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Calculations of Elementary Rainfall Floods According to Standard Meteorological Observations

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Abstract:

The article presents the results of mass calculations of local elementary runoff in daily resolution and according to weather stations over thousands of consecutive daily intervals. For computer calculations we used: database meteo.ru and a software package that is a DBMS and a system of equations linking the elements of the water balance with the elements of the heat balance.

Keywords:

Current Water Balances, Elementary Catchments, Hydrographs

1. Introduction

At the end of the 19th century, the largest Russian climatologist A.I. Voeikov recorded winged the phrase "Rivers are a product of climate." At the beginning of the 21st century through the creation and publication of online electronic database data [1] and the use of refinement conception of energy resource of the evaporation process [2], it became possible to generate local elemental runoff values from the sites of meteorological stations solely from the daily data of standard meteorological observations. As arguments used daily amount of rainfall and the average daily temperature.

2. Materials and Methods

Precipitation is measured with significant errors. Therefore, the values of measured precipitation have to be corrected by introducing correction factors. In cold countries, solid precipitation in winter is not involved in changes in soil moisture, nor in the formation of runoff and evaporation. In spring, when snow melts, solid precipitation has to be summed up with liquid precipitation of the first calculated intervals of the warm period. In connection with this kind of redistribution of moisture for the name of the actual moisture resources of the calculated interval when using precipitation already corrected for underreporting by the device, we had to introduce in the 1960s the concept of "total moisture", designating this value with the somewhat unfortunate name KX.

Using the system of equation (1) of V. S. Mezentsev [3], setting as arguments the average daily air temperature characterizing thermal resources, and the daily sum of corrected atmospheric precipitation KX, characterizing the income water to the surface of the catchment, the hydrologist receives for each calculated interval the following elements of the water balance: the final W_2 and the average W_{av} for the interval the humidity of the active soil layer, the total evaporation Z and the local elementary runoff Y.

$$H = KX + W_1 - W_2 = Z + Y$$

The system of Mezentsev equations and the preparation of mass data for calculations are described in detail in [4] and [5].

Since precipitation values are used to calculate soil moisture, total evaporation and runoff, the elementary land area under study should be imagined small (an area of several hundred square meters or several square kilometers), so that the precipitation layer measured by the instrument with a receiving surface area of 200 cm^2 (that is, from the standpoint of cartography, almost at the point), was representative of the entire area around the weather station.

3. Results and Discussion

Until now, hydrologists have constructed flow hydrographs in daily resolution only from the materials of daily measurements of water levels h in river gauges of large rivers, using the curve Q = f(h) to determine discharge. Now it has become possible to build long-term chains of hydrographs of runoff calculated by genetic method on daily intervals, using long-term arrays of temperature and precipitation obtained at the nearest to the studied catchment meteorological station.

Water runoff from the land surface, which forms watercourses and reservoirs, is the most important type of natural resources. This is the water resources of the territory. Since 99.8 % of the total number of watercourses and reservoirs on the planet has not been studied hydrometrically, that is, in most small and medium-sized rivers on all continents have never been measured levels, velocities and flow rates of water, hydrologists do not know the water resources of the vast territories.

The mosaic of fields’ isohyet of heavy rains and continuous rains studied statistically very weak. Wide-spread rain falls for hours without interruption with constant intensity over large areas, storm rainfall begins and ends suddenly, characterized by short duration, variable intensity (from 1 to 17 mm / min). The duration of the shower is from a few minutes to 1.5 hours. In St. Petersburg, a rainstorm was observed once for 21 hours, in Siberia and the far East, showers lasting up to 40 hours were observed.

With heavy rains, large areas, including the receiving surface of the pluviometer, are irrigated fairly evenly, when a rainstorm falls over the weather station, the data of this weather station for a neighboring catchment of considerable size, even with an area of several tens of square kilometers, are completely unrepresentative, and the average layer of precipitation in the catchment can be 2-3 times smaller than in the pluviometer.

According to the probability theory, there are also cases when numerous showers fall over the catchment, and no rain falls over the weather station located in the center of the catchment. In such cases the discrepancy between the calculated and the hydrometric data of the neighboring catchment can be huge. In chains of daily intervals, numbering hundreds and thousands of days, these discrepancies can be considered permissible errors.

Practice and the theory of Hydrometeorology established that only a network of devices with a density equal to one device per 1.5-2 km^2, can provide a one-hundred-percent probability of only recording precipitation in an area of approximately 25 km^2. In an area of 600 km^2, to ensure a 100% probability of detecting only the fact of precipitation, the density of the network of precipitation meters is required, equal to one device per 10 km2! In fact, in the North of Western Siberia, for example, one device accounts for an area of 28,000 km^2! However, as the mass calculations and the correlation graphs below show, in most cases, under plains conditions, the calculated runoff is close to the hydrometric measured-despite the following unfortunate inconsistencies described below.

Runoff Y is calculated by hydrologists based on measurements of water flow in the hydrometric channels of hundreds of large and medium-sized rivers and represents the amount of water collected by gravity from the surface of a river catchment area of thousands or hundreds of square kilometers. In the geographical analysis of the results of hydrological and climatic calculations, it should be borne in mind that the initial data on the measured flow of rivers, air temperature, precipitation are vectors obtained at points in space, chosen randomly and often very unrepresentative. For example, the vast majority of weather stations are located in settlements on the banks of rivers, in valleys, in relief depressions, over which precipitation, as we know, are always smaller because of the adiabatic expansion of air masses. It would be necessary to place measuring devices on uninhabited watersheds which occupy the most part of territories in comparison with valleys of the rivers.

When calculating the specific values of runoff hydrologists use a constant nominal value of the catchment area of the river to the target, which measures the water flow, but for many river basins in the conditions of flat terrain and small slopes, especially in the arid zone, the value of the catchment area in different years is different, and it is impossible to determine without specially organized expensive works. Therefore, the annual runoff modulus and layer calculated from measurements using the nominal constant catchment area is obtained in different years with significant errors that cannot be estimated.

In the vast areas of the arid zone there is no river network of permanent watercourses, there are no plots and water balance plots. But even in deserts, sometimes rains fall and surface runoff is observed. On the territories of Russia, especially Siberia, the network of weather stations and hydrometric posts is extremely rare-the distances between observation points are measured in tens or hundreds of kilometers. The Northern half of West Siberia is one of the least studied in relation to hydro-meteorological regions of the continent. In the North, in the Yamalo-Nenets Autonomous Okrug on an area of about 1 million square kilometers, only 36 weather stations are located in the area. On the Yamal Peninsula, where there are about 8,000 watercourses, none of which has been studied hydrometrically, all 10 weather stations are located on the coasts of the Peninsula, not on the watersheds. Thus, in the North

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of Western Siberia, one weather station accounts for an area of 28,000 square km, that is, an area of 280 km per 100 km!

In mountainous countries, where there are very few weather stations, and runoff and precipitation depend mainly on the height of the catchment above sea level and on the exposure of the slopes, the number of unexplored watercourses is expressed in the hundreds of thousands. In the conditions of such a weak study and in the complete absence of flow maps, it is impossible to accurately estimate the water resources of catchments, so the average error in determining the annual flow of 20-30% should be considered acceptable. As is known, the accuracy of regime measurements on the networks of national hydrometeorological services does not exceed: ± 10 % for measured water flow, ± 10-15 % - for liquid precipitation, ± 50-100 % - for solid precipitation.

For Figure 1 - Figure 7 the fragments of graphs describing initial data and results of calculations of elements of current water balances in daily resolution for several Russian meteorological stations are presented.

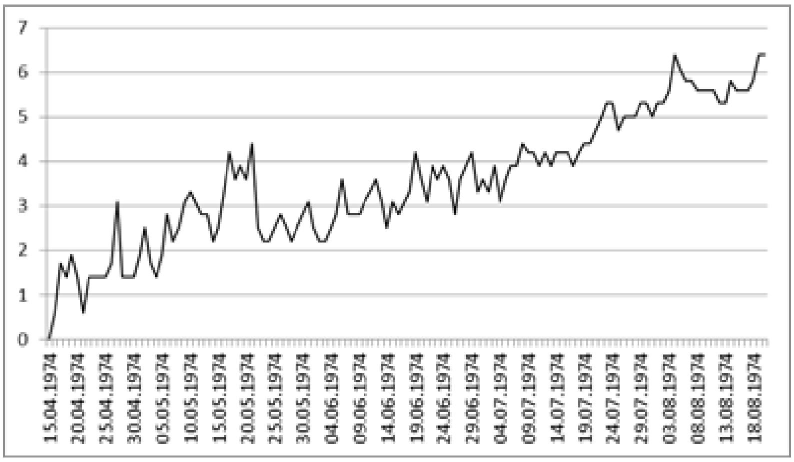

Figure 1. *Weather Station Vladivostok. Daily values Zm, mm / day.*

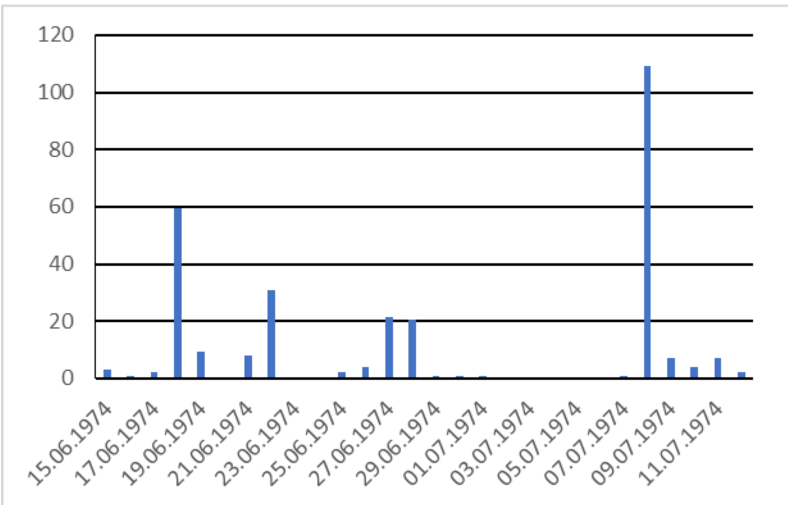

Figure 2. *Weather Station Vladivostok. Summer 1974. Daily corrected precipitation KX, mm / day.*

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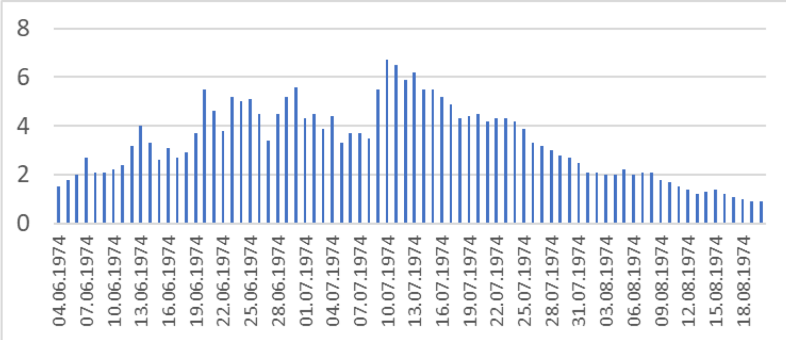

Figure 3. *Weather station Vladivostok. Hydrographs Y (mm/day) calculated from daily intervals).*

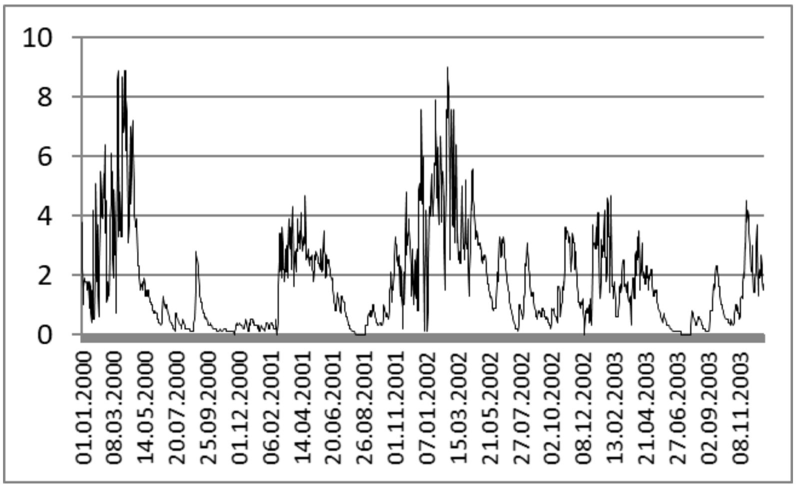

Figure 4. *Sochi weather station. Hydrographs Y, mm/day. 1460 days.*

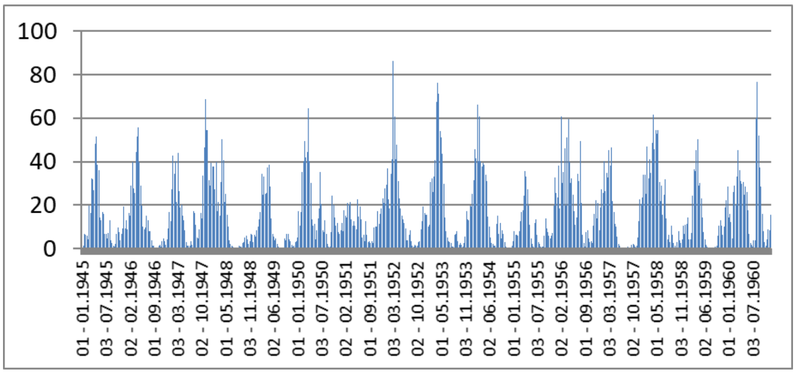

Figure 5. *Sochi. Decadal (10-day) runoff in mm, calculated at daily intervals for 16 years.*

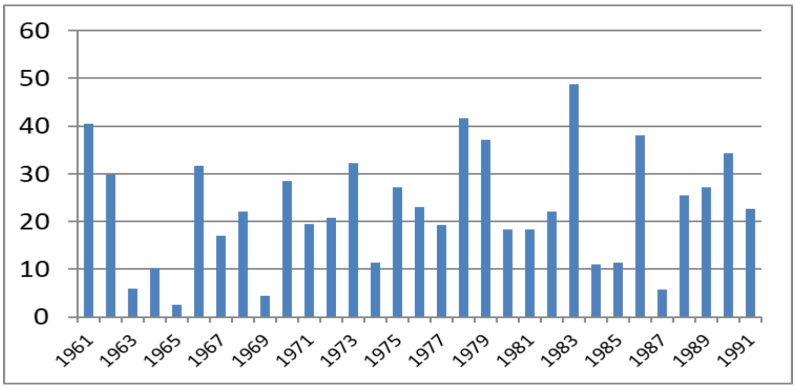

Figure 6. *Astrakhan. Calculated values of the annual local runoff layer (mm / year) for 31 years. 6200 calculated daily intervals.*

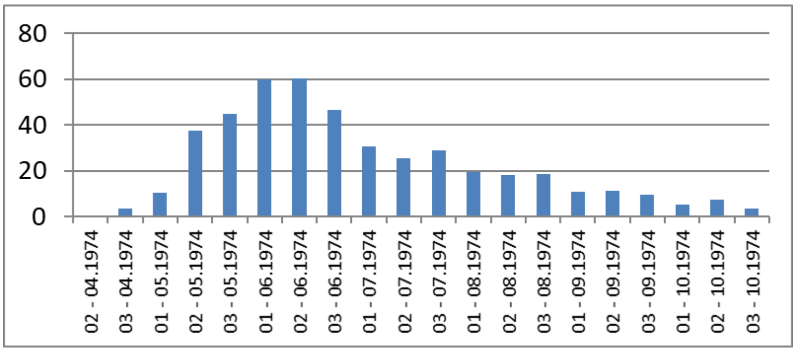

Figure 7. *Petropavlovsk-Kamchatsky. Decadal sums of runoff Y,(mm / dec). 01,02,03 - the name of the decade.*

The above graphs demonstrate the triumph of the birth of a new unified science of Hydrometeorology, which as a result of two hundred years of parallel development meteorology and hydrology finally received a unified system of analytical description of water transformation processes on the surface of catchments under the influence of gravitational and thermal drainage of catchments. These processes are described by a system of equations of water balance and heat energy balance. Hydrologists were able to start developing a new direction in the global study of local elementary runoff - a direction based on the use of detailed observations of meteorological stations. This is especially important for the practice of calculating the flow of unexplored areas of land, to determine the water resources of unexplored catchments, the number of which on the planet is estimated in millions.

Established in early 21st century electronic database of weather data of daily measurements of atmospheric moisture and air temperature allows us to calculate with sufficient for many engineering purposes precision values of water balance elements, that is purely hydrological characteristics. The task of the scientific community of hydrologists and the world meteorological organization (WMO) is to create in the coming years World Atlas of elements of water balances and Atlas of local water resources of all continents.

Comparison of the calculated runoff, soil moisture, total evaporation with the measured values for the monthly and annual intervals of the chains of specific years [4-6] shows that the calculated values of total evaporation are close to those measured not only in monthly amounts, but also in the daily course. At some stations, the calculated evaporation amounts are poorly correlated with the measured values.

The reason for this is not in the shortcomings of the computational model, but in known to hydrologists and meteorologists inconsistencies in the areal distribution of moisture, as well as, of course, in the measurement errors that the control bodies of the hydrometeorological service have not been able to detect so far. If the method of calculation was unsuccessful, there would be no close correlations in any case.

In warm countries and in the warm season in the region of seasonally frozen soils, elementary runoff is formed only during precipitation hours and does not depend much on thermal resources, and the value of the parameter n is a local constant determined by soil permeability and slopes of the earth's surface. In cold countries, the most difficult calculation period for analytical description is the period of snowmelt, but thanks to the speed of modern computers and the great possibilities of numerical experimentation, the researcher has the opportunity to improve the results by entering into the calculation – anywhere in the program with the help of conditional transitions – commands that allow changing the parameters of the system of equations within several calculation intervals. Of course, the solutions found should be universal for all weather stations of the cluster.

In the monograph [4], the results of the calculation were verified by comparing the runoff and evaporation with the published data of the Hydrometeorological Service, and the verification was mass (several years in a row by months) in all natural zones of Russia. In the article [7] presents the results of comparison of the total evaporation obtained in the calculation of the current daily water balances using the mathematical water balance model V.S. Mezentsev, with measured at weather stations in the Omsk region evaporation. The table 1 shows the correlation coefficients of the monthly amounts of evaporation with the monthly amounts calculated by meteorological data. The values of correlation coefficients, often exceeding 0.90, indicate that the method of calculating the elements of the water balance according to standard observations of weather stations allows to accurately describe the expenditure items of the water balance -total evaporation and runoff.

Table 1. *Correlation coefficients of monthly amounts of evaporation with monthly amounts calculated by meteorological data [7].*

Years	**The correlation coefficient**	
	Tara	**Omsk**
1993	0,833	0,845
1994	-	0,410
1995	0,994	-
1996	0,981	0,510
1997	0,999	0,491
1998	0,993	0,449
1999	0,750	0,692
2000	0,932	0,312
2001	0,829	0,635
2002	0,823	0,642

For the development of hydrology of unexplored areas of land, it is necessary to create, first of all, meteorological posts, as well as runoff plots with recorders at existing weather stations, to provide for the creation of runoff plots at new weather stations. Standard runoff plots could be successfully serviced by meteorologists. Water balance plots are needed not only to measure the flow, but also to control the calculated values of the flow and refine the algorithms for controlling the variable parameters in the system of Mezentsev equations in order to obtain in the near future universal for all areas of land Unified analytical model of current water balances.

One of the most important sections of engineering hydrology is the study of rain floods, which are formed in all natural areas under the influence of showers or rainfall. For Figure 8 - Figure 10 the graphs of the control comparison of the total annual runoff values calculated on the daily intervals and measured in the rivers closest to the weather station are given, and in Figure 11- Figure 16 the daily comparison of the runoff layers calculated according to the station Sverdlovsk (Yekaterinburg) and the measured flow in the river Chernaya in the range of the railway station Sagra (Northern outskirts of Yekaterinburg) is made. The catchment area of the river is 220 sq. km., and the area of the receiving hole of the rain gauge is 200 sq. cm, i.e. 11

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billion times less. Despite this difference, the results of precipitation measurements at the weather station are representative of the catchment.

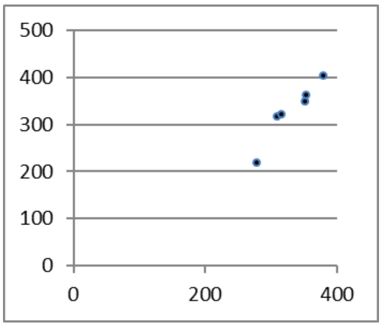

Figure 8. *Comparison of the calculated daily data of the weather station Turukhansk (ordinate axis) and measured in the river Turukhan – Yanov Stan (F= 10100 sq. km.) flow layer Y (mm / year) for 1967-1972. correlation Coefficient r = 0.956. Here and in Fig. 9, 10 the data of hydrometric measurements are deposited along the abscissa axis.*

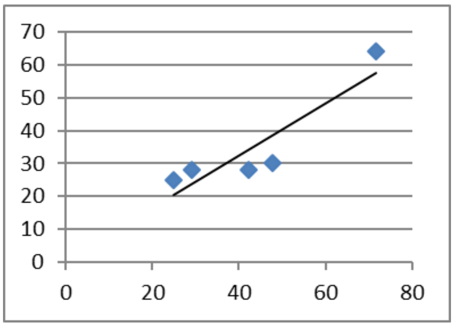

Figure 9. *Correlation of annual runoff layer amounts calculated by daily intervals in the area of Verkhoyansk weather station and annual runoff layer values by daily measurements of water levels in the Turagas river with a catchment area of 98.0 sq. km (up to 1.2 km from the mouth). 1971-1975 correlation Coefficient R = 0.910.*

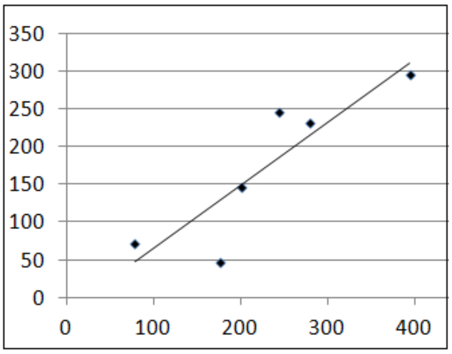

Figure 10. *Correlation of annual runoff values calculated by daily intervals in the Vladivostok region (in mm/year) for 1967-1972 with measurements in the Suifun river with a catchment area up to the Terekhovka hydrometric section equal to 15,500 sq. km (r = 0.88).*

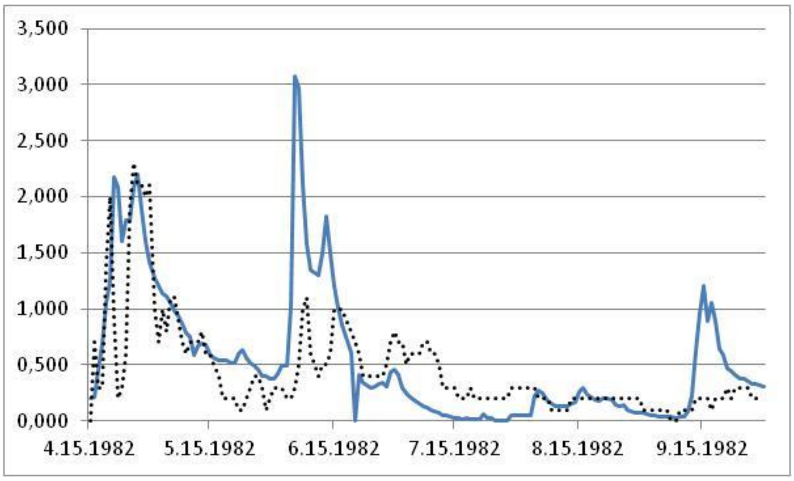

Figure 11. *Combined flow charts in summer 1982 Calculation data of the weather station Sverdlovsk (dotted line). Gauging the runoff in the Black river.*

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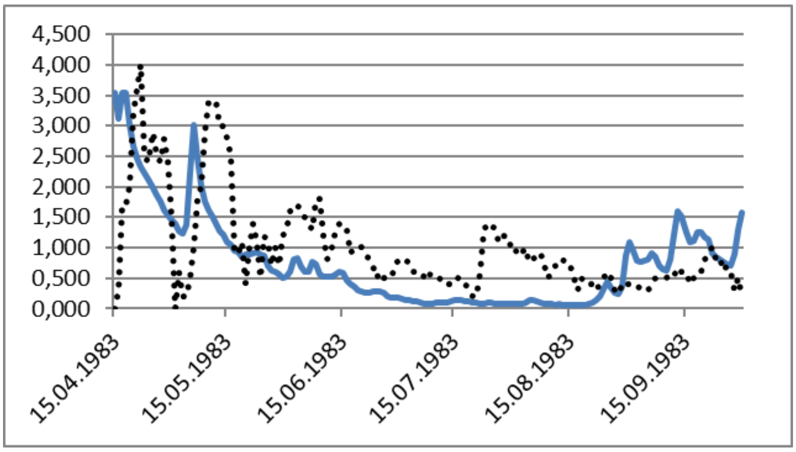

Figure 12. *Combined flow charts in summer 1983.*

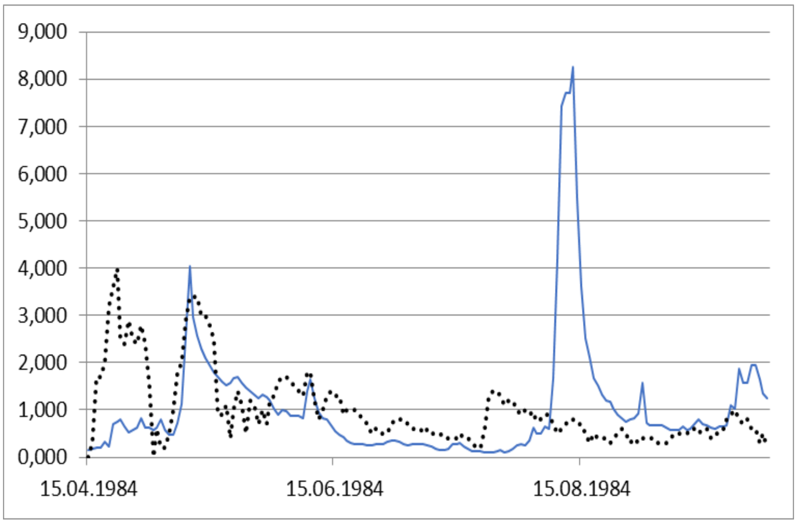

Figure 13. *Combined flow charts in 1984 Calculated flow – Sverdlovsk, measured-Black River.*

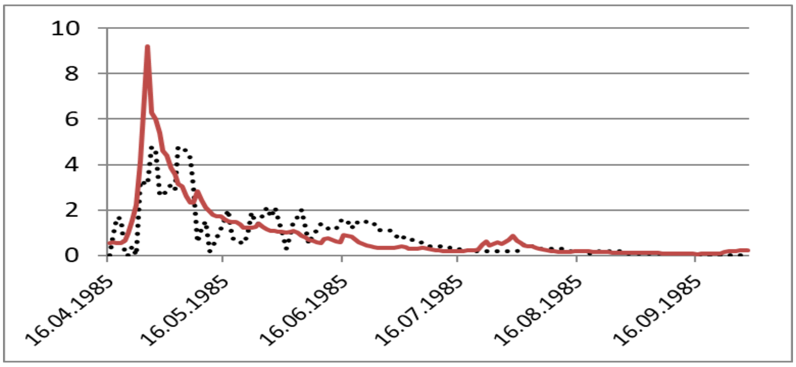

Figure 14. *Combined flow charts in 1985 Calculated flow (dotted line) - Sverdlovsk, measured-Black River.*

Discrepancies calculated elemental drain and gauging not only due to the differences in layer – average for the catchment and measured by the rain gauge at the station, but the effect of the lag of the flow in the river to target, which make measurements of levels. The peak of the calculated flood is timed to the true date, and the peak of the flood in the watercourse is the result of the transformation of flows coming to the range from different areas of the area a few days after the true date of elementary peaks.

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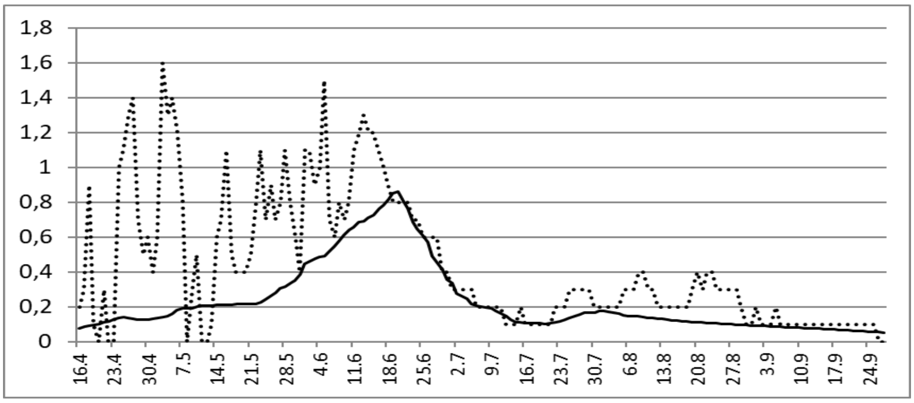

Figure 15. *The calculated local flow according to the weather station Tobolsk (dotted line) and current flow in R. Agitation – Yurt Mitkinskie 1985.*

In order to determine the time of reaching the flood waves to the staff gauge, the correlation coefficients of the daily values of the runoff layer – measured and calculated – were calculated with a sequential shift one day ahead of the meteorological calculated runoff data. Values of correlation coefficient at shift for 1-5 days at first increase, then after achievement of a maximum begin to decrease. The number of days from the beginning to the maximum is the time of reaching the peak of the wave transformed by the flood catchment. For Figure 16 - Figure 20 the results of such an experiment, made by comparing the daily runoff layer obtained by calculation according to the Tobolsk weather station from April 16 to September 20, 1985, and the daily runoff layers in the Agitka River, calculated from the daily water consumption published in the Hydrological Yearbook for the same 150 days, are presented. The shift of the local elementary runoff forward is performed from April 16 to April 25. The catchment area of the Agitka River is 125 km South of the Tobolsk weather station, the catchment area to the Mitkinskie Yurt is 3430 sq. km.

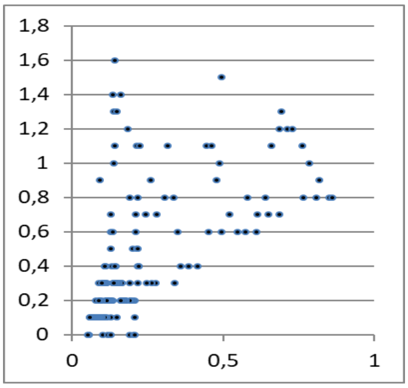

Figure 16. *Correlation of calculated and measured values of the daily water flow layer in the Tobolsk region and 125 km to the SE in the catchment of the Agitka River. r = 0.60.*

In order to determine the time of reaching the flood waves to the staff gauge, the correlation coefficients of the daily values of the runoff layer – measured and calculated – were calculated with a sequential shift one day ahead of the meteorological calculated runoff data. Values of correlation coefficient at shift for 1-5 days at first increase, then after achievement of a maximum begin to decrease. The number of days from the beginning to the maximum is the time of reaching the peak of the wave transformed by the flood catchment. For Figure 16 - Figure 20 the results of such an experiment, made by comparing the daily runoff layer obtained by calculation according to the Tobolsk weather station from April 16 to September 20,

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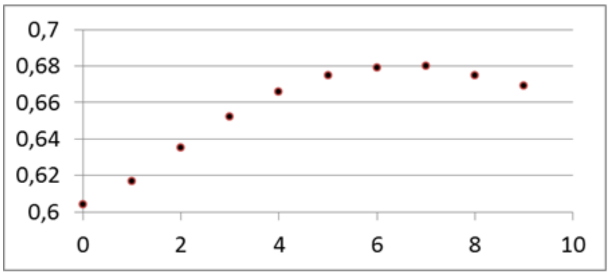

Figure 17. *The dependence of the correlation coefficient (the y-axis) of the shift calculated values (in days).*

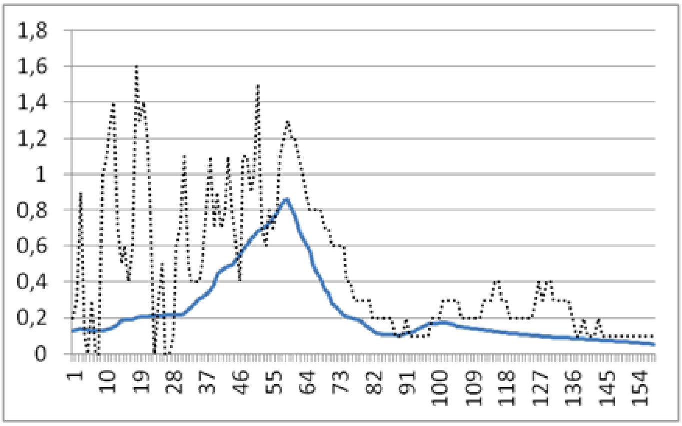

Figure 18. *The same as in Fig. 17, but with a shift of the calculated runoff forward on the time scale by 7 days. On the abscissa axis, the number of days from the beginning (April 16).*

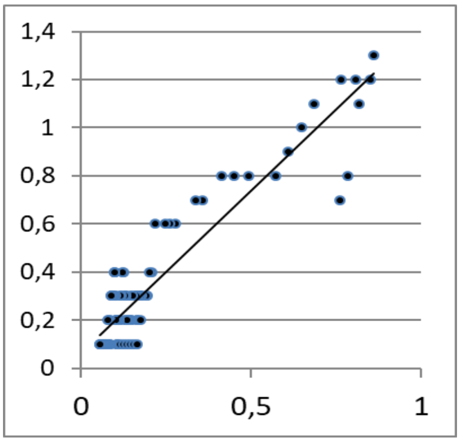

Figure 19. *The same as in Fig. 17 with a shift of 7 days. r = 0.68.*

Thus, the tightness of communication was much increased after the shift forward by 7 days of calculated ordinates. With a further shift, the values of the correlation coefficient begin to decrease (Table 1).

Studies of the heat and moisture supply of the territory based on the method of V.S. Mezentsev made it possible to adjust the amount of evaporation from catchments in the Omsk Region in the hydrological-mathematical model for forecasting the spring flood of the Irtysh River [8].

Table 1. *The dependence of the correlation coefficient from the shift of the ordinates of the elementary flow forward relative to the ordinates of the hydrometric flow. Tobolsk - R. Agitka. 1985.*

Shift, day	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
The correlation coefficient	0,604	0,617	0,635	0,652	0,666	0,675	0,679	0,68	0,675	0,669

4. Conclusions

Calculations of runoff according to meteorological stations – a new and very promising direction in engineering hydrology. It should be developed by calculating runoff from long-term data from all weather stations of the globe in order to compile an inventory of the local runoff of each continent.

To control the correctness of the calculation results, it is necessary to compare these results with the mass measurement materials on runoff plots, which should be created immediately at weather stations. Long-term data of observations on runoff plots will allow to refine the algorithm of calculations and to obtain a universal computer complex for calculations of runoff from meteorological data.

In uninhabited areas, meteorological posts, rather than hydrometric devices, should be established to study the water resources of unexplored watercourses and their dynamics. It's much cheaper than hygrometry.

The study of elementary runoff does not mean abandoning measurements on large and medium-sized watercourses, but will be the most rational way to study the giant expanses of Siberia, Canada, the Amazon and other areas of land, especially in the future, in the conditions of inter-basin transfers of runoff channels and pipelines.

Conflicts of Interest

The authors declares that there is no conflict of interest regarding the publication of this article.

Author Contributions

Conceptualization: I.V.K.; Methodology: A.B.; Validation: I.V.K, N.P.V.; Formal analysis: I.V.K.; Investigation: I.V.K.; Resources: I.V.K.; Data Curation: I.V.K; Writing – original draft preparation: I.V.K; Writing – review and editing: I.V.K, N.P.V.; Visualization: N.P.V.; Supervision: I.V.K; Project administration: I.V.K; Funding acquisition: I.V.K.

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