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Long-Term Forecasting of Mountainous Rivers Runoff on the Base of Mathematical Models

Ludmila N. Borovikova*, Natalja A. Agaltseva and Alexander V.Pak*****

*Deputy Director Sanigmi
** Scientific worker
*** Senior scientific worker
Sanigmi, Observatorskaja, 72, 700052
Tashkent Republic of Uzbekistan

SYNOPSIS

The paper considers the methodics of long-term forecasting of mountainous rivers runoff based on mathematical models as well as its realization in the form of automatized informational system of hydrological forecasting (AISHF) "UZGIDROMET".

Use of mathematical models allowing to extend, deepen and detail natural processes description may be considered as a prospective trend of hydrological forecasting development in terms of informational deficit.

During the past 15-20 years the scientists of SANIGMI (prof. Ju. M. Denisov & his school) were intensively developing models of the mountainous rivers runoff formation. And up to the present approbated enough models of hydrological cycle are available, including 3 main blocks: a) snow cover formation; b) computation of the melt(snow and glacial) and rainfall water inflow on a watershed surface; c) inflow transformation in the outlet.

Not concerning the description of models of snow cover formation in the mountains and computation of the water inflow to a watershed surface (as they are presented in detail by the works of prof. Denisov school [1,2] let's mention the main stages and difficulties of their realization for specific objects.

Adaptation of the snow cover formation model for a certain basin includes the following stages:

- precipitation and air temperature fields analysis for their numerical description;
- cartographic object presentation;
- snow resources computation with the help of the model, estimation of the model adequacy to field measurements.

Difficulties on the first stage are connected both with the lack of information (sparse network, missing of observation at high altitudes, etc.), and the complex pattern of actual precipitation distribution in the mountains. Often it is impossible to obtain a single relation between precipitation and altitude for a large basin (Chirchik, Karadarja) on the whole. Division into separate basins isn't successful in all cases. That's why we are to find more complicated description of precipitaion fields including other characteristics besides altitude (latitude, longitude, distance from the main range, openness to the water bearing flows, etc.).

In all cases for the description of higher levels precipitation less reliable additional data are used including: total precipitation, snow courses, computational glacial-climatic data on precipitation amount at the height of glaciers'firn line and many others.

The required cartographic object presentation is determined by the form of relations obtained for precipitation fields. Having one-factor relations between precipitation and altitude it's enough for further computations to have a function of basin area distribution with height - F(z). Computed result is in the form of snow resources (snow water content) distribution with height. Having multifactor discription of a precipitation field the computation is made in a relevant coordinate system in grid points, that's why it is necessary to have relief (alltitude) in grid points.

Taking into account that parameters of the meteorological elements fields discription have considerable errors, the process of their collection and simulation includes series of iterations till the required correspondence is achieved.

Input function presents total inflow of the melt (snow and glacier) and rainfall water to the basin in the runoff formation models with lumped parameters. It determins the presence of three blocks in the inflow model:

- computation of the snowmelt water inflow;
- computation of the rainfall water inflow;
- computation of the glacial melt water inflow.

It's necessary to have apriori data on the glaciers'area distribution in the basin - Fл(z) for the computation of the last component.

The block of the glacial runoff computation makes in possible to evaluate the role of the basin glaciation as additional water source and temporal regulator of runoff.

Among transformation models the linear two-volume model was chosen, in which a mountainous river basin is presented as two transforming reservoirs connected in parallel-successive order. The upper one serves as analog of the upper acquifier with rapid inflow transformation. The lower reservoir describes transformation by deeper acquifiers. Snowmelt and rainfall water inflow to the watershed surface serves as input to the model. Water dicharge in the outlet equals to the discharge sum of the upper and lower transforming reservoirs. The presence of some basis runoff independent on the given years inflow is also implied which is taken to be equal to the long-term minimum runoff Qmin.

Runoff transformation model is realized by the following stages:

- optimization of the model parameters by prescribed input function (computed inflow) and output one (measured runoff in the outlet) for different designed periods;
- estimation of parameters variability, both interannual and long-term one;
- estimation of the model adequacy to the measured runoff on the basis of dependent and independent data.

The stage of estimation of model parameters'variability determines its suitability for prediction purposes, because it considerably depends on the parameters'stability and their definition apriory. The practice of models realization on the Central Asian rivers has shown sufficient reliability of parameters definition when optimization is made separately for a set of years depending on water content (years with high, average and low water content). Such approach permits their definition appriori in prognostic version of the model, because estimation of the water content for any year can be made on the basis of snow resourses amount available in the basin up to the moment of the forecast issue.

Proceeding to a prognostic version of the model it's proporsed to use climatic characteristics for the period of earliness, prognostic values of temperature and precipitation anomalies or to make computation for a few versions (climate and different climatic deviations) and then to estimate the probability of each version.

The advantage of the long-term forecast based on the model lies in possibility of comprehensive analysis of the current and forthcoming weather situation which is especially important for the years of extreme weather in summer and spring. Realization of this technique gave positive results for the Tian-Shan and Fergana valley rivers. It allowed to forecast inflow into large water storages of Central Asia - Charvak and Andizhan ones.

Here we consider in more details the results of forecast development for vegetation runoff using technique presented above for Zeravshan river, which is typical for Central Asia.

The development of forecasting technique for vegetation runoff of Zeravshan river is a rather complex problem. The late flood outset and late runoff concentration are inherent to Zeravshan river being the river of glacial-snow alimentation. The complex orography of the Zeravshan basin causes mixed character of atmospheric precipitation and snow cover formation. Here precipitation amount ranges from 200 mm and less on lee sides up to 2000 mm on windward ones. In Zeravshan river basin precipitation is mainly formed by moisture-bearing flows of two directions: from the west through the mouth part of the valley and from the south through the passes of Gissar mountain ridge. Due to the complex relief of the basin the overlap of longitudinal-circilar and barrier effects arises, which makes the description of orographic factors effect on precipitation fields in a form of monotonic relation impossible. Poor data on precipitation of the mountain territory of the basin, and their actual absence at the altitude of more than 2.5 km necessitated the use of additional glacial climatic data and extrapolation of precipitation values by snow data for the analysis of the field of long-term average annual precipitation.

Thus, precipitation distribution in Zeravshan river basin was described by the system of the one-factor altitude relations for three subregions: Matcha river basin, Yagnob and Iskanderdarja river basins; lower reaches of Zeravshan river and Magiandarja river basin.

For each of these subregions the precipitation parameters being input data into the model of snow cover formation were computed. The results of precipitation rate field approximation by square-law form are presented in Fig. 1 by the example of seasonal total of pre-

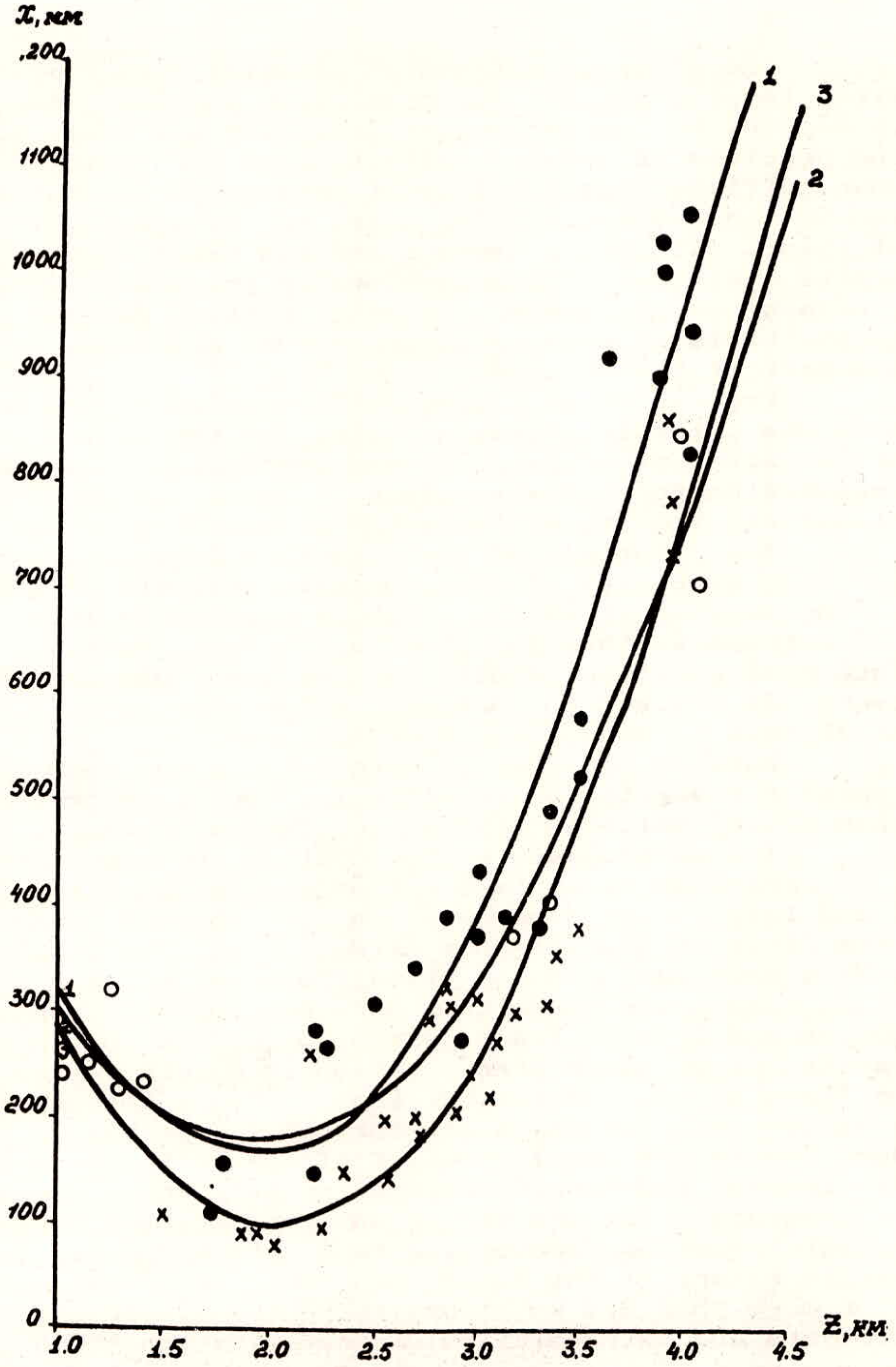

Fig.1 Relation between October-March precipitation in Zeravshan river basin and altitude
1 - Yagnob and Iskanderdarja river basin (subregion 2), 2 - Middle part of Zeravshan river including Magiandarja river basin (subregion 1),3 - Matcha river basin (subregion 1)

cipitation amount during October - March for three subregions.

Satisfactory coincidence of snow resources amount defined by the snow cover formation model on the basis of computed by above mentioned method precipitation fields with snow survey data (surface, airborne and satellite ones) serves as positive estimate of the technique accuracy. The computation of runoff hydrograph (the results of the transformation model) is to be considered as the final estimate of the designed precipitation fields.

The analysis of temperature and air humidity fields made it possible to define the altitude temperature gradients and their interannual variation along with a single altitudinal relation for moisture deficit and its interannual variation for numerous Central Asian regions and all parameters necessary for the computations.

Snow melt and rainfall water inflows computed by the snow cover formation model do not fully characterize inflow to the watershed if glacial inflow isn't taken into account, its contribution is especially important for seasons with high summer air temperatures and for years with low water content.

Five large glacial regions in Zeravshan river basin were chosen which included groups of glaciers with comparatively homogeneous conditions. Basin glaciation characteristics, outset date for glaciers melting and maximum height of snow line serve as input data for computation of glacial inflow.

Correlation analysis of snowmelt, rainfall and glacial components of the total amount of annual water inflow to the watershed in Zeravshan river basin has shown that the contribution of snowmelt component is the most significant irrespective of snow content of the year while glacial runoff contribution is was the most significant in the years with low and average snow content (Table 1).

Table 1. Correlation of snowmelt, rainfall and glacial components of the total annual water inflow to Zeravshan river watershed

Snow characteristic of year	Amount of total annual water inflow in km^3	Contribution of runoff components:					
		snowmelt		rainfall		glacial	
		km^3	%	km^3	%	km^3	%
Excessive snow amount	10,64	6,66	63	1,78	17	2.19	20
Temperate snow amount	8,73	5,20	60	1,16	13	2,37	27
Low snow amount	7,37	4,22	57	1,29	17	1,88	26

The computed values of snowmelt, rainfall and glacial water inflow to watershed surface, the height of the seasonal snow line, deficit of air humiduty at sea level are input data into the transformation model. At the first stage of the model operation the optimization of model parameters was made for sets of years with different snow content estimated by snow resources available at the end of March. At the next stage the computation of runoff hydrographs was made for the whole observational period using actual data, and the forecast was issued for vegetation runoff with monthly distribution for Zeravshan river in Dupuli line gauge. The comparison of computation and forecast estimates is shown in Table 2, forecast estimates being satisfactory on the whole.

Table 2. Estimates of computation and forecast.

Month Season	Computation beginning from the 1st ten-day period of April		Forecast-time of issue beginning from the 1st ten-day period of April		
	S/σ	P %	Forecast lead-time	S/σ	P %
April					
May	0,78	60	2	0,80	60
June	0,51	86	3	0,60	73
July	0,62	77	4	0,61	74
August	0,36	94	5	0,62	70
September	0,33	97	6	0.70	68
Apr-Sept	0,36	89	6	0,50	80

The lower values for the spring months are due to the fact that snow resources computations have taken into account only data obtained by the time of forecast issue (the end of March), while considerable snow accumulation occurs in April-May in Zeravshan basin. This shortcoming is eliminated by shifting of forecast issue time.

Runoff hydrographs of 1951 in designed and prognostic versions along with their comparision with the actual one are presented on Fig. 2 as an example.

The AISHF system represents a methodically and technologically interconnected complex of software and informational elements designed for development and issue of the long-term runoff hydrological forecasts on the basis of the model. The basic part of system is a mathematical model describing the complete cycle of the mountainous river runoff formation including computation of the spatial distribution of snow cover, snowmelt and rainfall water inflow to watersheds in the form of time realizations of the fields at every step of computation; computation of glaciers' runoff and runoff transformation. Automated system meets the requirements of the forecast issue operativeness, permits the most complete use of the model informative capabilities; successfully copes with rapidly increasing amount of information used.

The AISHF system includes (Fig. 3):

- hydrometeorological data base (HBD);
- algorithm software of the system (SW).

In its turn, the system SW is presented by:

- software complex for control and management of HBD (BASE);
- software complex realizing long-term forecasting technique for the mountainous river runoff on the basis of the model (MODEL).

Hydrometeorological data base represents a structurally organized set of informational objects covering physical-geographical and hydrometeorological data. For operation with HDB the specialized software complex BASE is included into AISHF system which func-

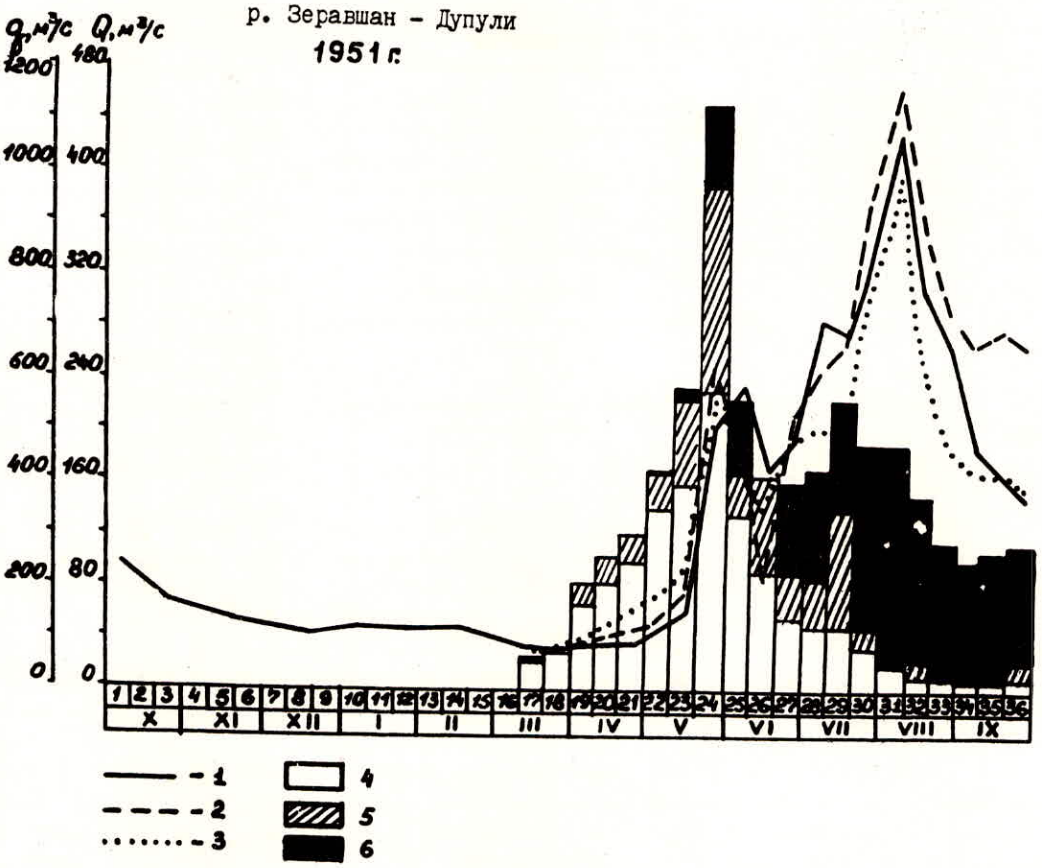

Fig. 2. Result of computation and forecast of vegetation runoff in Zeravshan river basin in 1951
1 - measured discharges, 2 - discharges computed by model, 3 - discharges under forecast, 4 - snowmelt contribution, 5 - rainfall contribution, 6 - glacial contribution

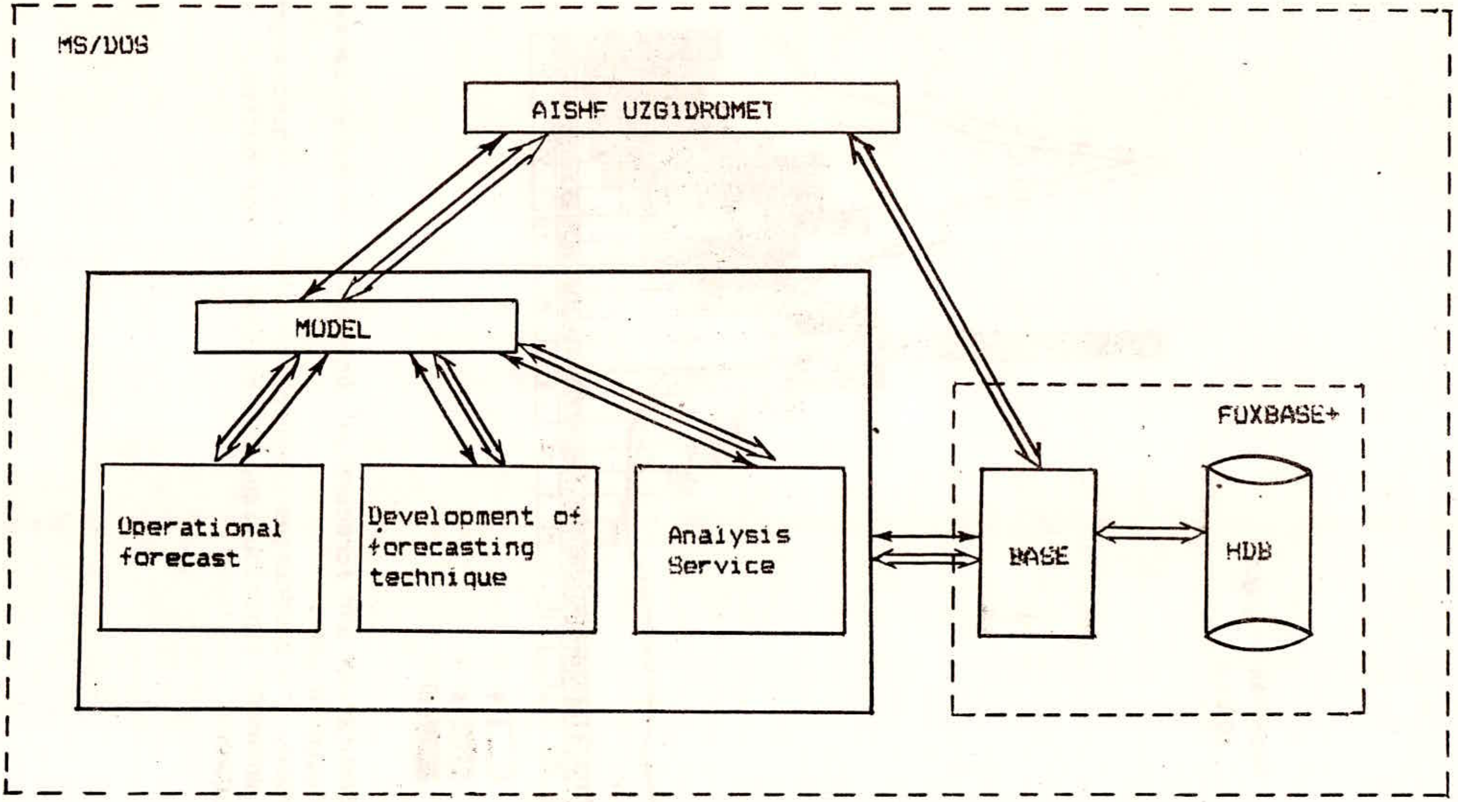

Fig. 3. Structure of UZGIDROMET automatized informational system for hydrological forecasting (AISHF)
MS/DOS - operating system, HDB - hydrometeorological database
FOXBASE+ - data base control system

tions in operational medium of the data base control system (DBCS) FOXBASE+ and realizes the following basic regimes of operation with HDB:
- data loading and correction;
- data sampling from HDB according to the prescribed criterion (key).

Data loading and sampling from it may be realized both in interactive and automatic mode.

Software complex MODEL realizes three main operational modes:

1) development of mountainous rivers runoff forecast technique;
2) issue of operational hydrological forecasts;
3) interactive analysis of hydrometeorological situation (forthcoming, current and preceeding ones).

For realization of the first two regimes the following programs are included into the system:
- computation of snow resouces and snowmelt and rainfall water inflow to the watershed (SNOP);
- glacier runoff computation (LEDNIK);
- computation of runoff transformation in the basin (MOTR).

Besides, software complex MODEL includes a number of subsidiary programs realizing certain stages of computational process:
- computation of precipitation amount, air temperature and moisture deficit (ZEROT, ZEROS, ZERVL) for the fixed altitude;
- re-formation of designed archives for the snowmelt and rainfall water inflow with account of glacial runoff (FORM).

The mode of interactive analysis of hydometeorologocal situaion is realized by means of specialized BASE package which provides data sampling from HDB and its representation in any suitable for the user form.

Hierarchical principle of operation is realized in the automized AISHF system. On each level of functioning the system offers a certain set of "Menu" of command functions with indication of their characteristics and possibility of choosing any of them.

The main modes of AISHF functioning are as follows:

1. Data base preparation - successive loading of physical-geographical and hydrometeorological data into HDB in interactive and automatic versions is realized by BASE program means. The output stage is AISHF data base ready for operation. The visual control and HDB data correction are possible.
2. Development of a forecast technique is the neccessary stage of operation during of which a model adaptation ("launching") is realized on a certain hydrological object: parameters determination, evaluation of the model adequacy by means of comparison of measured and computed characteristics of snow cover and runoff amounts. In the process of operation the data sampling from HDB and loading of computed information and numerical characteristics (parameters) in the form of designed archives into HDB are realized.
3. Operative forecast issue - sampling of the object characteristics and parameters of a forecast technique from HDB are realized, as well as the loading into HDB of the current year hydrometeorological data obtained by the time of the forecast issue and also hypothetical data for the forecast lead-time. Prognostic version is computed for runoff hydrograph, and also multivariant runoff forecast is possible in case of different versions of information presetting for the fore-

cast lead-time.

Hydrometeorological data base (HDB) covers all types of informational flows operating in long-term runoff forecasting system on the model basis. HDB foundation presents a certain step of informational system projection and includes questions for subject field analysis, choice of DBMS, data base model construction in the frames of DBMS chosen, of loading technology and data base management. The basic structural elements of the data base objects are informational objects themselves, their attributes and structural interconnections between them.

The following basic informational groups are distinguished:

1) physical-geographical characteristics of objects, numerical description of relief, meteorological fields parameters, transformation model parameters, hydrographic and hypsographic characteristics, glacial data;
2) hydrometeological data, which in their turn are separated into: meteorological data measured on networks of stations and gauges and designed data on precipitation, air temperature and moisture deficit, snow resources for basin altitudinal zones, snowmelt and rainfall water inflow to the watershed and glacial runoff, obtained for the zero point of the region.

Information is systematized in HDB by territorial signs. The largest unit is a region, incorporating basins of several rivers. At present forecasts are issued for three large Central Asian regions. They are: Chirchik-Akhangaran, Alaiskii (Northern slope of Alai range), Fergan (south-western slope of Fergan range) regions and Zeravshan river basin. In each basin separate subregions are distinguished according to precipitation amount and hydrological basins. In separate hydrological basins with glaciation glacial regions are distinguished.

At present in AISHF system long-term runoff forecasts are issued for 15 hydrological line gauges in Amudarja and Syrdarja river basins. Table 3 presents reliability of monthly and seasonal forecasts with lead-time of 6 months for vegetation runoff for Central Asian rivers. The highest forecast reliability is noticed for Chirchik-Akhangaran basin rivers, which is due to comparatively better informational provision of this territory and better knowledge of hydrological regime. For the other objects informational provision is much worse. Besides, it's necessary to take into account a very complex structure of precipitation fields on northern slope of Alai range, where Kurshab, Tar, Isfairam, Soh rivers are situated and also in Zeravshan river basin. The most important are long-term forecasts of inflow into large water storages of Central Asia - Charvak and Andizhan ones. Two year-experience of operational practice in the inflow forecast development has shown that reliability of this technique for these water storages is 90 % and 91 %, respectively.

Further improvement of forecasting technique; implementation of new methods into AISHF and also increasing of the number of hydrological objects are the main ways to rise operational significance of the developed forecast system.

Table 3. Reliability (in %) of monthlly forecast for the Certain Asian mountainous rivers runoff put into AISHF "UZGIDROMET"

River, gange	Monthly forecast						
	Lead time, months						
	1	2	3	4	5	6	Veg
1. Akhangaran - in Irtash river month	92	90	95	90	90	80	93
2. Chatkal - - Hudaidodsai gange	85	85	82	85	77	70	90
3. Pskem - Mullala gange	82	86	80	68	76	57	86
4. Inflow into Charvak water storage	86	82	82	82	79	84	84
5. Tentyaksai - Charvak gange	82	80	70	68	59	79	79
6. Kugart - Mikhailov-skoe gange	82	81	73	68	57	-	73
7. Karakuldzha - Aktash gange	76	71	60	60	68	68	-
8. Inflow into Andidzan water storage	-	93	67	73	87	58	87
9. Isfairam - Uchkorgon gange	-	58	67	71	71	100	79
10. Soh - Sarikanda gange	-	-	68	72	64	64	80
11. Zeravshan - Dupuli gange	-	60	73	74	70	68	80

Note: Symbol "-" notes absence of satisfactory computational results.

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