

Moduli of Maximum Runoff in Snow Melt Floods on Rivers of the Southeastern Part of Esil River Basin

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Abstract:

The Esil River Basin, including its southeastern part, is subject to frequent floods and inundations. The hydrometeorological knowledge of the basin is insufficient. Therefore, methods for calculating runoff moduli at unexplored river catchments are in demand. The article proposes one of such methods, developed using data of test catchments. Based on the use of the developed method in the dry steppes of Central Kazakhstan, it was found that in small catchments with area of up to 1000 km², the maximum modulus of snowmelt runoff of 100 year return period is 390,1 - 450 and more l/s*km², and at catchments from 1,000 to 5,000 km² – 230,1 - 390 l/s*km², from 5,000 to 10,000 km² – 170,1 - 230 l/s*km², from 10,000 to 16,500 km² - 90 - 170 l/s*km².

Keywords – Floods, Snow Melt Floods, Inundations, Moduli of Maximum Runoff of Snow Melt Floods, Factors of Snowmelt Runoff.

I. INTRODUCTION

The Esil River is a transboundary river and belongs to the category of large in area, but small by its river flow. The river originates from the mountains in Central Kazakhstan called Niyaz at an altitude of 800 m. Initially it flows from the southeast to the northwest, then after 680 km it turns north and then after 810 km it crosses the border with Russia, where it flows into the Irtysh River. The length of the river in Kazakhstan's territory is about 1780 km, the area of basin is 147,04 km² [1], and the drop of level from its source to the border with the Russian Federation is 700 m (from 800 to 75 m).

The Esil River Basin is divided into 6 sites by the water authorities of the republic [1]. The first 2 ones are attributed by the authors to the southeastern part of the basin (Figure 1), which are investigated in this article. The first site is “The source of the river – Nur-Sultan water storage reservoir” with a catchment area of 4,942 thousands km² and the site number 2 is “Nur-Sultan water storage reservoir - the mouth of the Zhabay River in the city of Atbasar” (a right tributary of the Esil River) with a catchment area of 48,474 thousands km² [1].

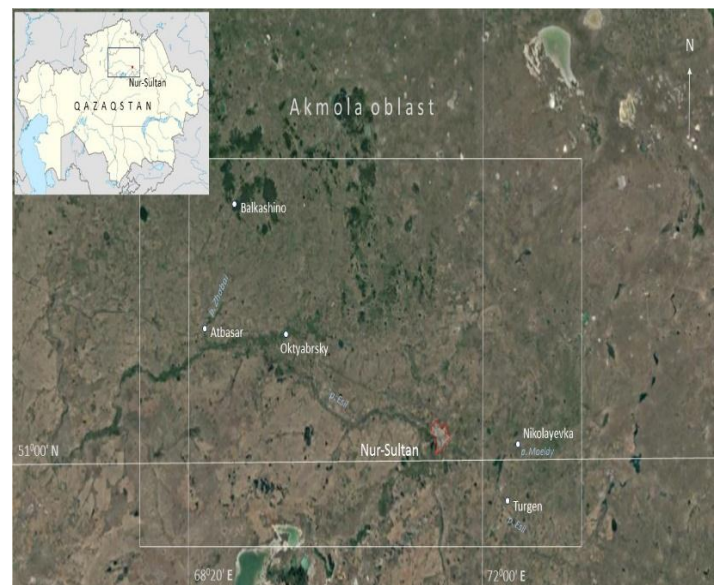


Fig. 1. The region under research of the moduli of maximum runoff in snow melt flood - the southeastern part of the Esil River Basin. 1 - location of the Nur-Sultan water storage reservoir

The researched area (Fig. 1) is the subject to frequent floods and inundations both on the main riverbed and its tributaries. Since 1975, 22 flush floods have been recorded in this region (1980, 1983, 1985, 1986, 1990, 1993, 1994, 1995, 1996, 2003, 2004, 2005, 2007, 2011, 2014 (3), 2015, 2016 (2), 2017 (2)), with the most damage caused by the recent floods observed in 2014-2017.

A dense drainage network is developed in the southeastern part of the Esil River Basin and a flat relief prevails with low mountains along the outskirts of the southeastern part of the basin - up to 600-800 m (Figs. 2, 3). During major floods in the region, numerous flood zones arise, causing significant damage to settlements, agriculture and production. As a rule, terrain inundations occur unexpectedly, intensively and not always in the same areas as before. Unfortunately, floods and inundations in Kazakhstan are not properly studied.



Fig. 2. Typical landscapes in the southeastern part of the Esil River Basin: overhead - the sources of Esil River; below - the Zhabay River near the city of Atbasar, 2 km from the confluence of the Esil River [2]

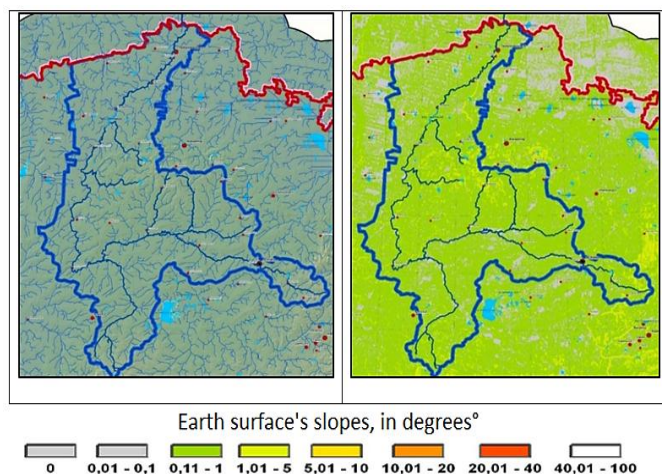


Fig. 3. Physical and geographical conditions of the Esil River Basin: on the left - hydrography; on the right - slopes of the earth's surface [3]

The aim of this work is to develop a method for calculating the moduli of maximum runoff for unexplored catchments in the southeastern part of the Esil River Basin. The number of such catchments is large. It was determined that the Esil River in the site from the source to the mouth of the Zhabay River has only about 25 first-order tributaries with a length of 15 km or more (Fig. 2, overhead), which pose a real danger during floods.

Similar studies were carried out in the work [4], where local relations of the moduli of the maximum snowmelt runoff from the mean height of the river basins of the Northwest Caucasus were established, which were used to estimate this runoff on the unexplored rivers. It was shown in the work [5] that, for an approximate estimation of the spring runoff norm and the maximum runoff modulus of unexplored rivers in Central Kazakhstan, the relations of the spring runoff layer from the catchment area and the relation of the maximum runoff modulus from the catchment area of the study area can be used.

During the research, geographic, analytical, hydrological, statistical and comparative research methods were used.

II. RESULTS AND DISCUSSION

II.1 Selection of Test Catchments for Determining Maximum Runoff Moduli

The southeastern part of the Esil River Basin is located in the dry-steppe zone of the republic. Only in the north part there are places of forest-steppe territories.

The hydrological knowledge of the southeastern part of the Esil River Basin is insufficient. There are currently 7 stream gauges in this region, of which 3 ones are located in the riverbed of the main river, and others in its tributaries.

The basic principle of selecting test catchments for determining the maximum runoff moduli was the presence of undistorted observational data and their representativeness. For this reason, data on the Esil River stream gauges – Volgodonovka village and Nur-Sultan city were rejected due to the regulatory influence of the Nur-Sultan water storage reservoir on the flow in the river stations of these stream gauges.

As a result, the series of maximum discharges for only 5 observation points were selected for analysis. There are r. Esil - v. Turgen; r. Moiylly - v. Nikolaevka; r. Kalkutan - v. Kalkutan, r. Zhabay - c. Atbasar and r. Zhabay - v. Balkashino.

The first stream gauge is located in the upper reaches of the Esil River, and the flow here is almost unregulated, except for the influence of the small Esil water storage reservoir with a volume of about 9,0 million m³. The next 4 stream gauges are located on the tributaries of the main river and also do not have any distortions according to the measured data associated with economic activity.

Table 1. Stream gauges located in the southeastern part of the Esil River Basin

№	River	The name of the stream gauge	Validity period		Distance from the mouth, km	Catchment	
			Open	Closed		F, km ²	H _{avg.} , m
1	Esil	v. Turgen	15.06.1974	Functions	2367	3240	524
2	Esil	v. Volgodonovka	19.07.1977	Functions	2299	5400	450
3	Esil	c. Nur-Sultan	01.09.1932	Functions	2241	7400	430
4	Moiyldy	v. Nikolaevka	08.07.1972	Functions	22	492	530
5	Kalkutan	v. Kalkutan	01.01.1936/ 14.04.1955	Functions	44	16500	361
6	Zhabay	v. Balkashino	14.10.1959	Functions	144	922	440
7	Zhabay	c. Atbasar	01.06.1936/ 26.06.1941	Functions	16	8530	364

II.II Specifications of Test Catchments

The Esil River – at the village of Turgen. The catchment is represented by the upper territory of the Esil River. It is located on the hilly terrain covered with meadow vegetation with the altitude range between 450 m and 800 m above sea level. The weighted average (WA) catchment altitude is 524 m. The Esil River in this site is formed by the confluence of several streams taking its origins from the Niyaz Mountains. The length of the river along the main riverbed is 71 km, the catchment area is 3240 km².

The Moiyldy River – at the village Nikolaevka. The river is the right tributary of the Esil River and flows into the water storage reservoir called Nur-Sultan. The catchment is located on a hilly area covered by meadow vegetation in the altitude range of 404-730 m. The weighted average catchment altitude is 530 m above sea level, the length of the river is about 35 km. The river is formed from the confluence of brooks, that flow at the foot of unnamed mountain hills. The catchment area is 492 km².

The Kalkutan River – at the village Kalkutan. The Kalkutan River is the largest tributary of the Esil River. Its length is about 170 km, and the basin area is 16,500 km². The catchment of the river stretches parallel to the Esil's riverbed from east to west. The river forms on hills covered with meadow vegetation at altitudes of 350 - 550 m. The Kalkutan River has a large tributary called Arshaly, which is 70 km long, originating in the Kokshetau's upland, partially in the forest-steppe zone (less than 5% by area). The weighted average catchment altitude is 371 m above sea level.

The Zhabay River - at the city of Atbasar. The river originates from the uplands of the Kokshetau in the forest-steppe zone at altitudes of 600-700 m. It flows from north to south. It has the length of about 140 km and the large tributary called Zhilandy with the length of about 70 km. The basin area is 8,500 km². Weighted average catchment altitude is 364 m.

The Zhabay River – at the village of Balkashino. It is represented by the upper territory of the Zhabay river. The

forest cover of the catchment is about 50 %, the area is 922 km², and the weighted average altitude is 440 m above sea level.

Regarding the test catchments, partially not including the last one, it should be noted that all of these catchments are located in almost uniform physical and geographical conditions - in the dry steppes of Central Kazakhstan. Differences in the average altitudes of catchments are not significant - not more than 200 m, and it is unlikely that these differences will significantly affect the maximum runoff.

II.III The Formation of Runoff of Snowmelt Floods

The factors that determine the formation of snowmelt runoff can be divided into 2 main groups. These are meteorological factors that determine the intensity of snowmelt and evaporation processes, and factors that define the processes of accumulation and regulation of snowmelt runoff, as well as its losses on the surface of catchments.

The types of accumulation and regulation of snowmelt runoff on the slopes are as follows [6]: 1) accumulation of water in the layer of seasonal snow cover; 2) the accumulation of water on the surface of the catchment; 3) accumulation in soil 4) regulation of runoff by micro brook network.

The next stage in the formation of snowmelt flood runoff is the temporary storage of snowmelt runoff, which is largely determined by the total area of catchment and the nature of the channel network. The larger the catchment and the more complex the channel network, the smaller the resulting runoff moduli. Therefore, to solve practical problems in determining runoff moduli at unexplored catchments, it is desirable to have ones at the slope border – river course. Thereby, in this research, runoff moduli for the initial stages of the channel network were determined along basins of tributaries or small catchments, where the influence factor of catchments' areas is minimal.

Table 2 shows the results of statistical calculations of runoff moduli of 1%, 5% and 10% of probability for 4 selected basins

for the same period - 1975-2015, which almost completely corresponds to the last full water cycle on the Esil River.

Table 2. Maximum water discharges (Q_m) and maximum runoff moduli (M_m) on the rivers of the southeastern part of the Esil River basin for the period 1975-2015

Name of the river – stream gauge	Catchment area, (km ² /H _{WA} , m)	River length, km	Maximum water discharges in m ³ /s and maximum runoff moduli in l/s*km ²					
			1,0 %		5,0%		10,0 %	
			Q_m	M_m	Q_m	M_m	Q_m	M_m
Esil River – v. Turgen (upper reaches of the Esil River)	3 240/524	71	724	223	506	156	409	126
Moiyldy River - v. Nikolaevka (a tributary of the Esil River)	472/492	35	220	466	137	290	107	227
Kalkutan River – v. Kalkutan (the tributary of the Esil River)	16 500/371	175	1478	90	964	58	743	45
Zhabay River - Atbasar city (the tributary of the Esil River)	8 530*/364	140	1547	181	1024	120	798	94
Zhabay River – v. Balkashino (the tributary of the Esil River)	922**/440	40	200	217	150	163	127	138

Note: *) and **) - forest cover of catchments - 5% and 50%

Based on the data in Table 2, the relations of the maximum runoff moduli (M_m) of the rivers of the southeastern part of the Esil River Basin from the catchment areas for 1%, 5%, and 10% of probabilities of these moduli were revealed. When identifying these relations, data on the Zhabay River – Balkashino stream gauge were not used, since the maximum runoff moduli for this one are significantly lower than the

background stream gauges due to the high forest cover of this catchment (about 50%).

Table 3 presents the averaged coordinates of the revealed relations of the maximum runoff moduli for the rivers of the southeastern part of the Esil River Basin on the catchment areas.

Table 3. Moduli of maximum runoff (l/s*km²) for catchments in the southeastern part of the Esil River Basin

Runoff modulus probability (M_m) in %	Catchment area, thousand km ²								
	≤ 0,5	1,0	2,0	3,0	4,0	5,0	10,0	15,0	≥ 16,5
1%	≥ 466	390	300	260	240	230	170	110	≤ 90
5 %	≥ 300	270	220	175	140	130	100	60	≤ 50
10 %	≥ 220	180	140	120	110	100	80	50	≤ 45

According to the Table 3, we can draw the following conclusions:

1) during extreme snowmelt on the slopes of the catchments in the southeastern part of the Esil River Basin, the maximum runoff of 100 year return period in small catchments can be 466 or more l/s*km² or in the water layer 40,3 mm per day. At the same time, on the large catchments with the area of several thousand km², the maximum runoff modulus is significantly reduced and will be 2–3 times less - up to 100–200 l/s*km² (Table 3).

The objectivity of the established scales of the maximum values of snowmelt runoff, for example, is confirmed by the results of hydrological studies on small glaciers of the Ile Alatau (Northern Tien Shan), for which the maximum daily average runoff moduli were determined in the amount of 0,4-0,5 and more m³/s*km² [7].

2) the danger of small catchments during extremely intense snowmelt increases sharply when there are conditions for the occurrence of unexpected local floods during the frozen state of soils and the formation of water-snow flows with sharp higher air temperature and heavy liquid precipitation on melting snow cover;

3) the data in Table 3 can be used for a preliminary assessment of the exposure of valuable territories to possible rare inundations and floods.

III. CONCLUSION

The significant relation of the maximum snowmelt runoff moduli for the rivers of the southeastern part of the Esil River Basin on the catchment areas was revealed.

The method is proposed for approximate determination of the maximum melt runoff moduli for unexplored small and medium catchments in the southeastern part of the Esil River Basin according to the catchment area information.

It has been established that in the dry steppes of Central Kazakhstan, the maximum snowmelt runoff modulus of 100 year return period in small catchments (up to 500 km²) can reach 466 or more l/s*km².

Small catchments in the southeastern part of the Esil River Basin pose a real danger for the occurrence of local floods during a combination of negative extreme circumstances.

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