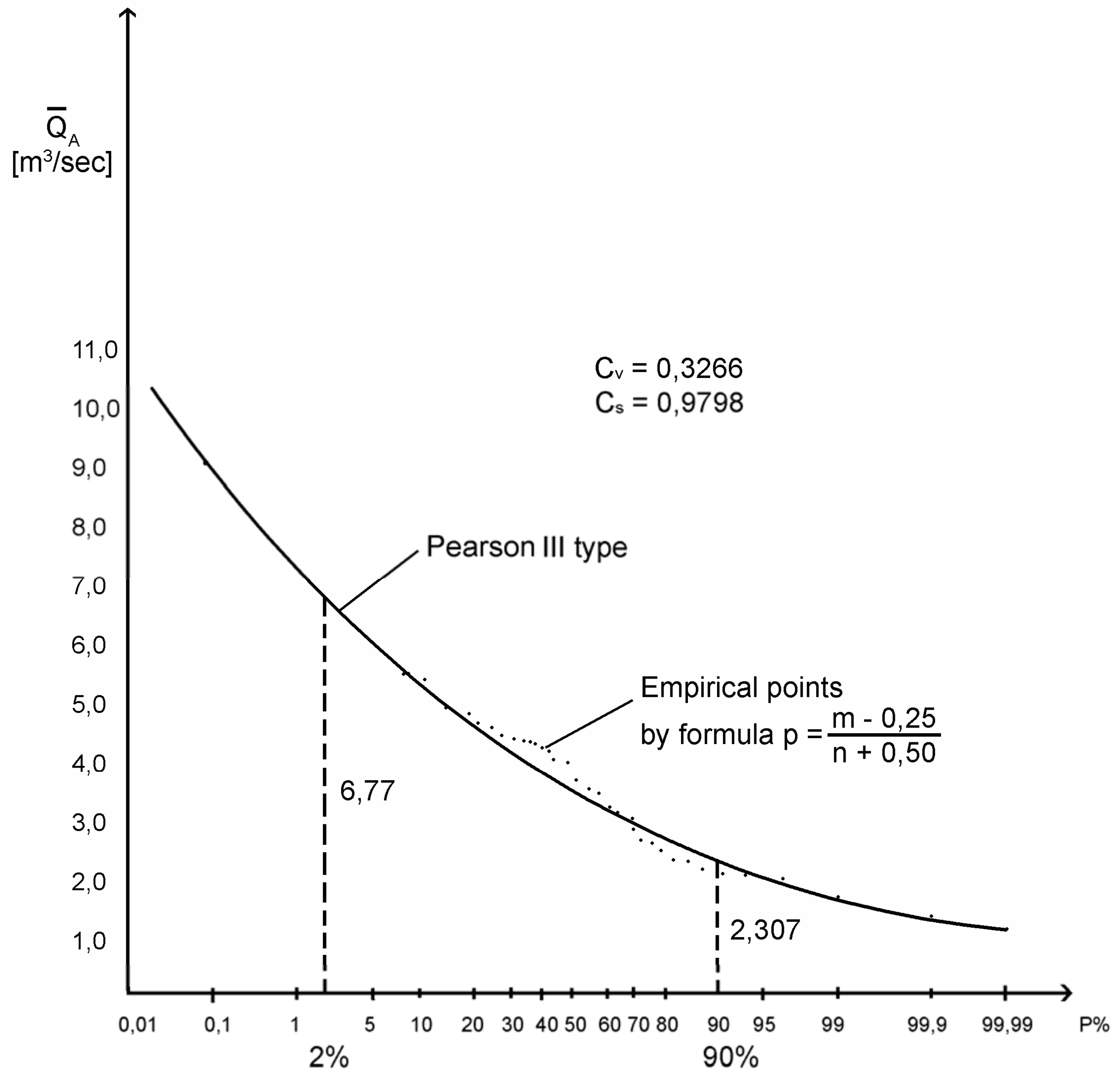


Fig. 2. Emperical probability and theoretical curve of Pearson III type for average annual water dischange $\overline{Q}_A$ of dam A

2.1 Computation of the density and the water discharge distribution function

The parameters of Pearson III type function are estimated as follow. The number of years is n=33, q=3.340, l_1=1.99.

$\hat{x}$=3.145 is abscissa of the mode; $x_o = x - \hat{x}$ is abscissa about the mode (Fig.1); (3)

For 2% from Fig. 2 x =6.77, x_o=6.77-3.145 = 3.625;

For 90% from Fig. 2 x=2.307, x_o=2.307-3.145 = -0.838;

$P_o = 11.677$, $P^{2\%}_{(3.625)} = 0.856$ (Fig.1), $P^{90\%}_{(-0.838)} = 8.134$ (Fig.1)

Or $-0.838 \le x_{oi} \le 3.625$ (4)

$P_{(x_{0i})} \le P^{\max}_{(x_{oo})} = 11.767$, for $x_o = 0$ (5)

The area under the differential curve of the probability density from 2% to 90% is presented in Fig.1 and the sum is equal to:

$$\sum_{p=2\%}^{90\%} f_p = \sum_{p=0.01}^{99.99\%} f_p - (\sum_{p=0.01\%}^{2\%} f_p + \sum_{p=0.01\%}^{99.99\%} f_p - \sum_{0.01\%}^{90\%} f_p) = \qquad (6)$$

=32.8-(0.65605+32.80-29.5224) = 28.866

The equal area below the differential curve of a probability density for 50 years in the field of the final water discharge from $\overline{Q}_{2\%} = x = 6.77 m^3/s$ to $\overline{Q}_{90\%} = x = 2.307 m^3/s$ is:

$$f = \frac{\sum_{p=2\%}^{90\%} f_p}{50} = \frac{28.866}{50} = 0.577 \qquad (7)$$

The probability $P_{(x_{oi})}$ and the water discharge $\overline{Q_i}$ for 50 years from 2% to 90% are found with the theoretical probability density (Fig.1) by means of the chain system below. The above mentioned model can be used to calculate the probabilities and the water discharges for 50 years by the scheme:

BOUNDARY CONDITIONS :

$f = 0.577 : P_{(x_{01})} = 0.856 : P_1 = 2\% : \overline{Q_{A1}} = x_1 = 6.77$

ITERATIVE SYSTEM :

$DO\, k = 2{,}50$

$$\Delta x_k : x_{0k} : P_{(x_{0k})} = P_0 (1 + \frac{x_{0k}}{l_1})^q e^{\frac{-q x_{ok}}{l_1}}$$

$$f = \Delta x_k \frac{P_{(x_{0k-1})} + P_{(x_{0k})}}{2}$$

$$P_k\% = \frac{\sum_{p=0.01}^{2\%} f_p + \sum_{1}^{k-1} f}{\sum_{p=0.01}^{99.99} f_p} x100$$

$$\overline{Q_k} = x_k = \hat{x} + x_{0k}$$

END DO

After determination of the above mentioned probabilities and water discharges the monthly distributions are settled. The monthly distributions $Q_{i,j}$ are improved, if an inadmissible difference has got among the years and months i.e. $\overline{Q_{i,j}}$ and $\overline{Q_i}$.

3 RESERVOIR REGULATION OF THE RUNOFF

By means of the regulation of runoff it will be verified if the foreseen useful volume of the dam A for seasonal regulation will secure always the built-up capacity N_v and the maximum working water discharge Q_v.

From the Table 1 the average many years water discharge is $\overline{Q_o}$=3.803 m^3/ s or the volume is W_o =3.803x31.536.10^6=72.75x10^6 m^3. The season regulated volume is taken approximately 30% from $W_{90\%}$ i.e. 22.10^6 m^3, Q_v=3x$\overline{Q_o}$=11.5 m^3/s and for H_{net}=100 m, N_v=10000 kW. The following symbols are used.

SYMBOLS FOR THE ALGORITHM

$W_{i,j}^{r}$ -river feeder in dam A during month j=I, ….,XII and in observed years i=1,2,….33;

t^{h} -diurnal hours of discharge to HPP for a peak coverage of the load;
winter 5h(I, II, XI,XII), spring and autumn 4h(III,IV,V,X), summer 3h(VI,VII,VIII,IX);

$W_{i,j}^{h} = Q_v\, t^{h}\, 3600\, t_{m.days}$ -useful volume in peak coverage during t^{h} of month j and year i;

$t_{m.days}$ -monthly days and nights;

$W_{\max}^{d}$ -max useful volume of the dam;

$W_{i,j}^{d}$ -useful volume of the dam during month j and year i;

$W_{i,j}^{of}$ -overflow volume water during month j and year i;

$W_{i,j}^{cs}$ -consumption from the HPP during month j and year i;

$W_{i,j}^{sh}$ -shortage from water volume during month j and year i;

$E_{i,j} = N_v t_{i,j} t_{m.days}$ -monthly output water power during month j and year i;

$E_i = \sum_{j=I}^{XII} E_{i,j}$ -annual output water power in year i;

$\overline{E}_i = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=I}^{XII} E_{i,j}$ – average annual output in i=n years;

$t_{m.days}$ = 31 (I, III, V, VII, VIII, X, XII), 30 (IV, VI, IX, XI), 28 (II) –number of monthly days;

h_{add} -additional day hours of discharge to the HPP, which will take part along t^{h} for a coverage of the charge diagram;

$t_{i,j}$ - night and day hours of a discharge to the HPP.

Criteria of Regulation (Nikolov, Maradjieva at all; 2005, USA)

If $W_{\max}^{d} \le 0.30 W_{90\%}^{r}$ -season regulation is; $0.30\overline{W}_o \langle W_{\max}^{d} \le 0.50\overline{W}_o$ -annual one is; and when $0.50\overline{W}_o \langle W_{\max}^{d} \le 2\overline{W}_o$ - long term period regulation is.

Table 1 Dam A -values of monthly, annual and long term period of water discharges [m^3/s]

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Ann Q	Max Q
1	1.997	2.266	7.741	10.91	16.27	10.54	2.811	2.774	2.740	2.534	1.757	1.128	5.290	45.30
2	1.073	0.795	1.877	5.354	3.949	2.710	0.999	1.054	0.805	1.248	1.794	3.866	2.127	15.81
3	2.589	2.238	1.822	8.138	14.51	13.99	4.411	1.766	0.869	1.748	1.655	2.867	4.735	159.0
4														
………														
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28														
29	2.312	3.357	2.710	4.624	4.430	1.914	0.980	2.220	1.036	1.064	2.635	2.192	2.451	33.66
30	1.794	1.424	2.784	5.216	10.03	5.586	1.156	0.777	0.610	1.258	1.479	1.267	2.784	41.34
31	2.016	1.239	6.104	5.197	4.383	1.692	0.832	0.712	0/814	0.758	0.731	1.128	2.145	49.75
32	1.304	1.359	1.748	7.953	6.325	2.136	0.832	0.897	0.638	0.767	1.507	2.007	2.284	15.07
33	1.239	1.618	2.321	5.771	2.367	4.606	2.858	1.119	0.684	0.629	0.832	0.832	2.062	73.61
Sum	65.93	67.41	115.2	243.3	399.8	233.2	93.10	47.52	41.79	54.44	66.68	72.53	125.4	
Qo	1.998	2.043	3.492	7.374	12.11	7.067	2.821	1.440	1.267	1.650	2.021	2.198	3.803	

The chart of a runoff regulation is presented in Fig. 3.

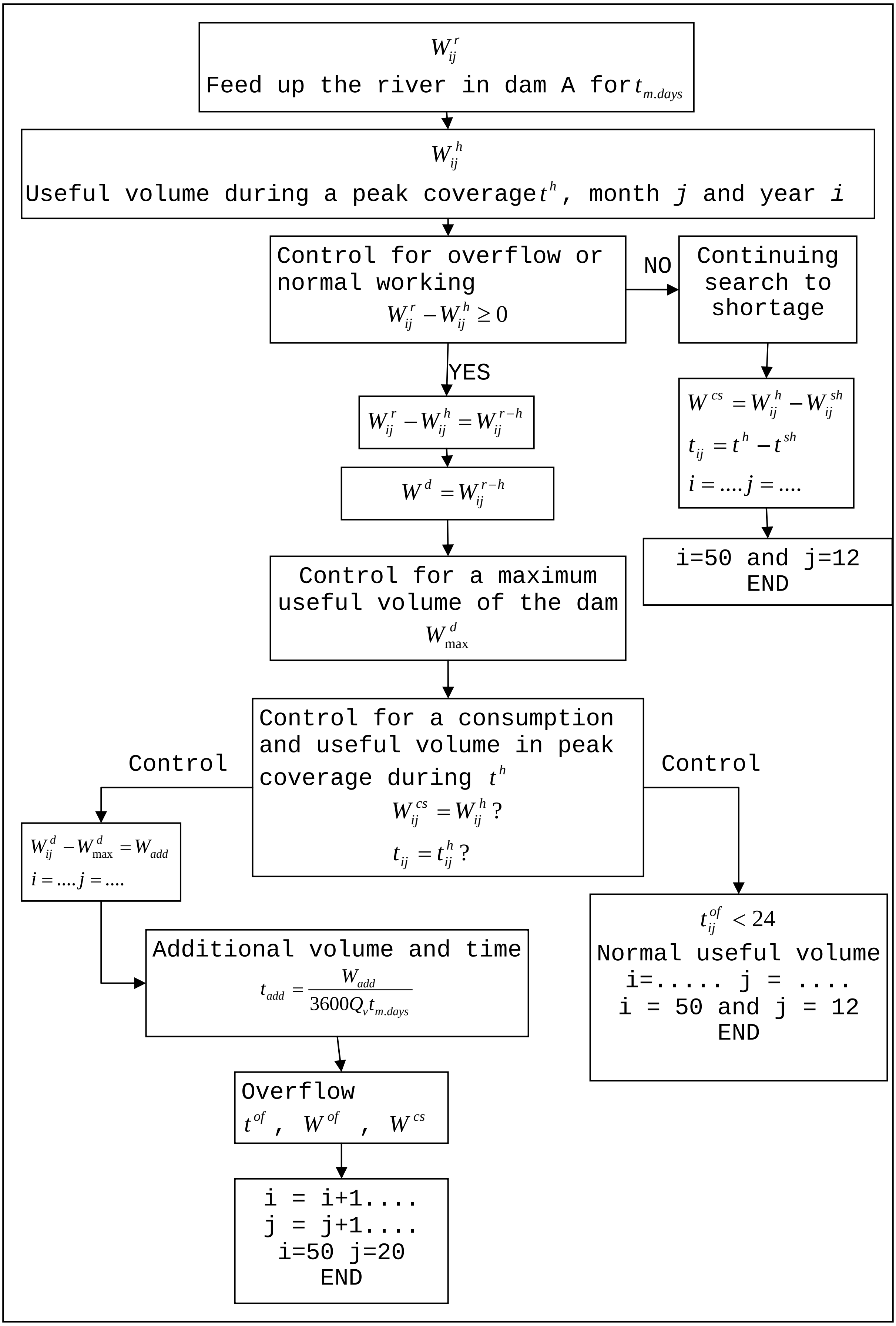

Fig. 3. General chart of the runoff regulation for 20 to 50 years

This algorithm is applied for two methods:
a) statistics;
b) observations
The calculated result with the upper algorithm b) is presented in Table 2 and Table 3 by means of a month observations for 33 years given in Table1 and a seasonal regulation according to Fig.4.

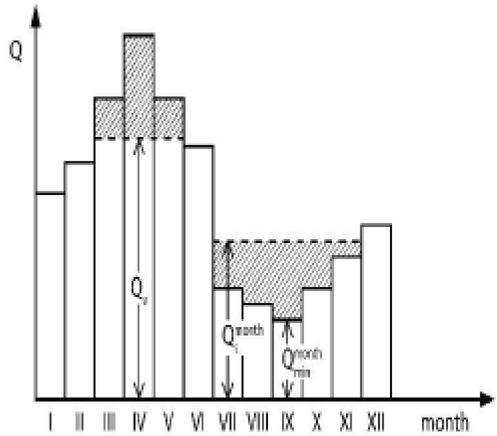

Fig. 4. Seasonal regulation

Table 2 Regulation of a runoff: feeder, discharge, shortage, overflows of dam A

I	Quantity	Measures	j=I	j=II	j=III	j=IV	j=V	j=VI	j=VII	VIII	j=IX	j=X	j=XI	XII	Sum
1	$W^r_{1,j}$	$10^6 m^3$	5.349	5.482	20.73	28.28	43.59	27.32	7.529	7.430	7.102	6.787	4.554	3.021	167.1
1	t^h	hour	5	5	4	4	4	3	3	3	3	4	5	5	
1	$W^h_{1,j}$	$10^6 m^3$	6.417	5.796	5.134	4.968	5.134	3.726	3.850	3.850	3.726	5.134	6.210	6.417	
1	t_{add}	hour				13.62	29.96	19.02	2.867	2.789	2.718	1.288			
1	$t_{1,j}$	hour	4.168	4.729	4	17.62	24	22.00	5.867	5.789	5.718	5.288	5	5	
1	$W^{cs}_{1,j}$	$10^6 m^3$	5.349	5.482	5.134	21.88	30.80	27.32	7.529	7.430	7.102	6.787	6.210	6.417	137.4
1	$W^d_{1,j}$	$10^6 m^3$			15.59	22	22	22	22	22	22	22	20.34	16.94	16.94
1	t^{of}	hour					9.967								
1	$W^{of}_{1,j}$	$10^6 m^3$					12.79								12.79
1	$t^{sh}_{1,j}$	hour	0.832	0.271											
1	$W^{sh}_{1,j}$	$10^6 m^3$	1.068	0.314											-1.38
2	$W^r_{2,j}$	$10^6 m^3$	2.874	1.923	5.027	13.87	10.23	7.258	2.676	2.823	2.086	3.343	4.650	10.35	67.12
2	t^h	hour	5	5	4	4	4	3	3	3	3	4	5	5	
2	$W^h_{2,j}$	$10^6 m^3$	6.417	5.796	5.134	4.968	5.134	3.726	3.850	3.850	3.726	5.134	6.210	6.417	
2	t_{add}	hour					1.119	2.844							
2	$t_{2,j}$	hour	5	5	4	4	5.119	5.844	3	3	3	4	5	5	
2	$W^{cs}_{2,j}$	$10^6 m^3$	6.417	5.796	5.134	4.968	6.570	7.258	3.850	3.850	3.726	5.134	6.210	6.417	65.33
2	$W^d_{2,j}$	$10^6 m^3$	13.40	9.532	9.425	18.33	22	22	20.82	19.79	18.15	16.36	14.80	18.74	18.74
2	t^{of}	hour													
2	$W^{of}_{1,j}$	$10^6 m^3$													
2	$t^{sh}_{1,j}$	hour													
2	$W^{sh}_{1,j}$	$10^6 m^3$													

3………
33………

Table 3 The monthly share in the coverage of the charge diagram and output of the HPP

I	Quantity	measure	j=I	j=II	j=III	j=IV	j=V	j=VI	VII	VIII	j=IX	j=X	j=XI	j=XII	Sum
1	$t_{1,j}$	hour	4.168	4.729	4	17.62	24	22	5.867	5.789	5.718	5.288	5	5	
1	$E_{1,j}$	10^6 kwh	1.296	1.324	1.240	5.286	7.440	6.600	1.819	1.795	1.715	1.639	1.500	1.550	33.20
2	$t_{2,j}$	hour	5	5	4	4	5.119	5.844	3	3	3	4	5	5	
2	$E_{2,j}$	10^6 kwh	1.550	1.400	1.240	1.200	1.587	1.753	0.930	0.930	0.900	1.240	1.500	1.550	15.78

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RESULTS

Type of the coverage of the charge diagram and the output of HPP

1) Peak load: winter 5h, spring 4h, summer 3h,
Sub-peak: winter 5h – 10h, spring 4h – 8h, summer 3h – 6h;
2) Daily: winter 10h – 16h, spring 8h – 16h, summer 6h - 16h;
3) Daily/nightly: winter16h - 24h, spring 16h = 24h, summer 16h – 24 h.

4 FORECASTING ANALYSIS

In the previous subsection 2.1 the water discharges for 50 years and the density functions were found by a chain system on the basis of the observed data. New approaches can be used for the runoff regulation and for the operation of HPP applying the forecast analysis. Two methods are possible: time series analysis and advanced series one. The both methods could be classified according three categories:

- Quantitative
- Qualitative
- Unpredictable

Quantitative forecasting is applied when the information about the past is available. The following three steps are used:

1-preliminary analysis; 2-choice and fit the model; 3-evaluation of forecasting.

The first step can be carried out by analysis the trend, seasonality, cycle, and random variations by means of exploratory analysis and fitted load data. Several methods are available for the realization of the second step as moving average, exponential smoothing, Holt-Winter linear algorithm, regression and finally advance series analysis of the type autoregressive model (AV), autoregressive moving average (ARMA), autoregressive integrated moving average (ARIMA),etc. Since a quantitative forecasting varies widely and could be fall easy the third step is obligatory.

4.1 Preliminary analysis of trend in time series

Smooth curves are chosen commonly to describe and average fluctuations of original data. The least square method (LSM) and R-Squared value (RSV) are applied to fit the best curve. The exponential form is commonly used:

$$Y = Ce^{DX} \quad (8)$$

Where Y, X are dependent and independent variables, C and D are parameters to be computed.

Many mathematical functions exist using various forms of LSM or by Moving Average MA. The best curve, estimated by RSV, is called a coefficient of determination. It is an indicator whose value ranges in the interval from nought to unit and shows how closely the trend values correspond to the actual data. In general this indicator is defined as:

$$R^2 = \frac{\sum_{1}^{N}(Y' - Y_{avg})^2}{\sum_{1}^{N}(Y - Y_{avg})^2} \tag{9}$$

Where Y and Y' are forecasting variable and its estimated results respectively, Y_{avg} is the calibration period.

After estimation of parameters in formula (8) the de-trended series are computed by dividing the original data with the trend component:

$$Y_t / T_t = S_t E_t \tag{10}$$

Where Y_t is the time series value (actual data), S_t is the seasonal component, T_t is the trend-cycle component and E_t is the random component at time t.

The random component is computed by dividing the seasonal one from (10) and the final formula has the form:

$$Y_t / (T_t S_t) = E_t \tag{11}$$

The next table shows the seasonal components in the series represented by the data for the last period of five years – 1979 to 1983 for water volumes in a river (load data). The last bold numbers in the final column are known as seasonal indices.

Table 4 Seasonal components (indices) of the series for the last five years

Years Months		1979	1980	1981	1982	1983	Average seasonal components (indices)
Jan	seasonal	0.94	0.84	0.93	0.96	0.96	**0.98**
	random	0.96	0.86	0.95	0.98	0.98	
Feb	seasonal	0.98	0.91	0.95	1.00	0.95	**0.981**
	random	1.00	0.93	0.97	1.02	0.97	
Mar	seasonal	1.08	1.01	1.12	1.06	1.13	**1.03**
	random	1.05	0.98	1.08	1.03	1.10	
Apr	seasonal	1.05	0.86	1.01	0.98	1.11	**1.062**
	random	0.99	0.91	0.96	0.93	1.05	
May	seasonal	0.97	0.88	1.06	0.98	1.07	**1.101**
	random	0.88	0.80	0.96	0.84	0.98	
Jun	seasonal	1.07	1.03	1.08	1.19	1.13	**1.152**
	random	0.93	0.90	0.94	1.01	0.98	
Jul	seasonal	1.169	1.17	1.19	1.21	1.21	**1.120**
	random	1.040	1.04	1.07	1.08	1.08	
Aug	seasonal	1.15	1.15	1.18	1.26	1.23	**1.061**
	random	1.09	1.09	1.12	1.19	1.17	
Sep	seasonal	1.04	1.06	1.08	1.07	1.06	**0.941**
	random	1.12	1.13	1.15	1.15	1.14	
Oct	seasonal	0.90	0.88	0.94	0.97	0.94	**0.923**
	random	0.99	0.96	1.03	1.06	1.02	
Nov	seasonal	0.781	0.751	0.84	0.86	0.79	**0.861**
	random	0.90	0.87	0.97	1.00	0.91	
Dec	seasonal	0.88	0.91	0.94	0.96	0.87	**0.900**
	random	0.97	1.01	1.05	1.07	0.97	

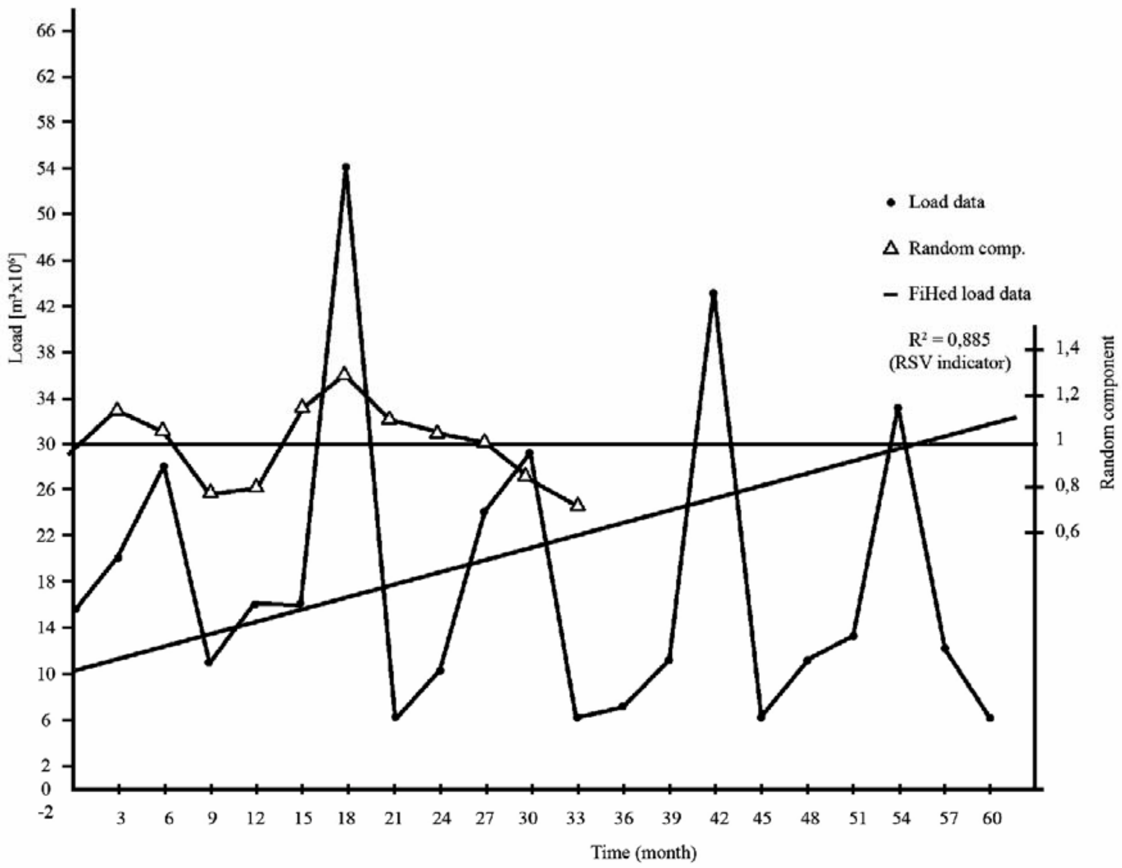

Fig. 5 Time series plot for the last five years

Graphical plot of the original load, fitted data and random components are presented in the above figure with the root square indicator RSV.

4.2 Choice and Fit the Model

Holt-Winter method was tested because it is based on three smoothing equations that account the level of the series, trend and seasonal components. Two applications of this method are used as a rule-multiplicative method and additional one. The first model is preferable when the seasonal fluctuations vary in the level of the series and it is chosen in this work with mean square error (MSE) by the formula:

$$MSE = \sqrt{\frac{\sum_{month} (Q_{demand} - Q_{estimated})}{N}} \qquad (12)$$

The following test gives an idea for the monthly consumptions of HPP (Table2) over the past 24 months and a forecasting two months ahead- table 5.

Table 5. Forecasting by Holt-Winter multiplicative method for two months ahead

Month	Demand	Level	Trend	Seasonal	Fitted Demand	Random
	[$m^3.10^6$]	[$m^3.10^6$]	[m^3s^{-1}]		[$m^3.10^6$]	
1	3,49	4,31	1,30	0,96	3,45	0,04
2	3,28	4,28	1,36	1,00	3,80	-0,52
3	4,68	4,70	1,75	1,06	4,10	0,58
4	20,61	5,65	7,95	0,98	21,62	-1,01
5	16,94	5,40	6,32	0,98	17,25	-0,21
6	5,54	4,80	2,14	1,19	6,02	-0,48
7	2,16	3,85	0,83	1,21	2,21	-0,05
8	2,40	3,90	0,89	1,26	2,45	-0,05
9	1,65	2,15	0,64	1,07	1,50	1,15
10	2,05	3,70	0,77	0,97	2,15	-0,10
11	3,91	3,90	1,51	0,86	4,10	-0,19
12	5,37	5,40	2,00	0,87	5,27	0,10
13	3,32	3,25	1,24	0,96	3,45	0,13
14	3,91	3,95	1,62	0,95	3,80	0,11
15	6,22	4,90	3,32	1,13	6,12	0,10
16	14,96	5,20	5,72	1,13	13,90	1,06
17	6,34	4,83	2,37	1,07	6,50	-0,96
18	11,94	5,13	4,61	1,13	12,04	-0,10
19	7,65	4,95	2,85	1,21	7,30	0,35
20	2,99	3,50	1,11	1,23	2,50	0,49
21	1,77	2,26	0,68	1,06	1,87	-0,10
22	1,68	2,25	0,63	0,94	1,88	-0,20
23	2,16	3,85	0,83	0,79	2,36	-0,20
24	2,16	3,85	0,83	0,87	2,36	1,49
-		α = 0,83 β = 0,075 γ = 0 MSE = 25%				
-		Forecasting 2 months ahead				
months	Demand	95% Confidence		95% Confidence		
	[$m^3.10^6$]	Upper Limits		Lower Limits		
25	3,21	3,85		2,95		
26	4,15	4,99		3,53		

4.3 Evaluation of forecasting by advance series analysis

Advance analysis includes other variables to describe the behaviour of the series using multiple time data. The new variables will capture additional effects for prediction and this comprehensive model depends on adequacy of calibration and residual uncertainty. In simulation the reservoir process, the principle of continuity is used to balance precipitation, storage, evapotranspiration and runoff written by (13). This conceptual model takes into consideration the nonlinearity, uncertainty factors, etc. (Friedel, 2006; JRBS):

$$\text{Precipitation} - \text{Actual} \quad \text{Evapotranspiration} \pm \text{Storage} = \text{Runoff} \tag{13}$$

An Auto Regressive process of order $\mathrm{p}, \mathrm{AR}(\mathrm{p})$ contains p number of parameters and can be expressed as:

$$\mathrm{x_t} = \phi_1 x_{t-1} + \phi_2 x_{t-2} + \ldots + x_{t-p} + a_t \tag{14}$$

Where $\phi_1 \ldots$ are the AR parameters which describe the effect of a unit change in $x_{t-1}\ldots.$ on x_t and which needs to be estimated; a_t is known as error or series white noise (Fig.6). A process with autoregressive and a moving average term is called an autoregressive moving process (ARMA) and it is represented by equation:

$$x_t = \phi_1 x_{t-1} + a_t - \theta_1 a_{t-1} \tag{15}$$

The higher order $\mathrm{ARMA}(p,q)$ is expressed as

$$x_t = \phi_1 x_{t-1} + \phi_2 x_{t-2} + \ldots \phi_p x_{t-p} + a_t - \theta_1 a_{t-1} - \ldots \theta_q a_{t-q} \tag{16}$$

Where θ_1 is a moving average parameter; p refers to the number of autoregressive parameters and q - the number of moving average parameters (Fig.7).

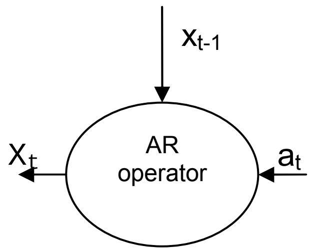

Fig. 6 Scheme of AR

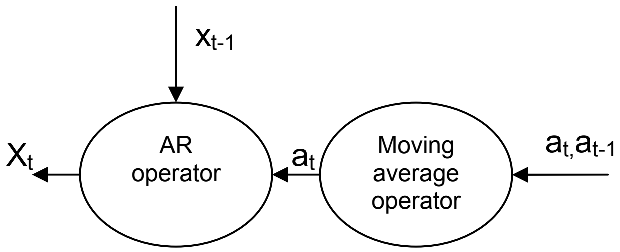

Fig. 7 Scheme of ARMA

5 CONCLUSION

The seasonal, annual and long term period of regulations of the runoff can be investigated with the help of the developed algorithm and software. The 12 monthly distributions in the individual years are established by statistical characteristics in the interval of probabilities among 2%-90%. Examples for the density and distribution functions are solved as well as a test for seasonal regulation of runoff with the monthly share in the coverage of the charge diagram and the output of HPP. Finally a forecasting analysis of runoff is estimated using the observed data.

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