Section 5

LOW-WATER PERIODS ON THE RIVERS

WINTER LOW FLOWS ON THE UPPER OB RIVER

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INTRODUCTION

An behaviour of winter low flows in a river is of importance for operation of reservoirs with seasonal regulation. The problem of seasonal regulation of river reservoir is considered for a case of the Novosibirsk hydropower reservoir operation on the Upper Ob River in an autumn-winter period of low flow. The total and operational volumes of the reservoir are 8.8 km^3 and 4.4 km^3 respectively at the average annual inflow 54.0 km^3. The deficit of water storage in the reservoir became regularly revealed in the winter period when the river inflow was much lower than usual one and much less than the release of water from the reservoir in this period.

The question is arisen: what is probability of occurrence of heavier situations caused by the unfavourable action of hydrological and meteorological factors, in particular – when a seasonal runoff and hence an inflow to the reservoir is extremely low in autumn and winter periods? To answer this question a special study has been tackled which is based upon the analysis of such factors as the seasonal runoff of the Upper Ob river, the water releases flow from the reservoir and the evaluation of its water balance in the autumn-winter period.

DESCRIPTION OF THE WINTER RUNOFF FOR THE UPPER OB RIVER BY THE EXAMPLE OF THE KAMEN-ON-OB STATION

The analysis of seasonal runoff variability for the Upper Ob River has been done mainly on the basis of regular observations at the Kamen-on-Ob station (an inflow section of the reservoir) since 1894 through 2001 years. This analysis revealed that the periods with the lowest seasonal flow occurred at the end of the 19th — the beginning of the 20th centuries. To assess the variability of winter runoff here the values of discharge over the three-month time-interval of January-March were evaluated. The normal winter discharge averaged over the three-month period is 335 m^3/s. The maximal mean flow at this period had been recorded in 1947 and it was equal to 541 m^3/s. The minimal mean discharges for the same period that were observed in 1900 and 1901 years are 187 and 179 m^3/s respectively (57% and 53% of the normal value). Annual variation of winter runoff in the period under consideration is estimated by the coefficient Cv = 0.2. Table 1 for some characteristic cases (including extreme ones).

A correlation between the long-term hydrological records of observations on the Upper Ob, Tom and Irtysh rivers and the climatic behaviour in the southern part of Western Siberia in the period under consideration has shown that the low-flow periods for river runoff, as a rule, correspond to "dry-year" ones. In particular, the sharpest situations related winter low flows follows heavy droughts. Thus, the long droughty period was observed from 1890 through 1902 years and the driest years were 1890, 1900 and 1911.

Table 1. Mean winter flow in the extreme cases

	Mean discharge (m^3/s)							
Year	1900				1901			
Month	I	II	III	Mean value (January-March)	I	II	III	Mean value (January-March)
Kamen-on-Ob	199	187	187	191	178	168	190	179
Novosibirsk	224	222	223	223	225	220	221	222

The analysis of continuance of the group "wet" and "dry" periods was performed for mean three-month winter flow at Kamen-on-Ob relatively normal winter discharge. The average times of the "wet" and "dry" periods are closely related and amount accordingly to 2.14 and 2.82 years. The one year periods predominate in the runoff fluctuations. The maximum continuance of the "dry" periods was equal to 7 years and was observed in the beginning of the 20th centuries (1905-1911, 1924-1930). The analysis of autocorrelation coefficients revealed presence close in-row connection between adjacent terms of series ($r(1)\approx 0,3$). The close in-row connection for series of winter runoff (discharge over the three-month time-interval of January-March) is observed to third lag and is the stable under changes of long time series.

PROBABILITY DISTRIBUTION CURVES

A comparative analysis has been undertaken to assess what types of analytical curves of probability distribution are fit the most appropriately for the set of observation data on the mean winter flow at Kamen-on-Ob (1894-2001). Six types of curves of the distribution were examined:
1. the tree-parameter gamma distribution (the Kritsky-Menkel model),
2. the Pearson type 3 distribution,
3. the log-Pearson type 3 distribution,
4. the log-normal distribution,
5. the Gumbel distribution,
6. the Gudrich distribution (Fig. 1).

The Pearson criterion χ^2 and the Kolmogorov criterion λ have been used as a goodness-of-fit test. The standard deviations σ_Q and σ_P of empirical points from the analytical curves also have been used for the deviations along the vertical and horizontal axis respectively. The results of assessing how the analytical distributions fit the observational data are shown in Tabl. 2.

Interpretation of the results here seems to be not easy thing. Surprisingly, according to the Pearson goodness-of-fit criterion χ^2 the best fitting to the total set of empirical data is provided by two-parameter distributions, namely — by Gumbel and Gudrich ones. However, the standard deviations σ_Q and σ_p used as criteria for assessing quality of approximation by the same probability distributions have given quite different result: according to these criteria the best approximation is achieved with use of the three-parameter distributions, what is rater natural. This conclusion is corobborated by using of the Kolmogorov goodness-of-fit criterion, in particular for the Kritsky-Menkel tree-parameter gamma distribution.

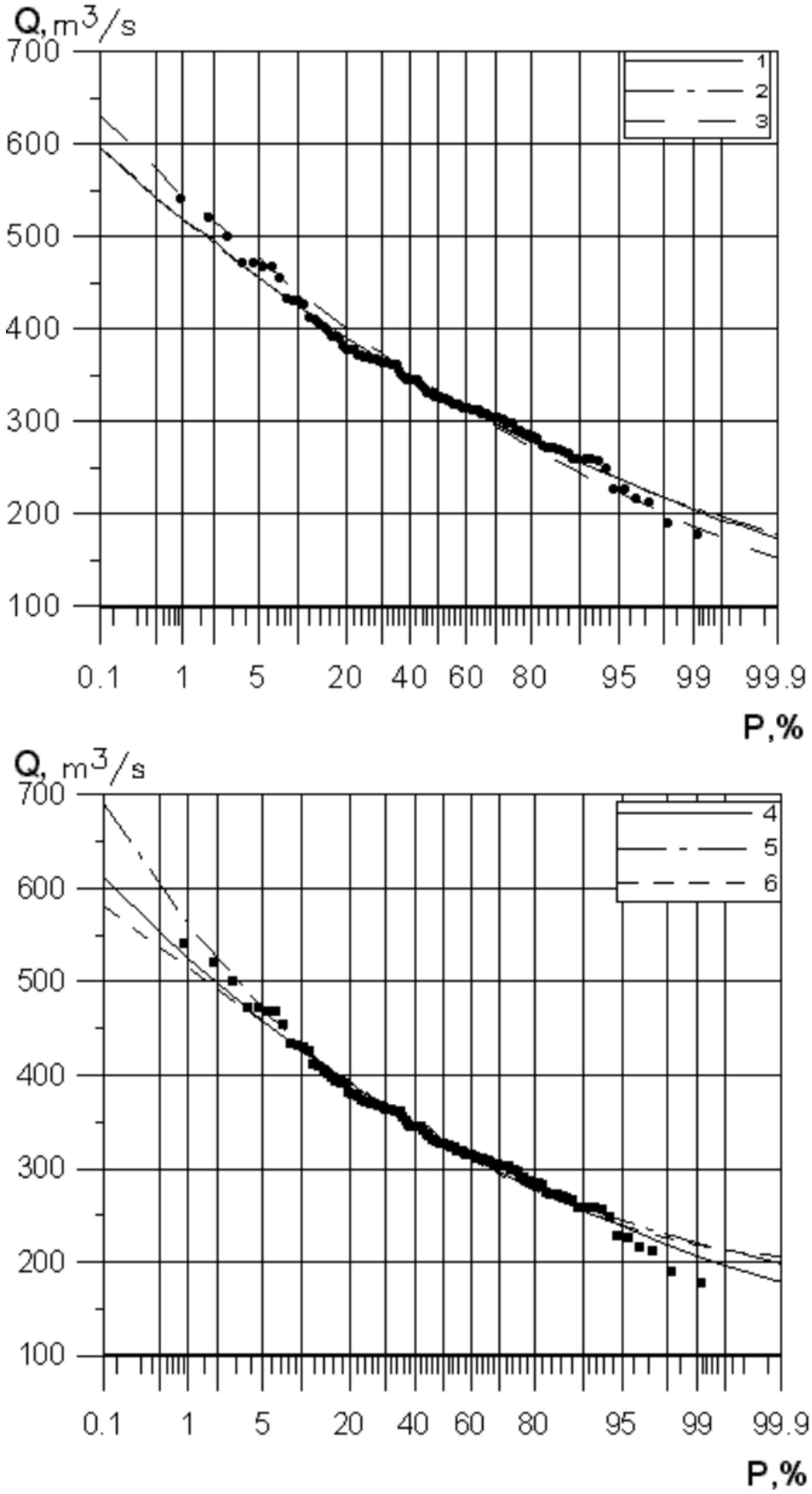

Figure 1. The probability distribution curves and the distribution of empirical frequencies for the winter flow at Kamen-on-Ob (the numbers of curves of distribution are correspond to those given in the text above, the dots represent the observational data

Table 2. Results of fitness assessment of different types of probability distribution and the discharges of different probabilities for the winter flow at Kamen-on-Ob

	Kritsky-Menkel	Pearson type 3	Log – Pearson type 3	Log-normal	Gumbel	Gudrich
χ^2	8.11	8.30	12.9	7.93	5.15	6.81
λ	0,561	0,622	0,812	0,601	0,808	0,716
σ_Q, %	2.33	2.32	3.57	2.26	2.94	3.70
σ_P, %	2.44	2.48	4.2	2.55	2.93	3.22
P,%	Discharge m^3/s					
50%	331	331	333	330	326	330
90%	255	255	245	255	259	254
95%	237	237	223	238	244	239
99%	204	206	187	207	220	218
99,9%	173	178	152	178	198	206

At the same time, it is easy to notice that practically all analytical curves considered here are fit poorly for the points of rare events when the lowest winter flow-rates were observed (e. g. in 1900, 1901, 1910 years). The log-Pirson curve shown on Fig. 1 is fitted better to these points, however it is not so for the majority of others. Such a location of the curve was obtained by fitting the value of the coefficient of variation Cv the logs of river discharges (the value of Cv ≈ 0.1 was taken for the variation of their logs).

One may conclude from the results presented here that there is an obvious need for further and deeper consideration of the topic. In particular, applying the method of truncated distributions could possibly be helpful to achieve better fit for the curve tails at the extremely low flows and respectively the low frequency of events.

APPLICATION OF THE CLUSTER ANALYSIS IN THE PROBLEMS OF REGIONALIZATION OF THE CASPIAN BASIN BY CHARACTERISTICS OF THE RIVER RUNOFF SEASONAL VARIABILITY

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Seasonal fluctuations of river runoff represent one of the important characteristics of the river hydrological regime. Research of mechanism of these fluctuations is actual as it allows to solve the problems connected both with economic, and with nature protection (ecological) problems. The river runoff is characterized by the big variability of distribution both on time, and on territory. Runoff observations cover all the spectrum of river hydrological regime insufficiently, and hydrological stations are located non-uniformly. Besides, long-term series of monthly water flow have length insufficient for researches because of the short period of observations; they are characterized by significant errors of measurements and presence of misses. All this complicates application of estimation and forecast methods according to observations on separate hydrological stations. The increase in the information due to the joint (group) analysis on groups of hydrological homogeneous objects enables to avoid many random errors. In this connection, regionalization by characteristics of river runoff seasonal variability has the important scientific and practical significance.

Great attention is given to the problems of classification of rivers and hydrological regionalization. The classification of rivers means their distribution into groups according to the most essential features revealed, and regionalization means the application of the received classification to concrete territory. This allows defining characteristics of poorly explored objects by analogy with the investigated ones. To solve the problems connected with the estimation of spatial distribution of river runoff and its seasonal variability, it is necessary to develop new variants of the regionalization. It is especially important for the territories that have high economic significance and are characterized by the great intraannual variability of river runoff. In particular, the Caspian Sea basin concerns to such kind of territories.

The approach to hydrological regionalization suggested in this work is based on the analysis of annual distribution of river runoff by extracting characteristics of its seasonal variability and grouping time series of average monthly water flow with the help of cluster procedures. TeleStat system was used as the computational-statistical support for the research [2]. It is intended for statistical analysis of multivariate data and time processes. Regionalization was carried out with the help of cluster procedures using “k-means” method and a new method based on regression analysis with the use of radial basis functions (RBF). Employment of such a regression procedure based on RBF gives the possibility to find group centers as well as to evaluate the group number. The result of clustering in both cases vitally depends on the specified distance between the objects. In the work the weighted Euclidian distance [2, 3] was used. When *k*-means method was used for the territory regionalization according to seasonal flow, variable weights were adjusted in such a way as to ensure both geographic proximity of the objects (hydrologic posts) and their criteria proximity.

As characteristic of seasonal variability of river runoff, there were used sets of characteristics of the low-flow periods (their duration, skewness and variability coefficients), seasonal indexes and some characteristics of spectral density functions of monthly water discharge time series.

Let's consider procedures of transformation of the source information into sets of secondary parameters.

1) DEFINITION OF QUANTITATIVE CHARACTERISTICS OF LOW-WATER PERIODS (WATER SUPPLY DEFICIT).

Long periods of low river runoff and extreme deficiencies of water supply can influence essentially the strategy of water economy management, including the character of runoff regulation, operating regimes of hydraulic constructions. They impact on operational reliability of water supply systems. Therefore, in the given work great attention is given to the analysis river runoff during low-flow periods. The basis of the research is the conception of the low-level runoff as a water deficiency relative to the set "threshold" value of the water discharge. It is the most frequently used quantitative characteristic of the low-level runoff based on the introduction of some threshold, water discharge being lower it, the deficiency is observed. The period during which water discharge is below the threshold is critical. Thus, it is offered to study statistical properties of distribution of water deficiencies and their durations. The determination of the critical (low water-level) periods is represented on fig. 1.

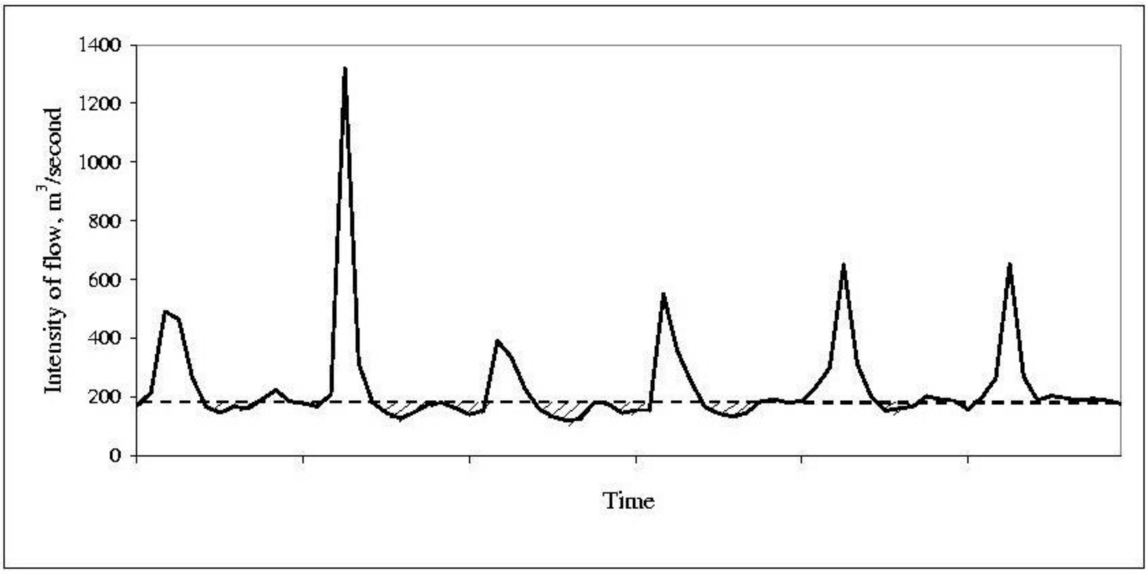

Fig.1. Determination of the critical (low water-level) periods of the river runoff by means of the threshold method

As threshold values of the runoff there are used reciprocal distributions of the low-level runoff discharge, estimated on the basis of Gumbel approximation [1]. Long-term series of the water deficiencies (in statistical terminology of "emissions") are received. Their statistical treatment is executed. Set of characteristics of the low-flow periods (duration, skewness and variability coefficients) are received for each time series.

2) ESTIMATING OF SEASONAL INDEXES WITH THE HELP OF SEASONAL DECOMPOSITION METHODS.

By seasonality we mean the influence of external factors which have a cyclic action with a known period. A simple model which takes in account seasonality is the seasonal effect model. In the additive version of this model a series is represented as

Y(t) = T(t) +S(t) + err,

where T(t) is trend, err stands for error and S(t) is the seasonal component which is supposed to be a periodic function of period L, i.e., S(t) = S(t+L). In reality, the function S is determined by its values lying within the range of any one period, say, S(1), ... , S(L). For the one-valuednes of the parameterization, it is generally assumed that S(1) + ... + S(L) = 0.

The values S(1), ... , S(L) are called seasonal indexes.
In this research were used the normalized seasonal indexes $SN(J) = S(J)/\|S\|$, where

$$\|S\|^2 = \sum_{J=1}^{L} S^2(J).$$

For estimating of seasonal indexes Theil-Wage algorithm was used [2].

3) EVALUATION OF SPECTRAL DENSITY CHARACTERISTICS.

Typical spectral density function of investigated time series contains pronounced maximums (peaks) at frequencies which correspond to periods 12, 6, 4 and 3 months. So for approximate description of such a function we used its relative values at these frequencies. The difference between the unit and the sum of relative values of spectral density on allocated frequencies was used to take into account other components of the spectral function.

Tables with long time series of variables of all the researched objects (hydrological stations) have been received after transformation of the input data. They contain geographical coordinates and characteristics of the runoff seasonal variability (duration of the critical low-flow periods, skewness and variability coefficients, seasonal indexes and some characteristics of spectral density functions of monthly water discharge time series. The long time series of these parameters and the corresponding coordinates of observation stations were used for hydrological regionalization. As the result, maps of statistically homogeneous regions according to the character of river runoff seasonal variability have been received for the Caspian Sea basin. 171 objects (hydrological stations with no less than 20 years of observations, having the similar regime, not having difficultly restored misses, and not subject to strongly appreciable human impact) has been selected and processed. Multiple numerical calculations have been realized with use of cluster analysis. The optimum number of groups for the Caspian basin (eight groups) was defined on the basis of regression approach with the use of radial basic functions. Multiple cluster procedures were carried out on the basis of the *k*-means approach with the set group number (eight). The optimum variant of regionalization has been chosen as a result of comparison of different variants on the basis of statistical estimations. So, the map of regionalization of the Caspian Sea basin is represented on the fig.2.

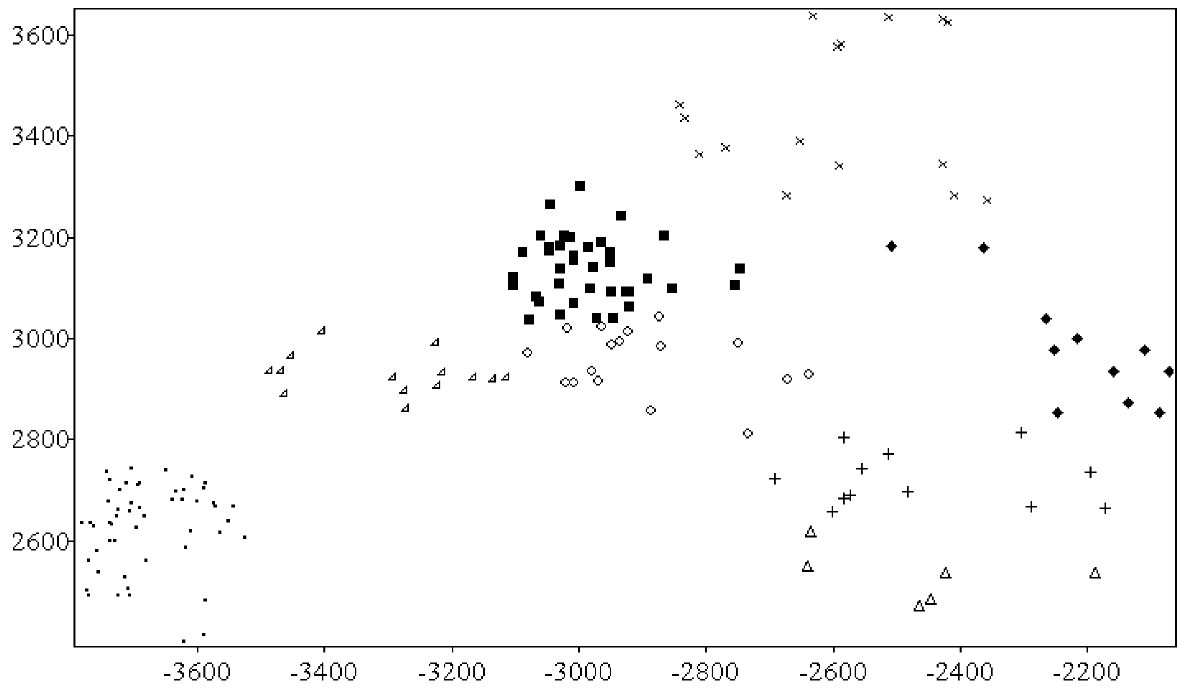

Fig. 2. Fragment of regionalization of the Caspian Sea basin by characteristics of river runoff seasonal variability (the transformed conditional geographical coordinates are submitted on the axes)

Basic criterion for evaluation of classification quality is Eta-coefficient or correlation ratio coefficient of the initial variables and grouping variable, obtained as the result of cluster analysis. The closer Eta is to 1, the more the contribution of the corresponding variable is for this classification.

The results of the researches were compared to the results of the existing regionalization of the rivers runoff. For this purpose, numeralization of the regions chosen in works [4, 5] has been made. Selection of the hydrological observation stations from the general database was made with the help of special computer programs for each region. It has allowed to receive the electronic map of existing regionalization. Then, with the help of visual analysis and with use of two-way contingency tables different variants of regionalization were compared. Regions obtained as a result of one variant of clustering procedures form columns of contingency table, and the ones obtained by the other variant form rows. For evaluation of the similarity of classifications the Pearson contingency coefficient was used. Choice of the "best" classification variant was based on the unbiased estimations of correlation ratios (between grouping variable and variables involved in the cluster criterion).

The comparative analysis has shown, that regionalization based on cluster analysis by river runoff seasonal variability do not contradict with the existing one made by river water regime. At that, statistical criteria of classification for the received regionalization are better, because the number of groups, as well as the dispersion of characteristics of the seasonal river runoff inside regions decrease.

Thus, hydrological regionalization of the Caspian Sea basin is received by river runoff seasonal variability. With this purpose most significant and informative parameters of the river runoff were defined by means of the statistical analysis of the long-term series. It is revealed, that such parameters are seasonal indexes and spectral density functions. Since extreme events on the rivers can occur during the low-flow periods, the major attention was given to the analysis of river runoff distributions during these periods. Durations of the low water-level periods and their statistical characteristics (skewness and variability coefficients) were accepted as parameters. Cluster procedures with *k*-means approach were applied to an assessment of spatial river runoff seasonal variability and allocation of statistically homogeneous regions. The optimum group numbers was defined with the use of radial basic functions. The multiple numerical experiments with different sets of the parameters of seasonal runoff fluctuations have allowed allocating homogeneous hydrological regions in the Caspian Sea basin.

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