Contract: No. PIA19-165 / 26.07.20192019 / DAF 02

Ref. PIA19-P165-HO-E-001

HYDROLOGICAL ASSESSMENT

of the outflow in the Biala River and its tributary Arpa Dere near the village of Gugutka, municipality of Ivaylovgrad, Haskovo region

PHASE: PP

PART: HYDROGEOLOGY

PART: HYDROGEOLOGY

SOFIA, October 2019

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ХИДРОЛОЖКА ОЦЕНКА НА ОТТОКА В Р. БЯЛА РЕКА И ПРИТОКА Й Р. АРПА ДЕРЕ ПРИ С. ГУГУТКА, ОБЩ. ИВАЙЛОВГРАД, ОБЛАСТ ХАСКОВО

ФАЗА: ПП

ЧАСТ: ХИДРОЛОГИЯ

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ПРОЕКТИРАНЕ И АНАЛИЗИ ЕООД СОФИЯ

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1 Research objectives

The objective of this engineering-hydrological study is to establish the hydrological and drainage characteristics of the Byala River and its tributary, the Arpadere River, at six points as follows:

- The Byala River before the confluence with the Arpadere River;
- The Biala River after the confluence with the Arpa Dere River;
- The Biala River after the confluence with the Arpa Dere River, excluding the Yuren Dere River;
- The Arpa Dere River before it joins the Yuren Dere River;
- The Yuren Dere River before it joins the Arpa Dere River;
- The Arpa River after the confluence with the Yuren River;
- The Arpa Dere River before it joins the Byala River;
- The Arpa Dere River before it joins the Byala River, excluding the Yuren Dere River

Necessary for determining the discharge and its distribution in typical years, the peaks of "high waters formed during intense rainfall, minimum waters during periods of low water, the influence of the discharge from the tributaries on the total inflow of the receiving river.

2 Source materials

The study was developed in compliance with the requirements of the Water Act and its subordinate legislation, using the following sources:

- Hydrological Reference Book of the Rivers of the Republic of Bulgaria, published by the Institute of Hydrology and Meteorology at the Bulgarian Academy of Sciences from 1944 to 1983.
- Available hydrological and climatic data; Data for hydrometric and hydrometeorological stations were used from the Hydrological Reference Book of the Rivers of the Republic of Bulgaria, published by the Institute of Hydrology and Meteorology at the Bulgarian Academy of Sciences from 1982 to 1990 for the period 1936 to 1983.
- Climatic Reference Book on Precipitation in Bulgaria - BAS Publishing House, 1990;
- Existing methodological guidelines contained in reference literature, including manuals, methodological guides and scientific publications;
- Data from the "Water" website of the Ministry of Environment and Water on the Internet;
- Data from the website of the East Belochorsky Basin Directorate, based in Plovdiv

Standard and proprietary software was used to process the information.

The hydrographic, hypsographic and other characteristics of the water source in the section from the river's source to the studied tributaries were established on the basis of maps in M 1: 25 000 and M 1:5000.

3 Location of the site

The six river sections for which the orohydrographic and hydrological characteristics will be determined are as follows

- **Section 1:** Biala River before the confluence with Arpa

  Dere River N 41°24'39.05", E 25°55'51.88"
- **Section 2:** Biala River after the confluence with Arpa

  Dere River N 41°24'36.23", E 25°55'52.41"
- **Section 3:** Biala River after the confluence with Arpa Dere River, excluding Yurendere River

  N 41°24'36.23", E 25°55'52.41"

- **Section 4:** Arpa Dere River before the confluence with Yurendere River N 41°26'17.24", E 25°55'58.16"
- **Section 5:** Yurendere River before its confluence with the Arpadere River N 41°26'16.53", E 25°55'56.60"
- **Section 6:** Arpadere River after the confluence with Yuren Dere River N 41°26'15.54", E 25°55'58.81"
- **Section 7:** Arpa Dere River at its confluence with the Byala River N 41°24'37.49", E 25°55'53.10"
- **Section 8:** Arpader River at its confluence with the Byala River, excluding the Yurender River N 41°24'37.49", E 25°55'53.10"

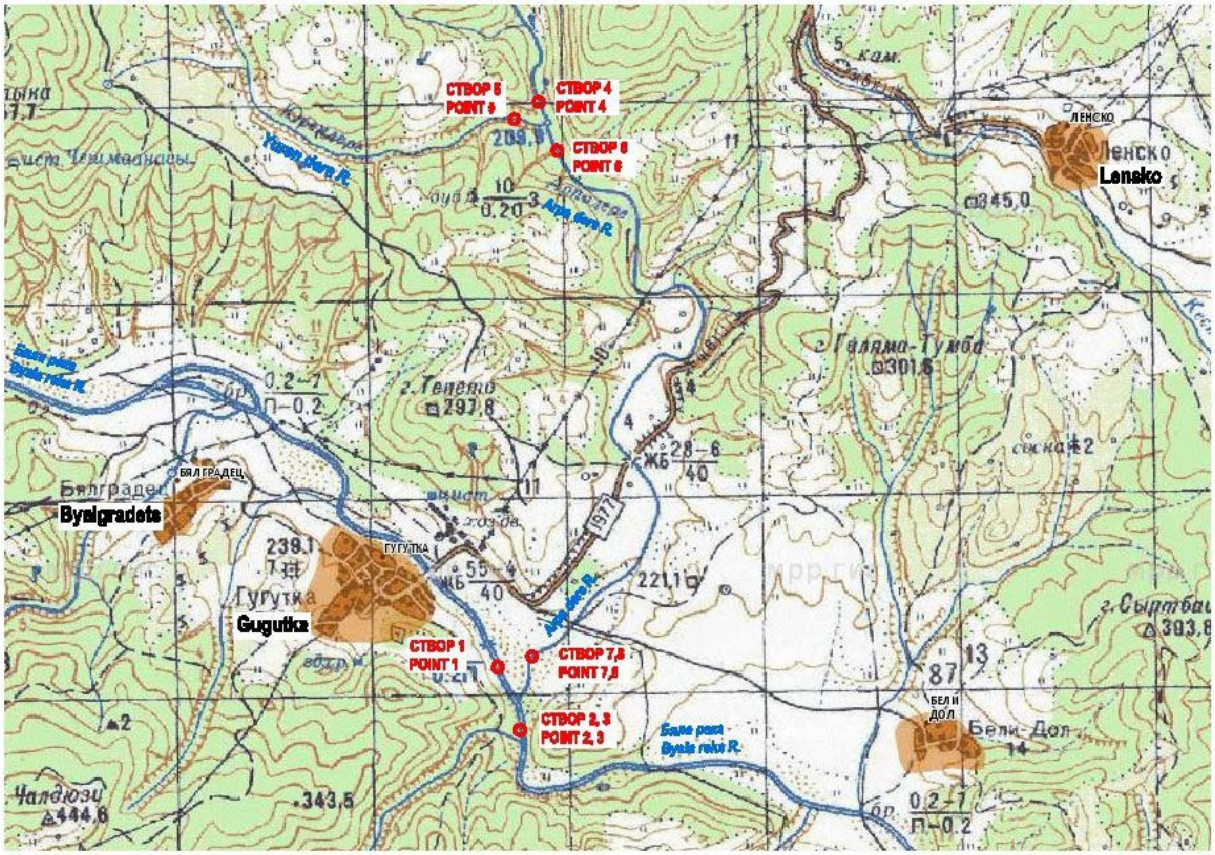

FIGURE 3-1: LOCATION OF THE STUDIED SECTIONS

4 General information about the Byala River

The Byala River (until 1942: Akche Hisar) is a river in southern Bulgaria, Kardzhali Province, Krumovgrad Municipality and Haskovo Province, Ivaylovgrad Municipality.

The Byala River is a left tributary of the Luda River from the Maritsa River basin.

Its length is 69.6 km, which ranks it 52nd among the rivers in Bulgaria. It is the largest tributary of the Luda River. It drains large parts of the Măglănik, Irintepe and Sărta ridges in the Eastern Rhodopes.

The Byala River rises under the name Kojadere at 660 m above sea level from the Măglănik mountain ridge in the Eastern Rhodopes, 2.2 km south of the village of Chernichevo, Krumovgrad municipality, at coordinates N 41.3247°, E 25.7717°.

For the first 15 km, it flows northwards in a deep and densely forested valley between the Irintepe ridge to the west and the Cherna Mountain (northern branches of the Măglănik ridge) to the east. At 3.6 km northeast of the village of Tintyava, Krumovgrad municipality, it makes a sharp turn to the southeast and its valley becomes asymmetrical – with steep right slopes and gentle left slopes. In the area of the village of Gugutka, there is a small valley widening, after which the valley narrows again and the beautiful meanders of the Byala River with steep rocky banks begin. They are part of the protected area of the same name with an area of 1532 ha.

After the village of Dolno Lukovo, the river turns northeast, and its meanders become less frequent and have a larger radius. North of the village of Mandritsa, the river valley widens significantly, turning east at the village of Odrynci and flowing into the Luda River on the left 2.7 km east of the village at an elevation of 52.5 m at coordinates 41.4339° N, 26.175° E.

The river has a catchment area with longer left and shorter right tributaries, covering an area of 594 km^2. The main tributaries are as follows:

- Korudere – left;
- Dermendere – left;
- Suldzandere – left;
- Musadere – right;
- Kojadere – left;
- Surgulyisko Dere – right;
- Kokardere – left;
- Zarnitsa (Hambar Dere) – right;
- Arpadere (Echemishka, largest tributary) – left;
- Chiflikdere – right;
- Chukur River – right;
- Yuruklerska River – right;
- Suhi Dol – left;
- Kazalchadere – right;
- Kondovska River – left;
- Kostilkovska River – left;
- Kozludzhan Dere – left;

The Byala River is mainly fed by rain, with the maximum flow in February and the minimum in September. The average annual discharge at the village of Dolno Lukovo is 7.53 m^3 /s.

There are seven villages located along the river: in the Kardzhali region, Krumovgrad municipality – the village of Chernichevo; in the Haskovo region, Ivaylovgrad municipality – the villages of Byalgradets, Gugutka, Meden Buk, Dolno Lukovo, Mandritsa and Odrinets.

The river is known for its beauty and clean water and is one of the areas in Bulgaria least affected by industrial pollution.

In the recent past, when the area through which the river flows was used for farming, albeit extensively, its waters were used for irrigation. From 1968 to 1992, the Dolno Lukovo pumping station operated with a flow rate of 50 l/s.

5 Boundaries and catchment area of the Biala River and its tributary, the Arpa Dere River, up to the points under consideration.

The catchment areas of the Biala River up to the confluence with the Arpa Dere River, the Arpa Dere River up to the confluence with the Yuren Dere River, and the catchment area of the Yuren Dere River will be described in sequence.

5.1 Catchment area of the Biala River up to the confluence with the Arpa Dere River

The catchment area of the Byala River up to the section under consideration is shaped like an irregular pentagon. The following boundaries have been formed: north-eastern, north-western, western, southern and south-eastern. The boundaries will be described starting from the easternmost point and moving counterclockwise.

The easternmost point of the part of the Biala River basin under consideration is located about 500 m north-northeast of the confluence of the Arpadere River at the bend in the road between the villages of Gugutka and Zhelezin. This is where the northeastern border begins. This border runs along the watershed with the Arpadere River. The predominant direction of the north-eastern border is north-west with a deviation to the west and north. In the first section of the border, we move north-northwest. We reach the peak of Tepeto with a height of 297.8 m. We deviate slightly to the northeast, then continue northwest. This direction is maintained for about 3 km until we reach the northeastern part of the peak of Tashlaka. Here, the direction changes to north with a slight deviation to the northeast. Moving in this direction, we cover about 2 km, passing through the western part of the village of Rozino. At the northwestern end of the village, the direction changes to northwest towards Ilinden Peak, following the road to the village of Konnitsa. Along the way, we pass through Bozalaka Peak, which is 461.9 m high. After about 3 km, we reach the western part of Ilinden Peak, which is
493.8 m.

From Ilinden Peak, we continue northwest for 5.5 km. We pass through the village of Konnitsa and reach an unnamed peak with an elevation of 612.1 m.

After this peak, there is a short section where we move west-northwest, following the road to the village of Starinsko. We reach another unnamed peak with a height of 650.9 m. After this peak, we enter the last section of the northeast border. The direction is north-northwest. We walk like this for about 3.5 km. Along the way, we pass through the peak of Cherkovna Mogila, which is 841.4 m high. The border ends at the junction of the road between the villages of Belopoltsi and Popsko. This is also the northernmost point of the Biala River basin before it joins the Arpadere River.

The north-western border runs along the watershed with the Krumovitsa River. The main direction is south-west. It follows the route of the Popsko - Belopoltsi - Perunika road, deviating from it in its last part. It passes through several characteristic points – Bataklaka Peak with a height of 732.9 m and Kojadar Peak with a height of 674.3 m. The border ends at Irantepe Peak with a height of 817.0 m. This peak is the westernmost point of the Biala River basin.

The western border of the catchment area also runs along the watershed with several right tributaries of the Krumovitsa River. This border is the longest. It can be divided into eleven sections where the direction changes.

Initially, we walk 1.5 km southeast and reach the turnoff from the Popsko-Perunika road to the villages of Orel and Steblovo. We continue along the road for another 1 km and reach the turnoff to the village of Steblovo. Here we move on to the next section. The direction is southwest for about 600 m, after which we head east-southeast. We reach the road to the village of Steblovo again. We continue along the road, moving south-southeast. After passing through the village of Steblovo, the direction changes to south-southwest. We continue along the road towards the village of Chernooki. The section is about 3 km long, passing through the village of Ochipole and Eldemirt Peak, which is 492.5 m high.

After reaching the northern end of the village of Chernooki, we change direction to west-southwest for about 400 m and reach an unnamed peak with a height of 482.8 m. In the next section, we head south-southwest again for about 1.25 km, then change direction to south-southeast, following the road to Mah. Trenitsa and reaching Gorna Mahala. Here, the direction changes to south for about 1.1 km. At the end of this section, we head southeast for about 400 m and reach the Yransurt peak, which is 732.5 m high.

From Yransert Peak to an unnamed peak with an elevation of 651.2 m, located southeast of the village of Uchilishna, we move southwest for about 1.2 km. We continue south-southwest, following the road to the village of Chernichevo. This brings us to an unnamed peak with an elevation of 664.9 m. After that, we head southeast to another unnamed peak with an elevation of 642.4 m. This brings us to an unnamed peak with an elevation of 664.9 m. After that, we head southeast to another unnamed peak with an elevation of 642.4 m.

This is followed by a section about 1.3 km long, where we move south-southeast until we reach the ridge located northeast of the village of Chernichevo. We continue southwest. We pass through the village of Chernichevo and reach an unnamed peak with a height of 641.4 m. From this peak to the peak of Praskova Chuka with a height of 667.9 m, we move south-southeast, almost reaching the southern part of the village of Chernichevo in this direction.

In the next section, the direction is south-southeast. We describe an arc and head southwest. Moving in this direction, we pass through an unnamed peak with a height of 691.6 m and reach another unnamed peak with a height of 655.6 m. From here to the end of the border, we move south-southeast again for about 1,200 m. We reach Janavarov Peak, located on the state border between Bulgaria and Greece, and continue along the border to border sign No. 131, where the described western border of the watershed ends. This is also the southernmost point of the described catchment area.

The southern border of the described part of the Biala River catchment area runs along the state border between Bulgaria and Greece. The initial direction from border marker No. 131 to Kukuda Peak, with an altitude of 701.8 m, is east with a slight deviation to the northeast. We continue northeast for about 1.7 km to border marker No. 138, then turn east again. We walk to border sign No. 140, then continue northeast to sign No. 142. This is followed by a section about 800 m long, where we walk east. We pass through Taushantepe Peak and reach border sign No. 144.

To the next landmark – Ushite Peak, with an elevation of 875.3 m, we head north-northeast. This is followed by a section where the direction is southeast. We walk along the Musova Yanama ridge for 3.5 km and reach Kyuchukchal Peak, 1086.9 m high, where border sign No. 149 is located.

For about 500 m, the direction is east. It changes to northeast for about 150 m, then continues east again to Papazlaka Peak, 1247.1 m high, where the southern border of the described part of the Biala River watershed ends.

The south-eastern border is conditionally divided into seven sections. Up to Kartalbunar Tepe peak, with an altitude of 1254.7 m, the direction is north-northeast. This is also the highest point of the described catchment area. In the next section, we move northwest for about 3 km and reach Požarite Peak, with an elevation of 906.0 m. Until the road to the village of Strazhets, the direction is north-northeast, then it changes to northeast and remains so until reaching Chala Peak, with an elevation of 306.0 m.

From the latter peak to the riverbed, we travel about 700 m east. After crossing the Byala River, we head north-northeast. Moving in this direction, after about 500 m we reach the starting point.

The highest point of the described catchment area is Kartalbunar Tepe peak, with an elevation of 1254.7 m.

The total area of the described catchment of the Byala River up to the section under consideration, determined by maps at a scale of 1:25,000, is 208.56 $km^2$with an average altitude of 499.52 m.

The following settlements from the municipalities of Ivaylovgrad and Krumovgrad are located in the described catchment area: the village of Gugutka, the village of Byalgradets, the neighbourhood of Kazak, part of the village of Konnitsa, the village of Chernichevo, the neighbourhood of Vis, the neighbourhood of Vetruska, the village of Belopoltsi, the neighbourhood of Gorsko, the village of Rozino, the neighbourhood of Danailovo, Gorna Mahala, Ovchitsa neighbourhood, Zhaltuga neighbourhood, Tintyava neighbourhood, Petrak neighbourhood, Sladunka neighbourhood, Trenitsa neighbourhood, Chernooki village, Karaveziler neighbourhood, Orlovo neighbourhood, Gerginovets neighbourhood, Poroy neighbourhood, Ochipole neighbourhood, Steblovo village, Bagriltsi village, Struja neighbourhood, Yanakmache neighbourhood, Doborsko neighbourhood, Baharsko neighbourhood, Poroy neighbourhood, Ochipole neighbourhood, Steblovo village, Bagriltsi village, Struja neighbourhood, Yanakmache neighbourhood, Doborsko neighbourhood, Baharsko neighbourhood, Poroy neighbourhood, Ochipole neighbourhood, Steblovo village, Bagriltsi village, Struja neighbourhood, Yanakmache neighbourhood, Doborsko neighbourhood, Baharsko neighbourhood, Poroy neighbourhood, Ochipole neighbourhood, Steblovo village, Bagriltsi village, Struja neighbourhood, Yanakmache neighbourhood, Doborsko neighbourhood, Baharsko neighbourhood, Poroy neighbourhood, Ochipole neighbourhood, Steblovo village, Bagriltsi village, Struja neighbourhood, Yanakmache

neighbourhood, Doborsko neighbourhood, Baharsko neighbourhood, Poroy neighbourhood, Ochipole neighbourhood, Steblovo village, Bagriltsi village, Struja neighbourhood, Yanakmache neighbourhood, Dob Ochipole, village of Steblovo, village of Bagriltsi, mah. Struja, mah. Yanakmahle, village of Doborsko, mah. Baharsko, mah. Doikintsi, mah. Melleyumler, mah. Spanchevo, mah. Boynitsa, mah. Manolovo.

There are no water facilities built in the catchment area – dams or micro-dams, as well as active water intakes from surface waters from the river or its tributaries.

5.2 The catchment area of the Arpa Dere River up to its confluence with the Byala River

The catchment area of the Arpa Dere River up to the section under consideration before it flows into the Yuren Dere River is shaped like an irregular quadrangle. The following boundaries are formed : eastern, north-eastern, north-western, and south-western. The boundaries will be described starting from the southernmost point and moving counterclockwise.

The southernmost point of the catchment area is before the confluence of the Yuren Dere River. This is where the eastern boundary begins. The initial direction is northeast. We walk about 1750 m, passing through the Arpabair peak with a height of 405.5 m.

In the second section of the eastern border, we move northwest for 2 km. This is followed by a section where we walk north-northeast for 1.4 km, after which we head east. We reach an unnamed peak with a height of 499.3 m. This is followed by a section in which the direction changes several times – initially north-northwest, then northeast, reaching the road to the village of Zheleznoto and continuing along it north-northeast until we reach the easternmost point of the described catchment area, located near the turnoff for the village of Zheleznoto from the Krumovgrad-Ivaylovgrad road, where the eastern border ends.

The northeast border can be conditionally divided into five sections that closely follow the Krumovgrad-Ivaylovgrad road. Initially, we move northwest for about 2.75 km. We continue north-northwest for 1.5 km. This is followed by a section in a north-northeast direction. It is about 1.25 km long. It passes through the Staria Kantona peak, which is 601.2 m high. To the Glumovska peak, with an elevation of 677.5 m, we move north-northwest, then continue northwest for 4.2 km to the end of the border. Along the way, we pass through the Tepedzhik peak, with an elevation of 619.4 m, and the Kochchasert peak, with an elevation of 679.8 m. The border ends in the eastern part of an unnamed peak at an elevation of about 730 m, which is the northernmost point of the described Arpadere River watershed.

The north-western border is the shortest. It can be divided into three sections. In the first section, we move west-southwest for about 3.1 km. We pass several unnamed peaks and reach the peak of Sveti Yani with a height of 843.8 m. We continue in the second section, moving south-southeast. We follow the road to Perunika. After 1 km, we turn southwest. We continue in this direction for 1 km to the end of the northwestern border of the described watershed. The point we reach – the turnoff for the village of Konnici - is the westernmost point of the Arpadere River watershed.

The southwestern border is the longest. It can be divided into six sections. It runs along the watershed with the Byala River and in the last two sections with the watershed with the Yurendere River.

The initial direction is southeast. After 1 km, we reach the peak of Cherkovna Mogila with a height of 841.4 m. We continue south-southeast for 2.75 km. We follow the road to the village of Konnitsa. We reach an unnamed peak with a height of 650.9 m. Here, the direction changes to east-southeast. We follow the road to the village of Konnici again and reach an unnamed peak with a height of 612.1 m. In the fourth section of the southwestern border, which is the longest, we move southeast for 7 km. For the first 2 km, we follow the road to the village of Konnici, then continue along the watershed with the Biala River. Along this section, we pass through the Ilinden peak, which is 493.8 m high, then through the Bozalaka peak, which is 461.9 m high, and reach the western end of the village of Rozino, where the section ends.

In the next section, which runs along the watershed with the Yurendere River, the direction is east-southeast. We pass through the village of Rozino and after about 1.5 km we reach the Agulot peak with a height of 415.5 m. In the penultimate section of the border, the direction is south with a slight deviation to the southeast. We reach an unnamed peak with a height of 360.5 m, after which we enter the last section of the southwestern border of the described part of the Arpa Dere River

watershed. We move east for about 900 m, then continue 300 m southeast and reach the starting point.

The highest point of the described catchment area is Sveti Yani peak, with an elevation of 843.8 m.

The total area of the described catchment of the Arpa Dere River to the confluence with the Yuren Dere River, determined from maps at a scale of 1:25,000, is 65.075 km^2, with an average altitude of 517.90 m.

The following settlements in the municipality of Ivaylovgrad are located in the described catchment area: the village of Popsko, the neighbourhood of Glumovo, the neighbourhood of Starinsko, the neighbourhood of Pashkul, the neighbourhood of Sborino, Chaush mahala, village of Planinets, mah. Nova livada, mah. Sokolentsi, part of the village of Konnitsa, mah. Nova mahala, part of the village of Rozino.

It has been established that several small dams have been built in the catchment area – one small micro-dam near the neighbourhood of Nova Livada neighbourhood, with an area of about 9 daa, two micro-dams in the territory of the village of Planinets with an area of 4.0 daa and 4.5 daa, respectively, and one in the territory of the neighbourhood of Sokolentsi with an area of 4.0 daa. There is no data on the technical parameters and condition of any of the dams.

There is no data on active water abstraction from surface waters from the river or its tributaries.

5.3 The catchment area of the Yuren Dere River up to its confluence with the Arpadere River

The catchment area of the Yuren Dere River up to the section under consideration until it flows into the Arpade River is shaped like an irregular quadrangle. The following boundaries have been formed: north-eastern, western, south-western and south-eastern. The boundaries will be described starting from the easternmost point and moving counterclockwise.

The easternmost point of the Yuren Dere river basin is the point where it flows into the Arpa Dere river. This is where the northeast boundary begins. It runs along the watershed with the Arpa Dere river. The boundary is conditionally divided into four sections.

The initial direction is northwest. It remains so for about 350 m. In the second section, the direction is west. This section is 800 m long. In the third section, we move north-northwest for 1.1 km and reach the peak of Agalar, with a height of 415.5 m. In the last section, we move 1.5 km west-northwest. We pass through the village of Rozino and reach the road to the village of Gugutka, where the border ends. This is also the westernmost point of the Yuren Dere River watershed.

The western border runs south-southwest. We pass through several unnamed peaks and reach the northern foot of Tashlaka Peak, which is the westernmost point of the Yuren Dere River basin. Then it continues south-southeast, reaching the northeastern part of the peak where the border ends.

The southeast border can be divided into two sections. The initial direction is east with a deviation to the southeast. It reaches the road to the village of Gugutka, after which the second section continues along the road to the southeast. It reaches an unnamed peak with a height of 320 m, which is the southernmost point of the Yuren Dere River basin, where the border ends.

The southeast border is the shortest. It is conditionally divided into three small sections. Initially, we walk east with a deviation to the northeast of about 400 m. We continue north with a slight deviation to the northeast, about 400 m, then turn northeast and reach the mouth of the river.

The highest point of the described catchment area is Tashlaka Peak with a height of 468.8 m.

The total area of the described catchment of the Yuren Dere River to the Arpadere River, determined by maps at a scale of 1:25,000, is 3.5 $km^2$with an average altitude of 347.98 m. The only settlement in the catchment of the Yuren Dere River is the village of Rozino. There are no water facilities built along the river.

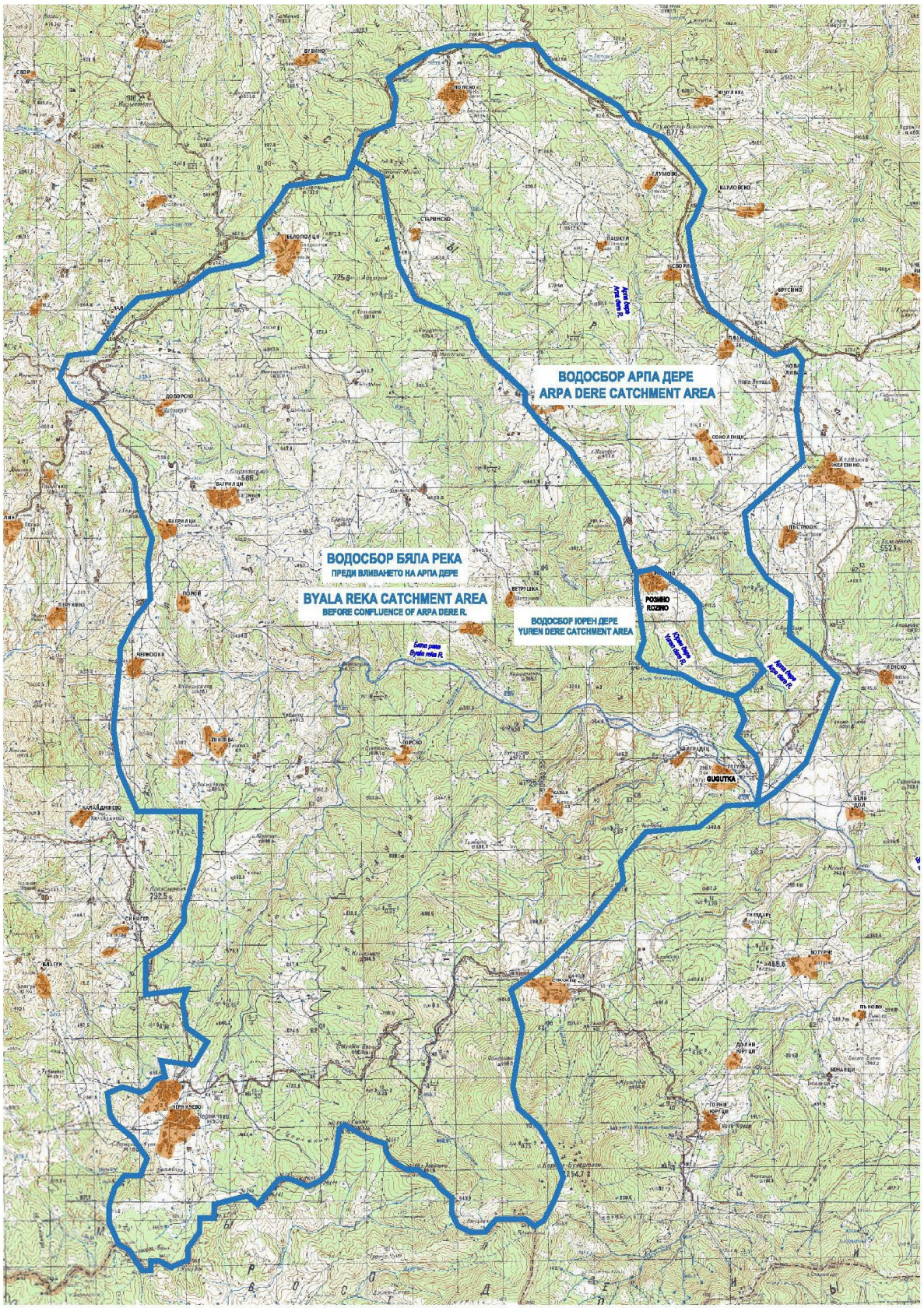

FIGURE 5-1: CATCHMENT AREAS OF THE BYALA RIVER, ARPADER RIVER AND YUREN DERE RIVER

6 Orographic characteristics of the rivers up to the confluences under consideration

The main hydrographic elements necessary for the hydrological study of the Biala River basin up to and after the confluence with the Arpadere River, of the Arpadere River up to its confluence with the Yurendere River and up to its confluence with the Byala River, and of the Yurendere River up to its confluence with the Arpadere River, are determined from topographic maps at a scale of 1:25,000 and are shown in the following table.

TABLE 6-1: OROGRAPHIC AND HYDROGRAPHIC CHARACTERISTICS OF THE CATCHMENT AREAS OF THE RIVERS UNDER CONSIDERATION

No	Characteristic	Measure	Biala River before the confluence with the Arpadere River	Biala River after the confluence with the Arpadere River	Biala River after Arpa Dere River without Yuren Dere River	Arpadere River before the confluence with Yuren Dere	Yuren Dere River	Arpadere River after the confluence with Yuren Dere River	Arpadere River at its confluence with the Byala River	Arpadere River at Biala River without Yuren Dere River
1	Length of the river from its source	km	28.1	28.1	28.1	19.7	3.2	19.7	23.8	23.8
2	Distance to the mouth	m	41.5	41.5	41.5	4.1	0	4.1	0	0
3	Spring elevation	m	650	650	650	752	400	752	752	752
4	Elevation point	m	175	175	175	209.9	209.9	209.9	175	175
5	Average slope of the river	%	16.904	16.904	16.904	27.518	59.410	27,518	24,244	24,244
6	Area of the municipality	km	208.56	281.85	278.35	65.08	3.50	68.575	73.29	69.79
7	Average elevation of the catchment area	m	499.52	498.51	500.40	517.90	347.98	509.23	495.64	503.05
8	Average slope of the catchment area	-	243.72	229.71	230.60	190.55	158.57	188.92	189.87	191.44
9	Density of road network	km/km2	1.314	1.293	1.294	1.245	1.229	1,244	1.23	1.23
10	Forest cover	%	35.00	34.44	34.24	32	50.00	32.92	32.86	32.00

7 Climate

The catchment basin of the Byala River falls within the continental-Mediterranean climate zone. This climate is characterised by sunny, hot and dry summers and relatively warm winters, with most of the winter precipitation falling as rain.

In the catchment area of the Biala River, observations of climatic elements have been made at four meteorological stations: Popsko, Boturche, Meden Buk and Mandritsa. The data for these stations have not been processed and published in the yearbooks and reference books of the National Institute of Meteorology and Hydrology (NIMH). For this reason, data from neighbouring meteorological stations for which measurement data have been published have been used to assess the climatic elements of the Biala River catchment area. These are the stations in Krumovgrad, Ivaylovgrad, Momchilgrad, Kardzhali, Ardino, Byal Izvor, Zlatograd, Davidkovo, Tokachka, Srednogorci and Zagrazhden. Until 1990, measurements were also taken at the rain gauge station in Avren. The location of the nearest climate and rain gauge stations is shown in Fig. 7-1.

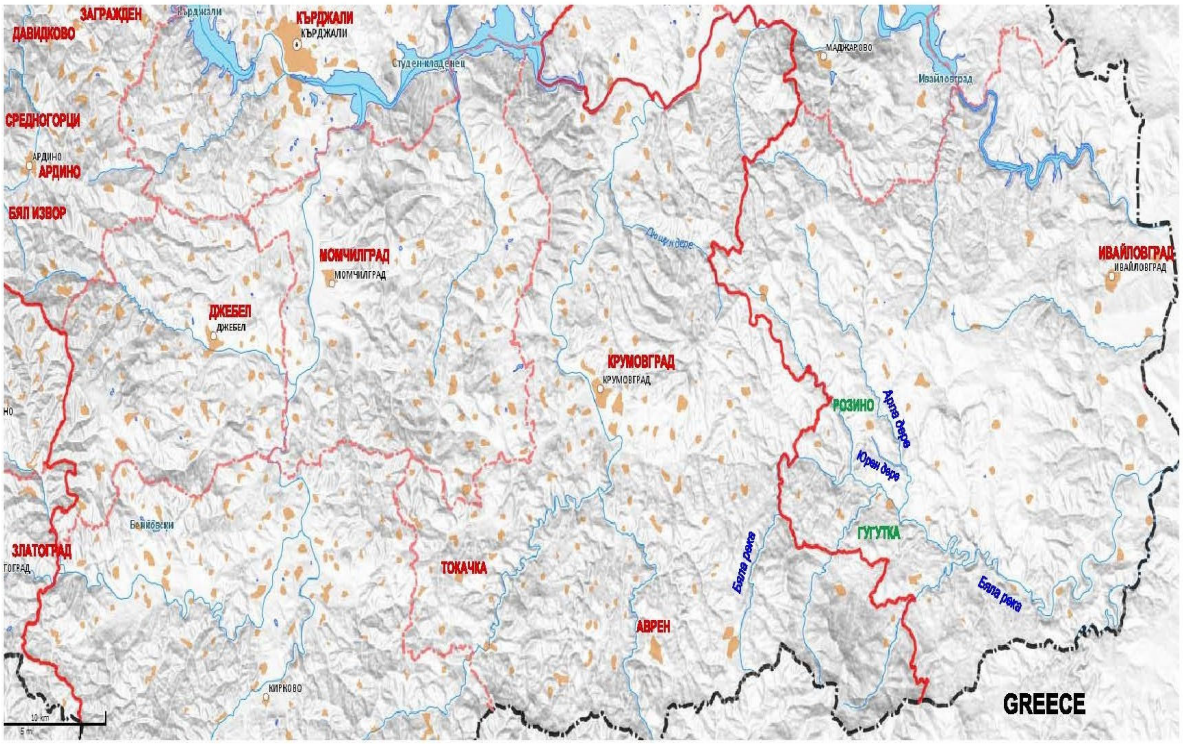

FIGURE 7-1 METEOROLOGICAL STATIONS NEAR THE STUDY AREA

7.1 Average annual values of climatic elements

The average values of the main climate characteristics such as precipitation, wind, temperature and air humidity are presented in the following tables.

TABLE 7-1: AVERAGE ANNUAL PRECIPITATION AMOUNTS BY MONTH IN MM

HMS	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Zlatograd	121	101	82	76	93	86	57	37	47	98	124	137	1058
Momchilgrad	80	58	53	54	66	63	36	26	34	64	79	91	704
Kardzhali	68	53	50	54	70	69	39	30	32	62	78	82	687
Krumovgrad	83	67	64	60	66	64	37	24	38	73	84	101	761
Sredna Gora	87	66	58	62	96	90	70	54	54	78	88	91	894
Ivaylovgrad	80	60	60	56	62	61	34	23	38	69	78	90	711
White Spring	86	68	64	60	96	78	72	46	48	75	93	105	891

TABLE 7-2: AVERAGE TEN-DAY SNOW COVER HEIGHT IN CM

Station	XII			I			II			III		
	1	2	3	1	2	3	1	2	3	1	2	3
Ivaylovgrad	-	-	4	6	7	7	-	-	-	-	-	-
Krumovgrad	-	-	-	7	6	-	-	-	-	-	-	-
Tokachka	-	4	7	13	11	10	8	7	6	3	4	-
Kardzhali	-	-	-	4	5	-	-	-	-	-	-	-
Ardino	-	-	-	6	8	7	5	4	4	3		-
Fenced	-	4	9	10	10	11	12	6	6	6	5	-
Zlatograd	-	-	4	5	6	7	4	-	-	-	-	-

TABLE 7-3: AVERAGE MONTHLY AND AVERAGE ANNUAL AIR TEMPERATURES IN °○ °C

HMS	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Ivaylovgrad	1.4	3.6	6.4	12.1	16.9	20.5	23.5	23.5	19.2	13.9	8.9	4.1	12.8
Krumovgrad	1.3	3.6	6.5	12.2	17	20.8	23.7	23.4	19.1	13.4	8.7	4.2	12.8
Kardzhali	0.8	3.0	6.2	12	16.8	20.5	23.4	23.1	18.7	13.2	8.4	3.7	12.5
Jebel	0.8	3.0	5.8	11.5	16.3	19.9	23.0	22.6	18.5	12.9	8.1	3.4	12.2
Zlatograd	0.8	2.3	4.8	9.6	14.5	18.1	20.6	20.5	16.3	11.4	7.7	3.4	10.8

TABLE 7-4: AVERAGE MONTHLY AND AVERAGE ANNUAL WIND SPEEDS IN M/S

Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Ivaylovgrad	2.4	2.7	2.6	2.5	2.6	2.7	2.8	2.8	2.6	2.4	2.1	2.4	2.5
Krumovgrad	2.1	2.2	2.1	2.0	1.7	1.5	1.9	1.7	1.6	1.6	1.8	1.8	1.8
Kardzhali	1.4	1.9	2.2	2.0	1.6	1.5	1.6	1.6	1.5	1.6	1.5	1.5	1.6
Jebel	2.2	3.2	3.0	3.2	2.1	1.8	1.8	1.9	1.8	2.1	2.1	2.4	2.3
Zlatograd	1.1	1.2	1.2	1.2	1.1	0.9	1.2	1.0	1.0	1.1	1.0	1.1	1.1

TABLE 7-5: AVERAGE MULTI-YEAR DATA FOR RELATIVE AIR HUMIDITY IN %

Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Ivaylovgrad	83	78	74	67	67	64	58	55	61	72	81	84	80
Krumovgrad	80	76	74	69	69	65	59	58	65	75	80	81	71
Kardzhali	83	78	74	68	69	67	60	57	66	75	81	83	72
Jebel	84	80	76	71	71	69	62	59	65	75	81	86	73
Zlatograd	83	80	78	73	73	73	66	64	69	78	85	83	75

From the data in the tables, the following relationship between altitude and precipitation (shown in Fig. 7-2) can be derived, and the following conclusions can be drawn regarding the climate in the region under consideration:

P = 0.4023.H + 636.46 [mm]

With a coefficient of determination $R^2 = 0.8270$; P

– amount of precipitation, mm;

H – altitude of the catchment area, m;

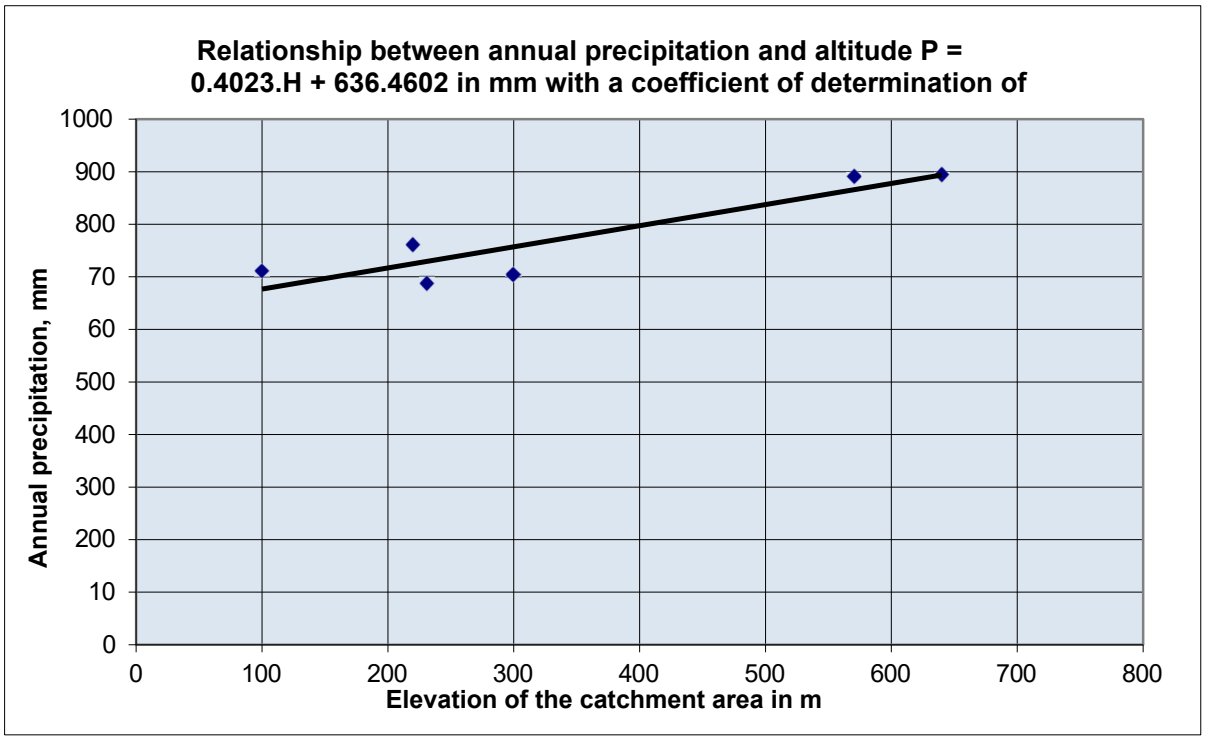

FIGURE 7-2: RELATIONSHIP BETWEEN ANNUAL PRECIPITATION AND ALTITUDE

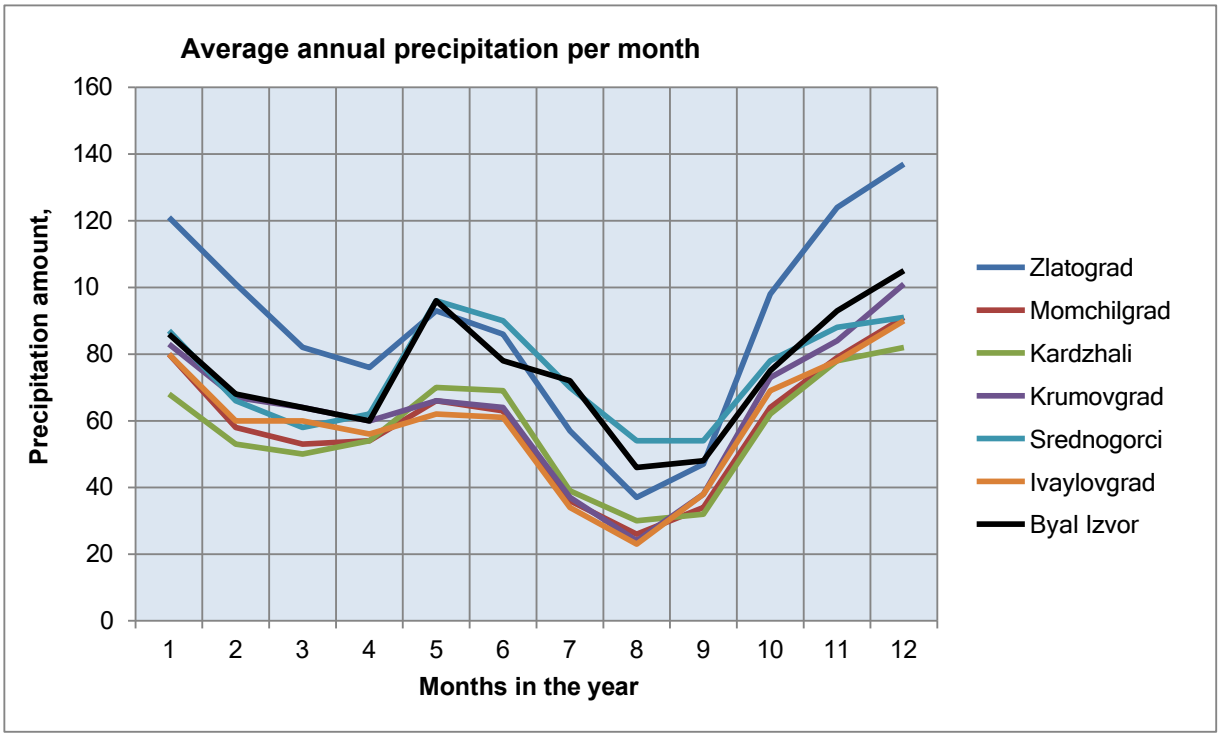

FIGURE 7-3: AVERAGE ANNUAL PRECIPITATION IN MM PER MONTH

Based on the relationship between precipitation amount and altitude, it can be estimated that the average annual precipitation heights in the catchment basins up to the considered river mouths are:

- Biala River before the confluence with the Arpadere River – average altitude 499.52 m, average annual precipitation 837.42 mm;
- Biala River after the confluence with the Arpadere River – average altitude 498.51 m, average annual precipitation 837.01 mm;

- The Byala River after the confluence with the Arpadere River, excluding the Yuren Dere River – average altitude 500.40 m, average annual precipitation 837.77 mm;
- Arpadere River before the confluence with Yuren Dere River – average altitude 517.9 m, average annual precipitation 844.81 mm;
- Yuren Dere River – average altitude 347.98 m, average annual precipitation 776.45 mm;
- Arpadere River after the confluence with Yuren Dere River – average altitude 509.23 m, average annual precipitation 841.32 mm;
- Arpadere River before merging with the Byala River – average altitude 495.64 m, average annual precipitation 835.86 mm;
- Arpadere River at its confluence with the Byala River without the Yuren Dere River – average altitude 503.05 m, average annual precipitation 838.84 mm;

Other characteristic features are:

- Precipitation is mainly rain;
- Snow cover in the lower part of the catchment area lasts from the second ten days of December to mid-February. Only in the higher parts of the catchment area does snow cover last from mid-December to mid-March;
- There is one peak in annual precipitation – the main one in the period December-January and a secondary one in May-June;
- Minimum precipitation occurs in August.
- The monthly temperature distribution corresponds to the monthly distribution of precipitation and river runoff.

7.2 Maximum daily (24-hour) precipitation

Intense 24-hour rainfall is a key factor in the formation of high water levels.

Generally speaking, the most significant maximum 24-hour rainfall is recorded during the autumn-winter period – from October to January. The maximum recorded 24-hour rainfall in the region is 234 mm.

To characterise the phenomenon, representative rain gauge stations for the area were selected with measurement results for a period of 43 to 81 years.

The available literature data on the maximum rainfall recorded in each month for the measurement period are shown in Table 7-6.

TABLE 7-6: MAXIMUM DAILY RAINFALL

Months	Zlatograd		Krumovgrad		Kardzhali		Davidkovo		Ivaylovgrad	
	mm	year	mm	year	mm	year	mm	year	mm	year
January	120.6	1978	75.3	1960	77.3	1969	86.0	1960	80.2	1960
February	216.0	1963	78.1	1979	68.	1937	59.5	1984	52.2	1982
March	92.5	1971	75.2	1984	43.4	1984	64.0	1962	75	1984
April	63.0	1937	72.0	1953	52.2	1940	48.3	1966	65.2	1940
May	82.8	1963	48.4	1975	54.8	1936	53.4	1966	76.6	1975
June	72.0	1960	107.5	1955	52.8	1953	57.0	1959	68.5	1964
July	79.5	1937	58.4	1982	46.2	1931	79.5	1966	78.4	1959
August	45	1951	48.0	1951	48.2	1975	32.7	1984	49.5	1968
September	120.0	1957	57.5	1941	85.0	1940	49.7	1978	90.3	1940
October	234.0	1970	83.2	1978	94.5	1970	58.0	1962	88.4	1953

Months	Zlatograd		Krumovgrad		Kardzhali		Davidkovo		Ivaylovgrad	
	mm	year	mm	year	mm	year	mm	year	mm	year
November	105.0	1961	96.0	1940	73.2	1940	76.0	1961	70.6	1940
December	103.8	1952	88.9	1969	84.3	1968	82.5	1956	105.3	1940
Maximum	**234.0**	**1970**	**107.5**	**1955**	**94.5**	**1970**	**86.0**	**1960**	**105.3**	**1940**

Based on these data, the NIMH has calculated the maximum rainfall with normative certainty as follows:

TABLE 7-7: MAXIMUM DAILY RAINFALL WITHVARYING RELIABILITY ACCORDING TO LITERATURE DATA - NIMH

Station	Obs. day max.		Reliability, %							
	mm	Year	2	5	10	25	50	75	90	95
Krumovgrad	107.5	1955	96	86	78	65	52	41	33	30
Zlatograd	234.0	1970	184	153	129	95	67	49	40	37
Ivaylovgrad	105.3	1940	94	83	74	60	48	39	34	32
Kardzhali	94.5	1970	93	82	73	59	46	36	30	27
Davidkovo	86.0	1960	107	94	83	68	54	44	38	36

In accordance with the requirements for determining maximum precipitation with a normative assurance of %, 1% and 5% of the series of recorded annual maximums of 24-hour precipitation amounts, the parameters of maximum precipitation $N_{max.\ avg}$ and coefficient of variation C_v .

With these data and an accepted asymmetry coefficient $C_s = 4C_v$, the values of maximum precipitation for these probabilities are determined using the theoretical probability curve with a ratio of $C_s = 4C_v$. In the calculations, the values of the coefficient of variation for the short series are increased by a guarantee correction ΔC_v .

$$\Delta C_V = \pm \frac{0.675}{\sqrt{2^n}} . \sqrt{1 + 2C_V^2} \quad \textbf{(2)}$$

Where: n - number of terms in the series;

TABLE 7-8: MAXIMUM DAILY PRECIPITATION

Station	Altitude	Nmax, abs	Nmax, avg	C_v	C_s	Reliability, %					
						0.1	0.5	1	3	5	10
	m	mm	mm			mm	mm	mm	mm	mm	mm
Krumovgrad	350	107.5	52	0.40	1.60	171.1	135.2	121.7	99.8	91.0	78.5
Zlatograd	430	234.0	78	0.55	2.20	361.5	266.0	231.7	180.2	157.6	129.9
Kardzhali	231	94.5	54	0.40	1.60	177.7	140.4	126.4	103.7	94.5	81.5
Ivaylovgrad	100	105.3	51	0.42	1.68	177.1	138.0	123.7	100.6	91.1	78.0
Avren	480	120.5	74.5	0.52	2.08	325.9	241.5	212.3	166.3	146.5	121.6

8 Drainage characteristics of the region

8.1 Hydrological research.

Water levels and water quantities on the Biala River have been monitored at three hydrometric stations shown in Table 8-1.

TABLE 8-1: HYDROMETRIC STATIONS ON THE BYALA RIVER

Nov No	Old No	Station location	Catchment area	Average altitude	Distance to mouth (border)	Year	
HMS	HMS		km2	m	km	start	end
	310	Mandritsa village	522.4	-	9.30	1 December 1950	15 November 1954
	310	Mandritsa village	522.4	-	9.30	8 December 1954	1 October 1955
	310 a	Meden Buk village	432	472	26	19 October 1954	31 December 1962
	433	village of Dolno Lukovo	448	453	21	1 December 1962	31 July 1971
62800	433	village of Dolno Lukovo	448,000	453	21.10	1.VIII.1971	Observation

Data from stations monitoring the regime of the Arda River and its tributaries at the stations shown in the following table were used to derive regional runoff dependencies.

TABLE 8-2: HYDROMETRIC STATIONS IN THE ARDA RIVER BASIN

Nov No	Old No	Name of the river	Location of the station	Catchment area	Average altitude	Distance to the mouth (border)	Year
HMS	HMS			km	m	km	
61050	322a,b	Biala Reka	village of Bostina	52.900	1300	4.78	1953 - n.p.

61330	346	Elkhovska River	Rudozem	83.900	1147	1.45	1950 - n.p.
61350	319	Cherna Reka	village of Tarun	234,400	1280	10.8	1951 - n.p.
61400	314	Malkata Arda	village of Banite	114,000	1172	10.26	1949 - n.p.
61450	313	Varbitsa	Vurli Dol village	471.200	647	43.25	1951 - n.p.
61500	312	Varbitsa	sp. Dzhebel	1149.000	584	9.97	1936 - n.p.
61550	311	Krumovitsa	Gorna Kula	497.600	494	21.2	1936 - n.p.
61650	320	Arda	Rudozem	257.700	1162	204.15	1950 - n.p.
61700	315	Arda	Vechino village	858.400	-	174.4	1952 - n.p.

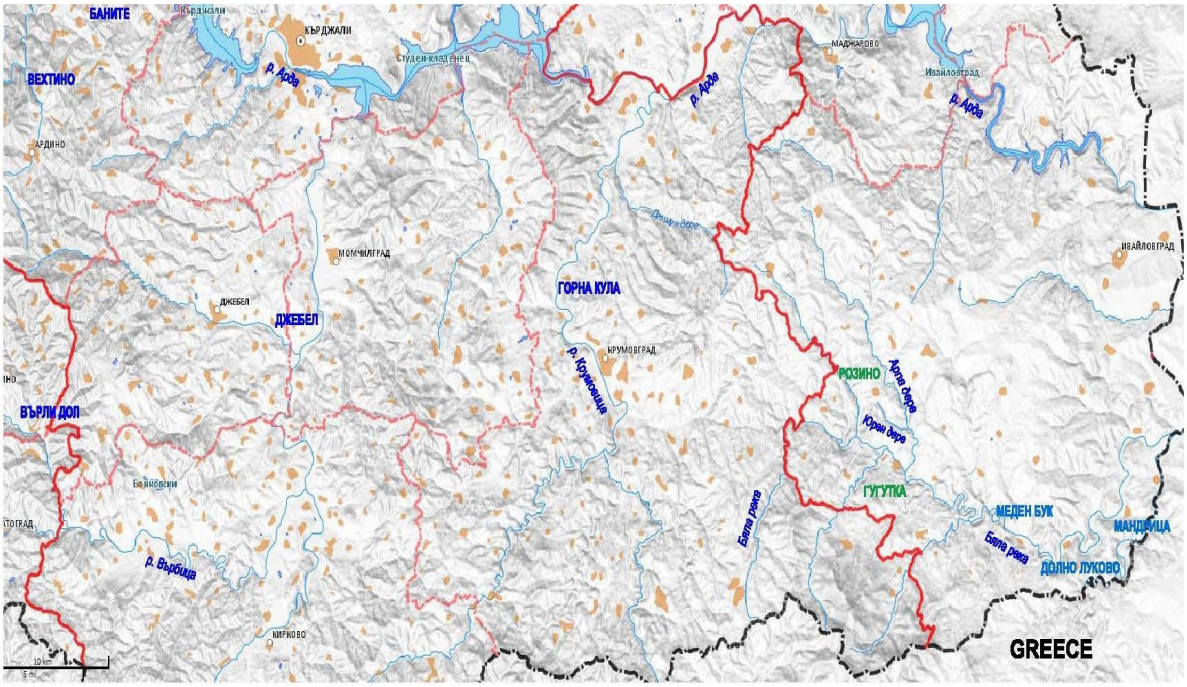

FIGURE 8-1 HYDROMETRIC STATIONS NEAR THE STUDY AREA

The main characteristics of the HMS in the area suitable for use in calculating the runoff parameters are shown in Table 8-3 below.

TABLE 8-3: OROGRAPHIC AND RUNOFF CHARACTERISTICS OF HMS

No	Characteristics	Measure	Elkhovska River – Rudozem	Varbitsa River – Varlidol village	Varbitsa – Dzhebel	Krumovitsa – Gorna Kula	Byala River – Dolno Lukovo
1	Number XMP new	-	61330	61450	61500	61550	62800
2	Number XMP old	-	346a	313	312a	311	433
3	Year of discovery	-	1950 n.a.	1951 n.a.	1936 n.a.	1936 n.a.	1962 n.a.
4	Length to XMP	km	18.95	54.85	88.15	37.3	48.5
5	Average slope of the river	%	47	18.4	12.1	19	-
6	Catchment area	km	83.90	471.20	1149.0	497.60	448.0
7	Average altitude	m	1147	647	584	494	453
8	Average slope of the catchment area	-	-	0.282	0.242	0.206	-
9	River network density	km/km2	-	-	-	-	-
10	Forest cover	%	-	-	43.3	35.3	-
11	Distance from the mouth	km	1.45	43.25	9.95	21.2	21.1
12	Point "0" elevation	m	688.69	292.22	229.32	197.4	86.41
13	Outflow rate	m3/s	2.46	8.74	19.3	8	5.744
14	Runoff module	l/s/km2	29.3	18.6	16.8	16.1	12.82

15	Coefficient of variation C_v	-	0.29	0.4	0.432	0.456	0.573

8.2 Regional runoff dependencies

To determine the runoff parameters from the data in Table 8-3 for the hydrometric stations in the area and neighbouring rivers, dependencies were established between the runoff module and the average altitude of the catchment area and between the runoff variation coefficient and the average altitude of the catchment area.

Average annual runoff module:

$Mo = 8.9204.e^{0.0011.H}$ [l/s/km^2]

with a coefficient of determination $R^2 = 0.9419$

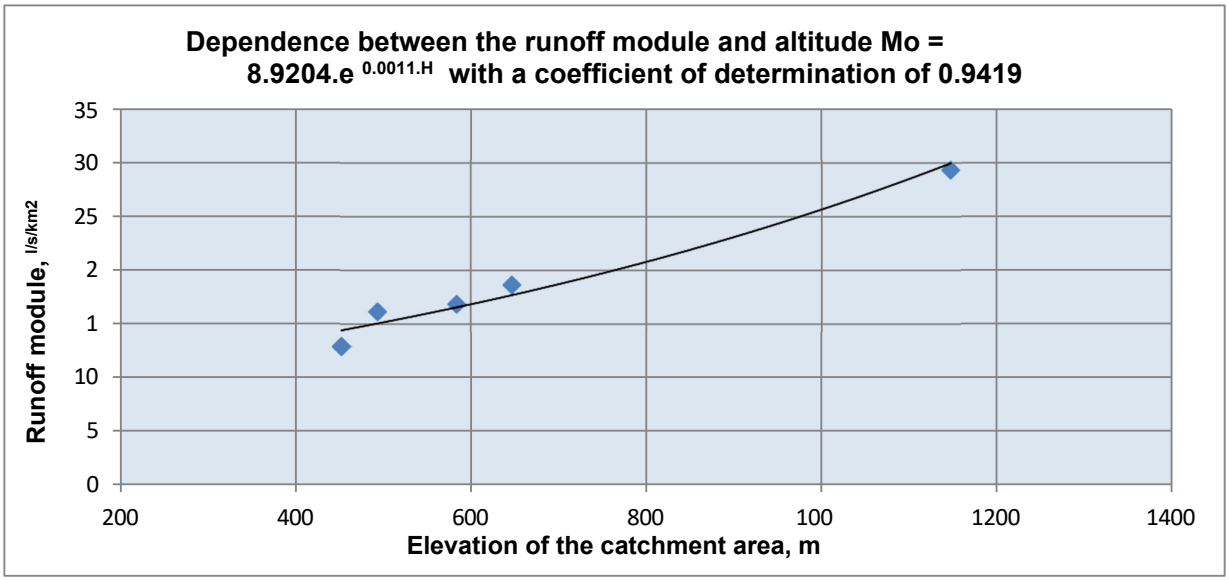

FIGURE 8-2: RELATIONSHIP BETWEEN RUNOFF MODULE AND ALTITUDE

Coefficient of variation of the average annual runoff:

$C_v = 22.5906.H^{-0.6116}$

with a coefficient of determination $R^2 = 0.8893$ and a coefficient of asymmetry $C_s = 2*C_v$.

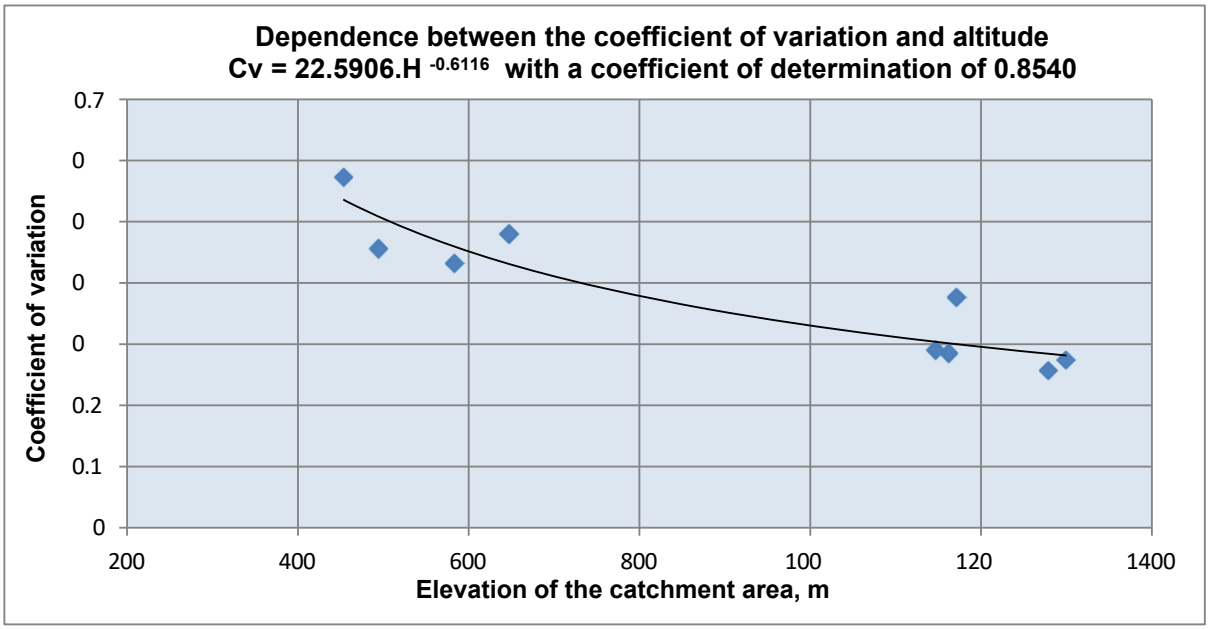

FIGURE 8-3: RELATIONSHIP BETWEEN THE COEFFICIENT OF VARIATION AND ALTITUDE

8.3 Parameters of the discharge of the Biala River and its tributary Arpa Dere

These dependencies were used to calculate the parameters of the discharge of the Biala River and its tributaries to the considered gauging stations. The parameters are shown in Table 8-4.

TABLE 8-4: PARAMETERS OF THE DISCHARGE OF THE BIALA RIVER AND ITS TRIBUTARY, THE ARPA DERE RIVER

No	Characteristic	Measure	Biala River before the confluence with the Arpadere River	Biala River after the confluence with the Arpadere River	Biala River after the confluence with the Arpadere River without	Arpadere River before the confluence with the	Yuren Creek	Arpadere River after the confluence with the Yuren Creek	Arpadere River at its confluence with	Arpadere River at its confluence with the Byala
1	Area of the catchment basin	km	208.56	281.85	278.35	65.08	3.5	68.575	73.29	69.79
2	Average altitude	m	499.52	498.51	500.40	517.9	347.98	509.23	495.64	503.05
3	Runoff module	l/s/km2	14.803	14.787	14.818	15.106	12.530	14.962	14.740	14,861
4	Outflow rate	m3/s	3.087	4.168	4.125	0.983	0.044	1.026	1.080	1.037
5	Coefficient of variation		0.5052	0.5059	0.5047	0.4942	0.6303	0.4993	0.5076	0.5031
6	Average annual water mass Wo	million m	97.364	131.432	130.071	31.002	1.383	32,357	34,069	32,707
7	Secured outflow 75	m³/s	1.944	2.622	2.599	0.628	0.023	0.651	0.678	0.655
8	Average annual water mass W 75%	million m	61.311	82.697	81,965	19,792	0.738	20,531	21,386	20.654
9	Secured outflow 90	m³/s	1.33	1.797	1.782	0.434	0.014	0.448	0.464	0.450
10	Average annual water mass W 90%	million m	42.033	56.673	56.211	13.683	0.453	14,128	14.640	14.18
11	Secured outflow 95	m³/s	1.041	1.403	1.393	0.342	0.01	0.352	0.362	0.352
12	Average annual water mass W 95%	million m	32.83	44.241	43.923	10.783	0.324	11.088	11.412	11.094

8.4 Maximum water quantities (high tide)

Maximum water quantities – so-called "high" waters – can be determined in several ways: directly through measurements or indirectly through other methods. The determination of the size of "high" waters is with a view to sizing the relief facilities and ensuring their unimpeded passage without endangering the underlying terrain, land, infrastructure and populated areas.

Due to the lack of direct measurements, the maximum water quantities with different levels of certainty are determined by indirect approximate methods. A relatively reliable value for the maximum water volume can be obtained using the so-called channel method, whereby the maximum flow rate is calculated using Chezy's hydraulic formula at the maximum water level in the river. This requires an on-site inspection to identify marks in the river cross-section indicating the maximum water flow in the past. As we do not have data from the on-site inspection, the maximum water volume is determined by two methods - by analogy using regional empirical dependencies

and by maximum rainfall.

8.4.1 Calculation of high waves using empirical formulas

The maximum water volumes based on the available data in a given region can be determined by the dependence of the water volume or the runoff module on the catchment area, i.e. the dependencies $\mathbf{Q_{max}= f(F)}$ or $\mathbf{M_{max}= f(F)}$. Based on the available data in the region for HMC, Table 8-5 shows the calculated maximum runoff modules for 0.1%, 1% and 5% reliability.

The check for the existence of a linear dependence shows that the coefficient of determination is between 0.25 and 0.45. The calculated values, compared to the data for HMC, show large deviations from the actual measured values at the point, which means that this dependence cannot be used for calculations.

A power dependence for the maximum flow module with the corresponding security is considered:

$$\mathbf{M_{max\ p\%} = A.F^{-n}}$$

$$\mathbf{Q_{max\ p\%} = M_{max\ p}\%.F}$$

where:

M – runoff module for the corresponding reliability, m^3 /s/km^2 ;

Q – maximum water quantity for the corresponding reliability, m^3 /s; A –

coefficient;

F – catchment area, km^2 ; n –

exponent;

p% – security, %;

TABLE 8-5: CHARACTERISTICS OF THE "HIGH" WAVES MEASURED AT THE HMS IN THE AREA OF THE ARDA RIVER AND ITS TRIBUTARIES

No	Characteristic	Measure	Arda River, Rudoze	Arda River, village	Elkhovska River, Rudozem	Cherna River, village of	Biala River, village of	Malkata Arda River,	Varbitsa River, village of	Varbitsa River, Dzhebel	Krumovitsa River, Gorna Kula	Biala Reka River, Dolno Lukovo village
1	Point		61650	61700	61330	61350	61050	61400	61450	61500	61550	62800
2	Catchment area	km	257.7	858.4	83.90	242.1	52.90	114.0	471.20	1149.0	497.60	448.00
3	HMP quota	m	691.89	553.62	688.69	687.22	851.19	683.26	292.22	229.32	197.4	86.41
4	Average altitude	m	1162	-	1147	1280	1300	1172	647	584	494	453
5	Outflow rate	m^3 /s	5,070	18,400	2,460	4,590	1.040	1,950	8,740	19,300	8,000	5,390
6	Runoff module - average	l/s/km2	19,700	21,400	29,300	19,000	19,700	17,100	18,600	16,800	16,100	12,000
7	Qmax average	m^3/s	202.90	714.86	122.56	97.558	24.45	61.63	422.44	1107.53	516.04	295.70
8	Average module of maximum flow	m^3 /s/km2	0.7874	0.8328	1.4607	0.4030	0.4621	0.5406	0.8965	0.9639	1.0371	0.6601
9	Qmax safety factor 0.1%	m^3 /s	1099.58	3414.08	621.39	368.58	117.71	329.97	2029.62	4855.25	2449.43	2266.51
10	Module with safety factor 0.1%	m^3 /s/km2	4.2669	3.9773	7.4063	1.5224	2.2251	2.8944	4.3073	4.2256	4.9225	5.0592
11	Qmax safety factor 1%	m^3 /s	673.57	2169.43	388.51	250.78	74.63	202.87	1287.57	3161.48	1559.12	1267.24
1	Module with 1% safety margin	m^3 /s/km2	2.6138	2.5	4.6307	1.0359	1.4107	1.7795	2.7325	2.7515	3.1333	2.8287
13	Qmax safety factor 3%	m^3 /s	511.71	1681.42	299.04	200.91	57.79	154.48	997.23	2475.27	1209.27	895.68
14	Module-max with safety factor 3 %	m^3 /s/km2	1.9857	1.9588	3.5643	0.8299	1.0923	1.3551	2.1164	2.1543	2.4302	1.9993
15	Qmax safety factor 5%	m^3 /s	440.42	1464.85	258.60	180.14	50.29	133.07	868.14	2179.67	1054.32	750.47
16	Module with 5% safety margin	m^3 /s/km2	1.7090	1.7065	3.0822	0.7441	0.9507	1.1673	1.8424	1.8970	2.1188	1.6752
17	Variation in outflow	C_v	0.285	0.317	0.29	0.257	0.2740	0.376	0.48	0.4320	0.456	0.573
18	Outflow asymmetry	C_s	0.57	0.634	0.58	0.5140	0.5480	0.7520	0.96	0.8640	0.912	1.1460
19	Variation in max. outflow	C_v	0.6356	0.56619	0.60029	0.45363	0.57072	0.62909	0.56949	0.52113	0.56282	0.85862
20	Asymmetry.max outflow	C_s	1.15116	0.56599	0.70977	0.9212	0.86474	1.10972	1.95972	1.00261	0.90309	2.0872

The obtained dependencies and the calculated values of the parameters in these dependencies are shown in the following three figures, and parameters A and n are summarised in Table 8-6 below.

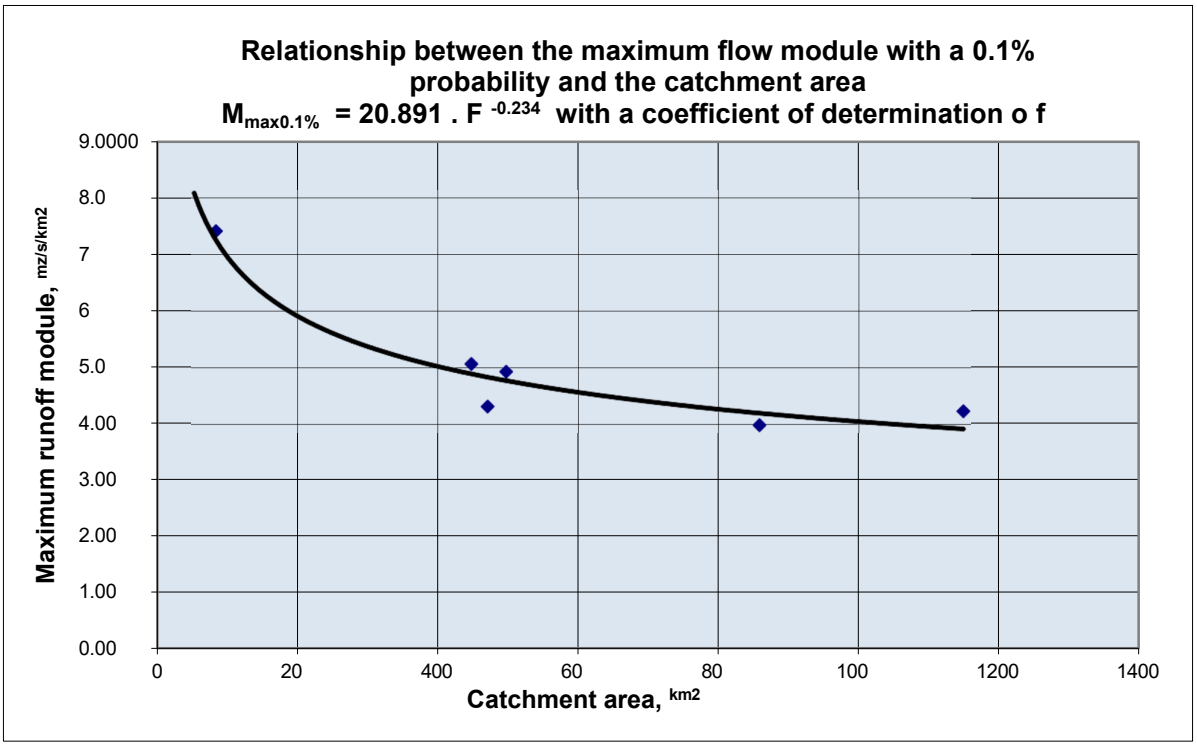

FIGURE 8-4: RELATIONSHIP BETWEEN THE MAXIMUM FLOW MODULE WITH A 0.1% PROBABILITY AND THE CATCHMENT AREA

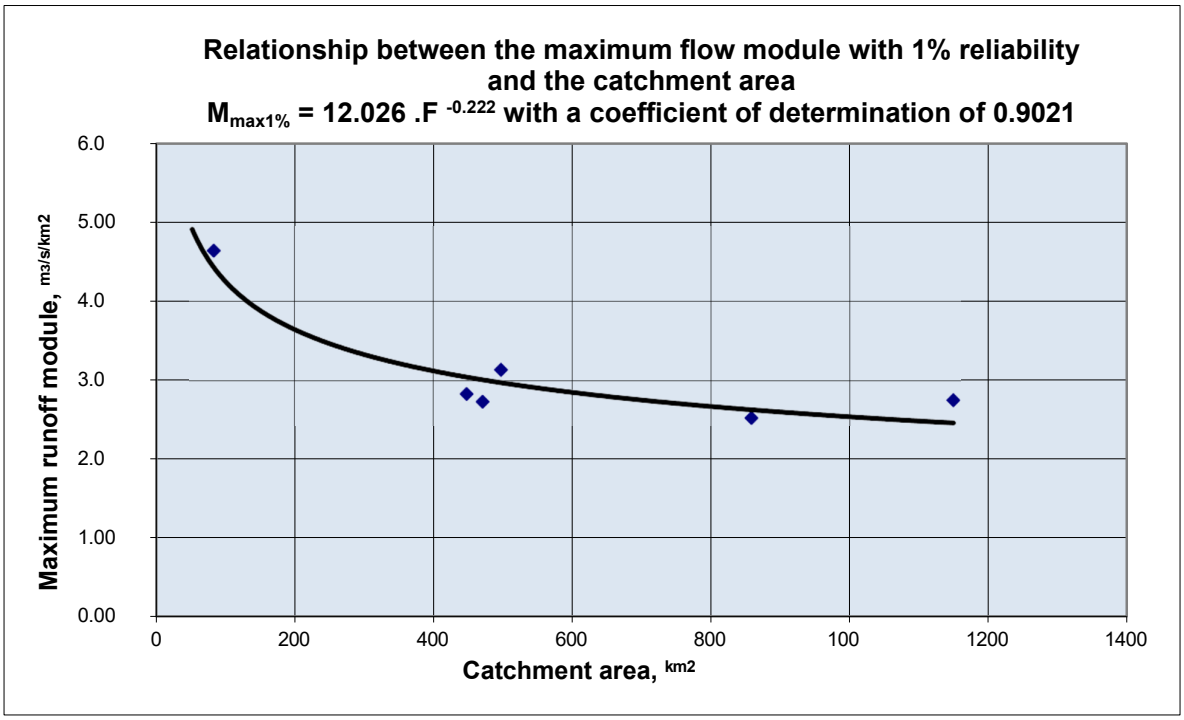

FIGURE 8-5: RELATIONSHIP BETWEEN THE MAXIMUM FLOW MODULE WITH A 1% PROBABILITY AND THE CATCHMENT AREA

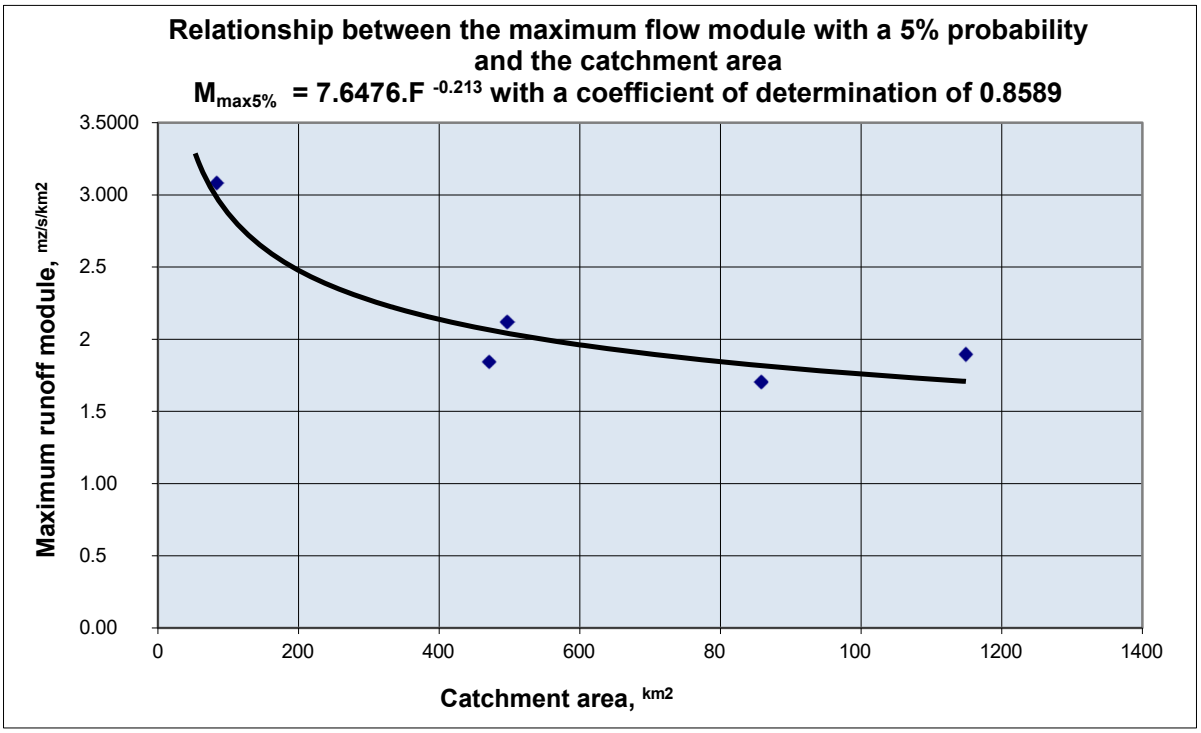

FIGURE 8-6: RELATIONSHIP BETWEEN THE MAXIMUM FLOW MODULE WITH 5% RELIABILITY AND THE CATCHMENT AREA

TABLE 8-6: VALUES OF COEFFICIENTS IN THE REGIONAL DEPENDENCE FOR CALCULATING "HIGH" WAVES WITH DIFFERENT SECURITY

Parameter	Probability		
Empirical dependence	0.1	1	5
Coefficient A	20.8911	12.0259	7.6476
Coefficient n	-0.2343	-0.2220	-0.2128
Coefficient of determination R^2	0.9626	0.9021	0.8598

With the coefficients thus determined, the peaks of the "high" waves with different reliability for the considered sections of the Biala River and its tributaries were calculated.

TABLE 8-7: PEAKS OF "HIGH" WAVES WITH DIFFERENT LEVELS OF ASSURANCE IN THE RIVER BASINS OF THE BIALA RIVER, ARPA DERE RIVER AND YUREN DERE RIVER

No	Section	Area	Probability		
			0.1	1	5
		km	m3/s	m3/s	m3/s
1	Biala River before the confluence with the Arpadere River	208.56	1246.799	766.44	511.946
2	Biala River after the confluence with the Arpadere River	281.85	1570.146	968.794	648.902
3	Biala River after Arpadere River, excluding Yurendere River	278.35	1555.195	959.422	642.55
4	Arpadere River before the confluence with the Yuren Dere River	65.08	511.114	309,728	204.67
5	Yuren Dere	3.5	54.520	31.872	20.50
6	Arpadere River after the confluence with the Yuren Dere River	68.58	532.002	322.593	213.28
7	Arpadere River at its confluence with the	73.29	559.791	339.72	224.74

	Byala River				4
8	Arpadere River at Byala River, excluding Yurendere River	69.79	539.205	327.031	216.252

8.4.2 Calculation of high waves based on maximum precipitation

Given the location of the catchment areas, the following stations can be considered representative for determining maximum rainfall: Krumovgrad, Zlatograd, Kardzhali, Ivaylovgrad and Avren.

For each of the catchments, depending on the distance from the centre of the catchment to the respective station, its weighting influence was calculated, and for each section, the average weighting rainfall heights for the respective security were calculated.

TABLE 8-8: AVERAGE WEIGHT DISTRIBUTION OF PRECIPITATION HEIGHTS

No	Station	R. Byala River to the confluence with the Arpadere River		Biala River after the Arpadere River		Arpadere River to the confluence with the Yuren Dere River		Arpadere River after Yuren Dere River		Yuren Dere River		Arpadere River at its confluence with the Byala River	
		distance	Weight	distance	weight	distance	weight	distance	weight	distance	weight	distance	weight
1	Krumovgrad	15.57	30.28	16.18	30.79	20.34	27.27	20.87	26.72	21.82	25.46	20.89	26.58
2	Zlatograd	61.99	7.61	63.51	7.84	68.32	8.12	68.54	8.14	68.84	8.07	68.8	8.07
3	Kardzhali	43.16	10.93	42.84	11.63	44.55	12.45	44.88	12.42	48.38	11.48	45.55	12.19
4	Ivaylovgrad	26.81	17.59	24.65	20.21	19.5	28.44	19.22	29.01	20.14	27.58	19.03	29.17
5	Avren	14.04	33.59	16.87	29.53	239	23.71	23.52	23.71	20.26	27.41	23.13	24.00

TABLE 8-9: MAXIMUM DAILY PRECIPITATION WITH DIFFERENT RELIABILITY

No	Rain gauge station	Nsr	Nmax Or	Nmax abs	C_v	C_s	Safety					
							0.10	0.50	1	3	5	10
		m	mm		-	-	mm	mm	mm	mm	mm	mm
1	Krumovgrad	350	107.5	52	0.40	1.60	171.1	135.2	121.7	99.8	91.0	78.5
2	Zlatograd	430	234.0	78.0	0.55	2.20	361.5	266.0	231.7	180.2	157.6	129.9
3	Kardzhali	231	94.5	54.0	0.40	1.60	177.7	140.4	126.4	103.7	94.5	81.5
4	Ivaylovgrad	100	105.3	51	0.42	1.68	177.1	138.0	123.7	100.6	91.1	78.0
5	Avren	480	120.5	74.5	0.52	2.08	325.9	241.5	212.3	166.3	146.5	121.6
Average weight Biala River before the Arpadere River							239.4	181.9	161.4	128.8	115	97.1
Average weight Biala River after Arpadere River							233.7	178.0	158.0	126.4	113	95.5
Average weight of the Biala River after the Arpadere River, excluding Yurendere							233.7	178.0	158	126.4	113	95.5
Average weight Arpadere River before Yuren Dere River							225.8	172.5	153.3	122.8	110	93.1
Average weight Yuren Dere							231.3	176.3	156.5	125.2	112	94.7
Average weight Arpadere River after Yuren Dere River							225.9	172.5	153.3	122.8	110	93.1
Average weight Arpadere River before the Byala River							226.2	172.7	153.5	123	110	93.2
Average weight Arpadere River before Byala River, excluding Yuren Dere							226.2	172.7	153.5	123	110	93.2

The average value of the maximum rainfall with normative reliability at the rain gauge stations in Krumovgrad, Avren, Ivaylovgrad, Kardzhali and Zlatograd is taken as an analogue.

Based on the determined maximum precipitation heights H_{max} (mm) with different probabilities P (%) and the reduction coefficients for IX region ψ_τ , the maximum precipitation heights h_{tp} (mm) were calculated for different rainfall durations t (mm) and probabilities P (%) for the point under consideration in Table 8-10.

TABLE 8-10: MAXIMUM PRECIPITATION HEIGHTS WITH DIFFERENT DURATIONS T (MM) AND PROBABILITY P (%) - H_{TP} (MM) FOR THE SECTION UNDER CONSIDERATION

P	Hmax	Duration t (mm)									
%	mm	5	10	20	40	60	90	150	300	720	144
p. Byala River to the confluence with the Arpadere River – H_{tp}											
0.	239.36	39.02	57.93	80.43	101.73	111.07	119.20	133.57	165.16	225.00	239.36
0	181.92	29.65	44.03	61.13	77.32	84.41	90.60	101.51	125.53	171.01	181.92
1	161.37	26.30	39.05	54.22	68.58	74.88	80.36	90.04	111.35	151.69	161.37
3	128.82	21.00	31.18	43.28	54.75	59.77	64.15	71.88	88.89	121.09	128.82
5	115.11	18.76	27.86	38.68	48.92	53.41	57.33	64.23	79.43	108.20	115.11
10	97.13	15.83	23.51	32.64	41.28	45.07	48.37	54.20	67.02	91.30	97.13
p.Biala River after the Arpadere River – H_{tp}											
01	233.7	38.10	56.5	78.53	99.34	108.45	116.40	130.42	161.27	219.71	233.73
05	178.02	29.02	43.08	59.82	75.66	82.60	88.66	99.34	122.84	167.34	178.02
1	158.04	25.76	38.24	53.10	67.16	73.33	78.70	88.18	109.04	148.55	158.04

3	126.36	20.60	30.58	42.46	53.70	58.63	62.93	70.51	87.19	118.78	126.36
5	113.04	18.43	27.36	37.98	48.04	52.45	56.29	63.08	78.00	106.26	113.04
10	95.51	15.57	23.11	32.09	40.59	44.32	47.56	53.29	65.90	89.78	95.51

P	Hmax	Duration t (mm)									
	mm	5	10	20	40	60	90	150	300	720	1440
p. Byala River after the Arpadere River, excluding the Yuren Dere River – H_{tp}											
01	233.73	38.1	56.5	78.53	99.34	108.45	116.40	130.42	161.27	219.71	233.73
05	178.02	29.02	43.08	59.82	75.66	82.60	88.66	99.34	122.84	167.34	178.02
1	158.04	25.76	38.24	53.10	67.16	73.33	78.70	88.18	109.04	148.55	158.04
3	126.36	20.60	30.58	42.46	53.70	58.63	62.93	70.51	87.19	118.78	126.36
5	113.04	18.43	27.36	37.98	48.04	52.45	56.29	63.08	78.00	106.26	113.04
10	95.51	15.57	23.11	32.09	40.59	44.32	47.56	53.29	65.90	89.78	95.51
p. Arpadere to the confluence with the Yuren Dere River – H_{tp}											
0	225.80	36.	54.64	75.87	95.96	104.77	112.45	125.99	155.80	212.25	225.80
0	172.47	28.11	41.74	57.95	73.30	80.03	85.89	96.24	119.01	162.12	172.47
1	153.27	24.98	37.09	51.50	65.14	71.12	76.33	85.52	105.76	144.07	153.27
3	122.81	20.02	29.72	41.26	52.19	56.98	61.16	68.53	84.74	115.44	122.81
5	110.03	17.94	26.63	36.97	46.76	51.06	54.80	61.40	75.92	103.43	110.03
10	93.13	15.18	22.54	31.29	39.58	43.21	46.38	51.96	64.26	87.54	93.13
R. Yuren Dere – H_{tp}											
0	231.31	37.	55.98	77.72	98.31	107.33	115.19	129.07	159.60	217.43	231.31
0	176.26	28.73	42.66	59.22	74.91	81.79	87.78	98.35	121.62	165.69	176.26
1	156.50	25.51	37.87	52.58	66.51	72.62	77.94	87.33	107.99	147.11	156.50
3	125.19	20.41	30.29	42.06	53.20	58.09	62.34	69.85	86.38	117.67	125.19
5	112.02	18.26	27.11	37.64	47.61	51.98	55.78	62.51	77.29	105.30	112.02
10	94.67	15.43	22.91	31.81	40.23	43.93	47.15	52.83	65.32	88.99	94.67
p. Arpadere after the Yuren Dere River – H_{tp}											
01	225.86	36.	54.6	75.89	95.99	104.80	112.48	126.03	155.84	212.31	225.86
05	172.51	28.12	41.75	57.96	73.32	80.04	85.91	96.26	119.03	162.16	172.51
1	153.30	24.99	37.10	51.51	65.15	71.13	76.34	85.54	105.77	144.10	153.30
3	122.83	20.02	29.72	41.27	52.20	56.99	61.17	68.54	84.75	115.46	122.83
5	110.04	17.94	26.63	36.97	46.77	51.06	54.80	61.40	75.93	103.44	110.04
10	93.13	15.18	22.54	31.29	39.58	43.21	46.38	51.97	64.26	87.54	93.13
p. Arpadere at the confluence with the Byala River – H_{tp}											
01	226.17	36.87	54.7	75.99	96.12	104.94	112.63	126.20	156.06	212.60	226.17
05	172.72	28.15	41.80	58.03	73.41	80.14	86.01	96.38	119.18	162.36	172.72
1	153.48	25.02	37.14	51.57	65.23	71.21	76.43	85.64	105.90	144.27	153.48
3	122.96	20.04	29.76	41.31	52.26	57.05	61.23	68.61	84.84	115.58	122.96
5	110.15	17.95	26.66	37.01	46.81	51.11	54.86	61.46	76.00	103.54	110.15
10	93.21	15.19	22.56	31.32	39.62	43.25	46.42	52.01	64.32	87.62	93.21
p. Arpadere at the confluence with the Byala River, excluding the Yuren											

Dere River – H_{tp}

P	Hmax	Duration t (mm)									
	mm	5	10	20	40	60	90	150	300	720	1440
01	226.17	36.87	54.73	75.99	96.12	104.94	112.63	126.20	156.06	212.60	226.17
05	172.72	28.15	41.80	58.03	73.41	80.14	86.01	96.38	119.18	162.36	172.72
1	153.48	25.02	37.14	51.57	65.23	71.21	76.43	85.64	105.90	144.27	153.48
3	122.96	20.04	29.76	41.31	52.26	57.05	61.23	68.61	84.84	115.58	122.96
5	110.15	17.95	26.66	37.01	46.81	51.11	54.86	61.46	76.00	103.54	110.15
10	93.21	15.19	22.56	31.32	39.62	43.25	46.42	52.01	64.32	87.62	93.21

The maximum water quantity is determined by the formula:

$Q_{max} = 16.67 . \alpha . Hp . F/T$, m^3 /s

where:

α – runoff coefficient, α = 0.45÷0.55;

H_{pt} – design rainfall for the respective reliability, mm;

F – catchment area, km^2 ;

T – duration of intense rainfall, T = 60÷210 min; The results obtained are

shown in Table 8-11 below.

TABLE 8-11: HIGH WAVE PEAKS CALCULATED USING MAXIMUM RAINFALL

Section	Probability, P	Runoff coefficient α	Precipitation, Htp	Duration of intense precipitation	Water catchment	Water quantity, Qmax	Volume of wave height, Vmax
			mm	min	km^2	m3/s	million m3
p.Biala River to the confluence with the Arpadere River Arpadere	0.10	0.55	133.57	210	208.56	1216.198	15.321
	1	0.50	90.04	210	208.56	745.373	9.39
	5	0.45	64.23	210	208.56	478.533	6.028
p.Biala River after the Arpadere River	0.10	0.55	130.42	210	281.85	1604.895	20.218
	1	0.50	88.18	210	281.85	986.489	12.427
	5	0.45	63.08	210	281.85	635.066	8
p.Biala River after the Arpadere River, excluding the Yurendere River	0.10	0.55	130.42	210	278.35	1584.97	19.967
	1	0.50	88.18	210	278.35	974.238	12.273
	5	0.45	63.08	210	278.35	627.180	7.901
Arpadere River to the confluence with the	0.10	0.55	125.99	150	65.08	501.194	4.510
	1	0.50	85.52	150	65.08	309.281	2.783
	5	0.45	61.40	150	65.08	199.830	1.798

Yuren Dere River							
River	0.10	0.55	107.33	60	3.5	57.402	0.207
	1	0.50	72.62	60	3.50	35.307	0.127
	5	0.45	51.98	60	3.50	22.744	0.082
p.Arpadere after r.Yuren dere	0.10	0.55	126.03	150	68.575	528.253	4.753
	1	0.50	85.54	150	68.575	325.947	2.933
	5	0.45	61.40	150	68,575	210.580	1.895

Structure	Security, P	Runoff coefficient α	Precipitation, Htp	Duration of intense precipitation	Water catchment	Water quantity, Qmax	Volume of high Wave, Vmax
			mm	min	km²	m3/s	million m3
Arpadere River at its confluence with the Byala River	0.10	0.5	126.2	150	73.29	565.364	5.087
	1	0.50	85.64	150	73.29	348.771	3.138
	5	0.45	61.46	150	73.29	225.281	2.027
Arpadere at Biala River without Yuren Dere River	0.10	0.55	126.20	150	69.79	538.36	4.844
	1	0.50	85.64	150	69.79	332.115	2.988
	5	0.45	61.46	150	69.79	214.492	1.93

From the comparison of the results obtained by the two methods shown in Table 21 below, it can be concluded that the results are approximately the same. Given that the derived dependencies are based on actual measured water quantities in rivers, it is assumed that the calculated peaks of "high" waters formed during intense rainfall will be equal to those determined by the empirical dependencies for the selected normative security levels.

TABLE 8-12: COMPARISON OF THE RESULTS OF THE TWO METHODS

Water catchment	Calculation method	Measure	Security		
			0.10	1	5
p.Biala River to the confluence with the Arpadere River	According to empirical formulas	m3/s	1246.799	766.442	511.946
	By maximum rainfall	m3/s	1216.198	745.373	478.533
p.Biala River after the Arpadere River	According to empirical formulas	m3/s	1570.146	968.794	648.902
	By maximum rainfall	m3/s	1584.970	974.238	627.180
p.Biala River after the Arpadere River without Yurdere	According to empirical formulas	m3/s	1604.895	986.489	635.066
	By maximum rainfall	m3/s	1555.200	959,422	642.510
Arpadere to Yuren Dere	According to empirical formulas	m3/s	511.114	309.728	204.678
	By maximum rainfall	m3/s	501.194	309.281	199,830
Yuren Dere River	According to empirical formulas	m3/s	54.52	31.872	20.503
	By maximum rainfall	m3/s	57.402	35,307	22.744
Arpadere River after Yuren Dere River	According to empirical formulas	m3/s	532.002	322.593	213.282
	By maximum rainfall	m3/s	528.253	325,947	210.580
Arpadere River at its confluence with the Byala River	According to empirical formulas	m3/s	559.791	339.721	224.744
	By maximum rainfall	m3/s	565.364	348,771	225.281
p.Arpadere at the Biala River without the Yuren Dere River	According to empirical formulas	m3/s	539.205	327.031	216.252
	Through maximum rainfall	m3/s	538.360	332,115	214,492

The maximum design water quantities for the selected regulatory security levels are determined by the calculated peaks of the "high" waters increased by a safety factor of 1.05.

TABLE 8-13: MAXIMUM DESIGN WATER QUANTITIES

Catchment	Measure	Security		
		0.10	1	5
p. Byala River to the confluence with the Arpadere River	m3/s	1309.139	804.764	537.54
p. Byala River after the Arpadere River	m3/s	1648.65	1017.234	681.347

p. Byala River after the Arpadere River without Yurendere	m3/s	1633	1007.40	674.640
p. Arpadere to the confluence with the Yurendre River	m3/s	536,670	325,214	214,912
Yuren Dere River	m3/s	57.246	33.466	21.528
p. Arpadere after the Yuren Dere River	m3/s	558.602	338.723	223.946
Arpadere River at its confluence with the Byala River	m3/s	587.781	356,707	235.981
Arpadere River at the Biala River without Yurendere	m3/s	566.17	343.380	227,060

8.5 Determination of the distribution of runoff in typical years

As an analogue for determining the distribution of runoff during the year in the sections of the Biala River and its tributaries, the Arpadere River and the Yuren Dere River, HMS 62800 on the Biala River near the village of Dolno Lukovo was adopted, where measurements of the water flow in the river have been carried out since 1963.at the village of Dolno Lukovo, where measurements of the water flow in the river have been carried out since 1963.

The reasons for choosing this point as an analogue of the outflow are as follows:

- there are no runoff regulators in the catchment area of the Biala River upstream of the hydrometric station;
- the hydrometric station and the gauges under consideration are on the same river and from the same catchment area;
- the available data from observations at HMP 62800 are of sufficient duration and make it possible to determine the distribution of the outflow in the specified characteristic years;

The data by year for the period 1963-1983 for the average annual water quantity at HMP 62800 on the Biala River near the village of Dolno Lukovo are shown in the following table.

TABLE 8-14: AVERAGE ANNUAL WATER QUANTITIES FOR THE BIALA RIVER NEAR THE VILLAGE OF DOLNO LUKOVO HMP 62800

No	Chronological order		Descending order		Security P, %
	Year	Q_{avg} , m3/s	year	Q_{avg} , m3/s	
1	1963	13.791	1963	13.791	3,271
2	1964	3,167	1966	12,180	7,944
3	1965	7,442	1969	8,595	12,617
4	1966	12,180	1965	7,442	17,290
5	1967	4,572	1980	6,961	21,963
6	1968	3,320	1979	6,501	26,636
7	1969	8,595	1981	6,412	31,308
8	1970	5,763	1973	5,926	35,981
9	1971	5,828	1971	5,828	40,654
10	1972	3,491	1970	5,763	45,327
11	1973	5,926	1967	4,572	50,000
12	1974	3,138	1978	4,530	54,673
13	1975	4,296	1977	4,400	59,346
14	1976	2,937	1975	4,296	64,019
15	1977	4,400	1982	4,223	68,692
16	1978	4,530	1972	3,491	73,364
17	1979	6,501	1968	3,320	78,037

18	1980	6,961	1964	3,167	82,710
19	1981	6,412	1983	3,153	87,383
20	1982	4,223	1974	3,138	92,056

21	1983	3,153	1976	2,937	96.729
Average		**5.744**		**5.744**	
Cv		**0.50423**		**0.50423**	
Cs		**1.38352**		**1.38352**	

The security curve for the average annual water quantities in the Biala River at HMS 62800 near the village of Dolno Lukovo is shown in the following figure.

The main characteristics of the runoff are:

- average annual water quantity in the river Q_{avg} = 5.744 m^3 /s;
- coefficient of variation of the discharge C_v = 0.504232;
- asymmetry coefficient of the runoff Cs = 1.38352;

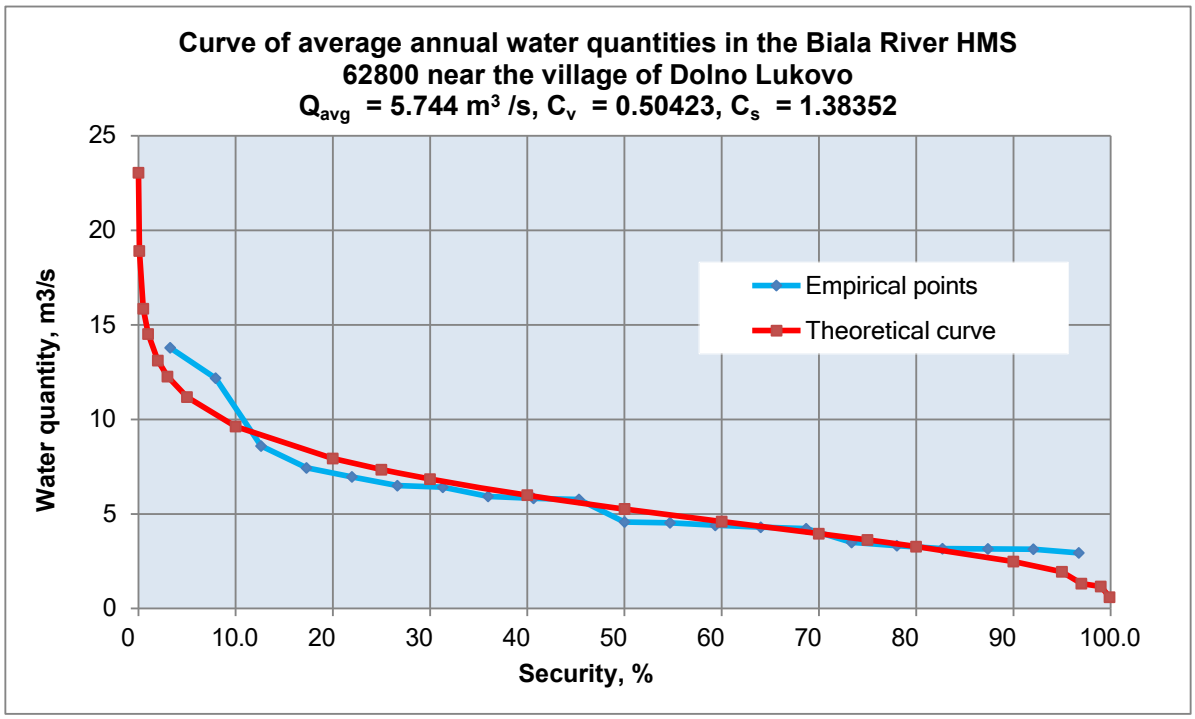

FIGURE 8-7: CURVE OF AVERAGE ANNUAL WATER QUANTITIES IN THE BIALA RIVER AT THE HMS 62800 STATION NEAR THE VILLAGE OF DOLNO LUKOVO

Using the monthly and annual data from HMS 62800, the following years were defined as characteristic: "average" with 50% reliability – 1970, "dry" with 75% reliability – 1972, "very dry" with a 90% probability – 1974, and "extremely dry year" with a 95% probability – 1976.

The monthly distribution of the average flow at the HMS 62800 gauging station is given in Table 8-15.

TABLE 8-15: DISTRIBUTION OF AVERAGE MONTHLY DISCHARGE FOR FOUR CHARACTERISTIC YEARS IN TERMS OF RELIABILITY FOR THE BIALA RIVER AT HMS 62800, DOLNO LUKOVO

Year	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average year
Average year 50 %	Q, m^3/s	12.80	8.26	23.60	11.40	2.21	0.78	0.57	0.62	0.28	2.40	1.93	4.27	5.76
	W, m^3 .^{106}	34.28	19.98	63.21	29.55	5.92	2.02	1.53	1.66	0.73	6.43	5.0	11.44	181.75
	%	18.86	10.99	34.78	16.26	3.26	1.11	0.84	0.91	0.40	3.54	2.75	6.29	100.00
	Q, m^3 /s	1.73	11.7	3.4	2.6	3.3	0.89	0.56	0.21	0.19	14.60	1.78	0.98	3.48

Dry year 75			0											
	W, m^3 .^{106}	4.63	29.32	9.27	6.77	8.92	2.31	1.50	0.56	0.49	39.10	4.61	2.62	110.11
	%	4.21	26.62	8.42	6.14	8.10	2.10	1.36	0.51	0.45	35.52	4.19	2.38	100.00

Very dry year 90 %	Q, m³ /s	0.72	7.43	9.36	3.67	5.12	0.91	0.24	0.16	0.30	0.32	2.25	7.42	3.42
	W, m³ .106	1.93	17.97	25.07	9.51	13.71	2.36	0.64	0.43	0.78	0.86	5.83	19.87	98.97
	%	1.95	18.16	25.33	9.61	13.86	2.38	0.65	0.43	0.79	0.87	5.89	20.08	100.00
Except dry year 95 %	Q, m³ /s	1.73	7.5	1.71	4.0	1.34	0.59	0.17	0.38	0.21	2.08	5.0	10.60	2.53
	W, m³ .106	4.63	18.87	4.58	10.47	3.59	1.53	0.46	1.02	0.54	5.57	12.96	28.39	92.61
	%	5.00	20.37	4.95	11.31	3.88	1.65	0.49	1.10	0.59	6.02	13.99	30.66	100.00

8.6 Outflow parameters in the studied sections, calculated using the analogue point

The reduction coefficient from analogue XMP 62800 on the Biala River near the village of Dolno Lukovo is equal to the ratio between the calculated discharge rate for each of the studied sections and the discharge rate of 5.744 m3/s established from observations at point XMS 62800.

$$Kr = Q_{weir} / Q_{№62800}$$

Using the above formulas, the discharge characteristics and parameters for each of the points under consideration were calculated. This coefficient is used to reduce all water quantities, including the minimum ones. By distributing the analogue point, the distribution of the average flow for the four characteristic years was obtained for the studied sections of the Biala River and its tributary, the Arpadere River, with the Yuren Dere River.

TABLE 8-16: BYALA RIVER BEFORE ARPADERE RIVER, $_{CR}$ = 0.53743

Year	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average year
Average year 50 %	Q, m3/s	6.88	4.4	12.68	6.1	1.19	0.42	0.31	0.33	0.15	1.29	1.04	2.29	3.10
	W, m3.106	18.43	10.74	33.97	15.88	3.18	1.09	0.82	0.89	0.39	3.45	2.69	6.15	97.68
	%	18.86	10.99	34.78	16.26	3.26	1.11	0.84	0.91	0.40	3.54	2.75	6.29	100.00
Dry year 75	Q, m3/s	0.93	6.29	1.86	1.40	1.79	0.48	0.30	0.11	0.10	7.85	0.96	0.53	1.87
	W, m3.106	2.49	15.76	4.98	3.64	4.79	1.24	0.81	0.30	0.26	21.02	2.48	1.41	59.17
	%	4.21	26.62	8.42	6.14	8.10	2.10	1.36	0.51	0.45	35.52	4.19	2.38	100.00
Very dry year 90 %	Q, m3/s	0.39	3.99	5.03	1.97	2.75	0.49	0.13	0.09	0.16	0.17	1.21	3.99	1.84
	W, m3.106	1.04	9.66	13.47	5.11	7.37	1.27	0.35	0.23	0.42	0.46	3.13	10.68	53.19
	%	1.95	18.16	25.33	9.61	13.86	2.38	0.65	0.43	0.79	0.87	5.89	20.08	100.00
Except dry year 95 %	Q, m3/s	0.93	4.05	0.92	2.17	0.72	0.32	0.09	0.20	0.11	1.12	2.69	5.7	1.36
	W, m3.106	2.49	10.14	2.46	5.63	1.93	0.82	0.24	0.55	0.29	2.99	6.97	15.26	49.77
	%	5.00	20.37	4.95	11.31	3.88	1.65	0.49	1.10	0.59	6.02	13.99	30.66	100

TABLE 8-17: BYALA RIVER AFTER ARPADERE RIVER, $_{KR}$ = 0.87563

Year	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average year
	Q, m3/s	9.29	5.99	17.1	8.27	1.60	0.57	0.41	0.45	0.20	1.74	1.40	3.10	4.18

Average year 50 %	W, $m3.10^6$	24.88	14.5	45.87	21.44	4.30	1.47	1.11	1.20	0.53	4.66	3.63	8.30	131.88
	%	18.86	10.99	34.78	16.26	3.26	1.11	0.84	0.91	0.40	3.54	2.75	6.29	100.00
	Q, m3/s	1.26	8.49	2.51	1.89	2.42	0.65	0.41	0.15	0.14	10.59	1.29	0.71	2.53

Dry year 75	W, $m3.10^6$	3.36	21.27	6.7	4.91	6.47	1.67	1.09	0.41	0.36	28.38	3.35	1.90	79.9
	%	4.21	26.62	8.42	6.14	8.10	2.10	1.36	0.51	0.45	35.52	4.19	2.38	100.00
Very dry year 90 %	Q, m3/s	0.52	5.39	6.79	2.66	3.72	0.66	0.17	0.12	0.22	0.23	1.63	5.38	2.48
	W, $m3.10^6$	1.40	13.04	18.19	6.90	9.95	1.71	0.47	0.31	0.56	0.62	4.23	14.42	71.81
	%	1.95	18.16	25.33	9.61	13.86	2.38	0.65	0.43	0.79	0.87	5.89	20.08	100.00
Except dry year 95 %	Q, m3/s	1.26	5.4	1.24	2.93	0.97	0.43	0.12	0.28	0.15	1.51	3.63	7.69	1.84
	W, $m3.10^6$	3.36	13.69	3.32	7.60	2.6	1.11	0.33	0.74	0.39	4.04	9.40	20.60	67.20
	%	5.00	20.37	4.95	11.31	3.88	1.65	0.49	1.10	0.59	6.02	13.99	30.66	100

TABLE 8-18: BYALA RIVER AFTER ARPADERE RIVER, WITHOUT YUREN DERE, $_{KR}$ = 0.71505

Year	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average year
Average year 50 %	Q, m3/s	9.19	5.93	16.95	8.19	1.59	0.56	0.41	0.45	0.20	1.72	1.39	3.07	4.14
	W, $m3.10^6$	24.62	14.35	45.39	21.22	4.25	1.45	1.10	1.19	0.52	4.62	3.59	8.21	130.50
	%	18.86	10.99	34.78	16.26	3.26	1.11	0.84	0.91	0.40	3.54	2.75	6.29	100.00
Dry year 75	Q, m3/s	1.24	8.4	2.48	1.87	2.39	0.64	0.40	0.15	0.14	10.48	1.28	0.7	2.50
	W, $m3.10^6$	3.33	21.05	6.65	4.86	6.4	1.66	1.08	0.40	0.35	28.08	3.31	1.88	79.06
	%	4.21	26.62	8.42	6.14	8.10	2.10	1.36	0.51	0.45	35.52	4.19	2.38	100.00
Very dry year 90 %	Q, m3/s	0.52	5.34	6.72	2.64	3.68	0.65	0.17	0.11	0.22	0.23	1.62	5.33	2.46
	W, $m3.10^6$	1.38	12.91	18.00	6.83	9.85	1.69	0.46	0.31	0.56	0.62	4.19	14.27	71.07
	%	1.95	18.16	25.33	9.61	13.86	2.38	0.65	0.43	0.79	0.87	5.89	20.08	100.00
Except dry year 95 %	Q, m3/s	1.24	5.41	1.23	2.9	0.96	0.42	0.12	0.27	0.15	1.49	3.59	7.61	1.82
	W, $m3.10^6$	3.33	13.55	3.29	7.52	2.58	1.10	0.33	0.73	0.39	4.00	9.31	20.39	66.50
	%	5.00	20.37	4.95	11.31	3.88	1.65	0.49	1.10	0.59	6.02	13.99	30.66	100.00

TABLE 8-19: R. ARPADERE BEFORE YUREN DERE, $_{CR}$ = 0.17114

Year	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average year
Average year 50 %	Q, m3/s	2.19	1.41	4.04	1.95	0.38	0.13	0.1	0.11	0.05	0.41	0.33	0.73	0.99
	W, $m3.10^6$	5.87	3.42	10.82	5.06	1.01	0.35	0.26	0.28	0.12	1.10	0.86	1.96	31.10
	%	18.86	10.99	34.78	16.26	3.26	1.11	0.84	0.91	0.40	3.54	2.75	6.29	100.00
Dry year 75	Q, m3/s	0.30	2.0	0.59	0.45	0.57	0.15	0.10	0.04	0.03	2.50	0.30	0.17	0.60
	W, $m3.10^6$	0.79	5.02	1.59	1.16	1.53	0.39	0.26	0.10	0.08	6.69	0.79	0.45	18.84
	%	4.21	26.62	8.42	6.14	8.10	2.10	1.36	0.51	0.45	35.52	4.19	2.38	100.00

Very dry year 90 %	Q, m3/s	0.12	1.27	1.6	0.63	0.88	0.16	0.04	0.03	0.05	0.05	0.39	1.27	0.59
	W, m3.106	0.33	3.08	4.29	1.63	2.35	0.40	0.11	0.07	0.13	0.15	1.00	3.40	16.94

	%	1.95	18.16	25.33	9.61	13.86	2.38	0.65	0.43	0.79	0.87	5.89	20.08	100.00
Except dry year 95 %	Q, m3/s	0.30	1.29	0.29	0.69	0.2	0.10	0.03	0.07	0.04	0.36	0.86	1.81	0.43
	W, m3.106	0.79	3.23	0.78	1.79	0.61	0.26	0.08	0.17	0.09	0.95	2.22	4.86	15.85
	%	5.0	20.37	4.95	11.31	3.88	1.65	0.49	1.10	0.59	6.02	13.99	30.66	100.00

TABLE 8-20: R. YUREN DERE, $_{CR}$ = 0.00766

Year	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average year
Average year 50 %	Q, m3/s	0.10	0.06	0.18	0.09	0.02	0.01	0.00	0.00	0.00	0.02	0.01	0.03	0.04
	W, m3.106	0.26	0.15	0.48	0.23	0.05	0.02	0.01	0.01	0.01	0.05	0.04	0.09	1.39
	%	18.86	10.99	34.78	16.26	3.26	1.11	0.84	0.91	0.40	3.54	2.75	6.29	100.00
Dry year 75	Q, m3/s	0.01	0.09	0.03	0.02	0.03	0.01	0.00	0.00	0.00	0.11	0.01	0.01	0.03
	W, m3.106	0.04	0.22	0.07	0.05	0.07	0.02	0.01	0.00	0.00	0.30	0.04	0.02	0.84
	%	4.21	26.62	8.42	6.14	8.10	2.10	1.36	0.51	0.45	35.52	4.19	2.38	100.00
Very dry year 90 %	Q, m3/s	0.01	0.06	0.07	0.03	0.04	0.01	0.00	0.00	0.00	0.00	0.02	0.06	0.03
	W, m3.106	0.01	0.14	0.19	0.07	0.1	0.02	0.00	0.00	0.01	0.01	0.04	0.15	0.76
	%	1.95	18.16	25.33	9.61	13.86	2.38	0.65	0.43	0.79	0.87	5.89	20.08	100.00
Except dry years 95 %	Q, m3/s	0.01	0.06	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.02	0.04	0.08	0.02
	W, m3.106	0.04	0.14	0.04	0.08	0.03	0.01	0.00	0.01	0.00	0.04	0.10	0.22	0.71
	%	5.0	20.37	4.95	11.31	3.88	1.65	0.49	1.10	0.59	6.02	13.99	30.66	100.00

TABLE 8-21: R. ARPADERE AFTER YUREN DERE, $_{CR}$ = 0.17862

Year	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average year
Average year 50 %	Q, m3/s	2.29	1.48	4.22	2.04	0.39	0.14	0.10	0.11	0.05	0.43	0.34	0.76	1.03
	W, m3.106	6.12	3.57	11.29	5.28	1.06	0.36	0.27	0.30	0.13	1.15	0.89	2.04	32.46
	%	18.86	10.99	34.78	16.26	3.26	1.11	0.84	0.91	0.40	3.54	2.75	6.29	100.00
Dry year 75	Q, m3/s	0.31	2.09	0.62	0.47	0.59	0.16	0.10	0.04	0.03	2.61	0.32	0.18	0.62
	W, m3.106	0.83	5.24	1.66	1.21	1.59	0.41	0.27	0.10	0.09	6.98	0.82	0.47	19.67
	%	4.21	26.62	8.42	6.14	8.10	2.10	1.36	0.51	0.45	35.52	4.19	2.38	100.00
Very dry year 90 %	Q, m3/s	0.13	1.33	1.67	0.66	0.91	0.16	0.04	0.03	0.05	0.06	0.40	1.33	0.61
	W, m3.106	0.34	3.21	4.48	1.70	2.45	0.42	0.11	0.08	0.14	0.15	1.04	3.55	17.68
	%	1.95	18.16	25.33	9.61	13.86	2.38	0.65	0.43	0.79	0.87	5.89	20.08	100.00
Except dry year 95 %	Q, m3/s	0.31	1.35	0.31	0.72	0.24	0.11	0.03	0.07	0.04	0.37	0.89	1.89	0.45
	W, m3.106	0.83	3.37	0.82	1.87	0.64	0.27	0.08	0.18	0.10	1.0	2.31	5.07	16.54
	%	5.0	20.37	4.95	11.31	3.88	1.65	0.49	1.10	0.59	6.02	13.99	30.66	100

TABLE 8-22: R. ARPADERE BEFORE R. BYALA REKA, $_{CR}$ = 0.18802

Year	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average year

Average year 50 %	Q, m3/s	2.41	1.55	4.4	2.14	0.42	0.15	0.11	0.12	0.05	0.45	0.36	0.8	1.08
	W, m3.106	6.45	3.76	11.88	5.56	1.11	0.38	0.29	0.31	0.14	1.21	0.94	2.15	34.17
	%	18.86	10.99	34.78	16.26	3.26	1.11	0.84	0.91	0.40	3.54	2.75	6.29	100.00
Dry year 75	Q, m3/s	0.33	2.20	0.65	0.49	0.63	0.17	0.11	0.04	0.04	2.75	0.33	0.18	0.65
	W, m3.106	0.87	5.51	1.74	1.27	1.68	0.43	0.28	0.11	0.09	7.35	0.87	0.49	20.70
	%	4.21	26.62	8.42	6.14	8.10	2.10	1.36	0.51	0.45	35.52	4.19	2.38	100.00
Very dry year 90 %	Q, m3/s	0.14	1.40	1.76	0.69	0.96	0.17	0.05	0.03	0.06	0.06	0.42	1.40	0.64
	W, m3.106	0.36	3.38	4.71	1.79	2.58	0.44	0.12	0.08	0.15	0.16	1.10	3.74	18.61
	%	1.95	18.16	25.33	9.61	13.86	2.38	0.65	0.43	0.79	0.87	5.89	20.08	100.00
Except dry year 95 %	Q, m3/s	0.33	1.42	0.32	0.76	0.25	0.11	0.03	0.07	0.04	0.39	0.94	1.99	0.48
	W, m3.106	0.87	3.55	0.86	1.97	0.67	0.29	0.09	0.19	0.10	1.05	2.44	5.34	17.41
	%	5.0	20.37	4.95	11.31	3.88	1.65	0.49	1.10	0.59	6.02	13.99	30.66	100

TABLE 8-23: R. ARPADERE BEFORE R. BYALA REKA, WITHOUT YUREN DERE, $_{KR}$ = 0.18056

Year	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average year
Average year 50 %	Q, m3/s	2.31	1.49	4.26	2.06	0.4	0.14	0.10	0.11	0.05	0.43	0.35	0.77	1.04
	W, m3.106	6.19	3.61	11.41	5.34	1.07	0.37	0.28	0.30	0.13	1.16	0.9	2.07	32.82
	%	18.86	10.99	34.78	16.26	3.26	1.11	0.84	0.91	0.40	3.54	2.75	6.29	100.00
Dry year 75	Q, m3/s	0.31	2.11	0.62	0.47	0.6	0.16	0.10	0.04	0.03	2.64	0.32	0.18	0.63
	W, m3.106	0.84	5.29	1.67	1.22	1.61	0.42	0.27	0.10	0.09	7.06	0.83	0.47	19.88
	%	4.21	26.62	8.42	6.14	8.10	2.10	1.36	0.51	0.45	35.52	4.19	2.38	100.00
Very dry year 90 %	Q, m3/s	0.13	1.34	1.69	0.66	0.92	0.16	0.04	0.03	0.05	0.06	0.41	1.34	0.62
	W, m3.106	0.35	3.25	4.53	1.72	2.48	0.43	0.12	0.08	0.14	0.15	1.05	3.59	17.87
	%	1.95	18.16	25.33	9.61	13.86	2.38	0.65	0.43	0.79	0.87	5.89	20.08	100.00
Except dry year 95 %	Q, m3/s	0.31	1.36	0.31	0.73	0.24	0.11	0.03	0.07	0.04	0.38	0.90	1.91	0.46
	W, m3.106	0.84	3.41	0.83	1.89	0.65	0.28	0.08	0.18	0.10	1.01	2.34	5.13	16.72
	%	5.00	20.37	4.95	11.31	3.88	1.65	0.49	1.10	0.59	6.02	13.99	30.66	100.00

8.7 Minimum water quantities in the studied river basins.

8.7.1 Theoretical eco-minimum

The Ministry of Environment and Water's "Instructions for determining the minimum permissible flow in rivers" were used to determine the minimum water quantities.

According to these instructions, in order to preserve river ecosystems, it is recommended that rivers have a flow equal to 10 per cent of the average multi-year water quantity, but not less than the minimum average monthly water quantity with 95 per cent reliability for the respective point under undisturbed conditions.

The minimum average monthly water quantity with 95% reliability is determined by analysing all available data on the average monthly water quantity at the analogue point HMS 62800 on the Biala River near the village of Dolno Lukovo.

TABLE 8-24: AVERAGE MONTHLY DISCHARGE IN M²/S AT THE ANALOGUE POINT ON THE BYALA RIVER NEAR THE VILLAGE OF DOLNO LUKOVO IN THE PERIOD 1963-1983

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1963	18,600	98,900	19,000	12,000	5,480	7,200	0.870	0.23	0.260	0.780	1.270	8.030
1964	2.390	7,250	8,310	2,910	3,090	1,080	0.310	0.110	1.760	1.35	1.270	8.15
1965	9,760	32,200	17,700	8,130	11,900	0.860	0.310	0.230	0.130	0.180	1.030	8.640
1966	20.30	5,970	14,600	10,100	5,430	2,630	0.610	0.340	0.290	2.210	23.80	58.9
1967	22,100	8,970	11,200	6,300	1,570	0.950	0.480	0.480	0.220	0.290	0.38	2.010
1968	13.7	10.9	5.220	1,420	0.57	0.320	0.061	0.059	0.130	0.074	3.640	3.88
1969	19.5	41.80	18,600	7,700	2,410	0.38	0.180	0.11	0.240	0.11	0.190	14.30
1970	12.80	8.26	23,600	11,400	2,210	0.780	0.570	0.620	0.280	2.400	1.930	4.270
1971	16,200	9,070	22,400	8,220	2,770	2,610	1,390	0.250	0.5	0.420	2.500	3.610
1972	1.730	11,700	3,460	2,610	3,330	0.890	0.560	0.210	0.190	14.600	1.780	0.98
1973	11,600	21,100	21,200	12	2,590	1,020	0.32	0.170	0.16	0.280	0.32	1.490
1974	0.72	7.430	9.360	3.670	5.120	0.910	0.240	0.160	0.300	0.320	2.250	7.420
1975	7.08	4,080	5,400	4,840	14,900	5,460	0.850	1,340	0.340	1.000	1.730	4.360
1976	1,730	7,530	1,710	4,040	1,340	0.590	0.170	0.38	0.21	2.080	5.00	10.60
1977	11,100	26,700	7,440	2,160	0.99	1,200	0.270	0.068	0.280	0.21	0.460	3.640
1978	2.574	8.89	9,588	16,414	2,353	1,608	0.181	0.136	0.976	0.585	3.513	8.107
1979	23.103	26,094	3,977	3,108	4,742	1,503	0.458	0.261	0.240	0.679	9.326	6.036
1980	21.716	6,509	7,736	9,096	8,610	6,160	0.472	0.188	0.130	0.141	14.060	8.508
1981	16.46	36,650	15,152	2,301	1,809	0.248	0.155	0.056	0.053	0.142	1.629	4.518
1982	1.895	6.782	12,112	13,453	3,501	2,984	0.799	0.093	0.059	0.144	0.316	8.786
1983	2.933	17.205	3.627	2,412	0.493	4.933	0.733	0.136	0.242	0.120	0.323	5.883

The analysis of the data in Table 8-24 shows that the average monthly water quantity with 95% reliability is equal to 120 l/s. Using the reduction coefficient $K_p$for the Byala River to the respective section, the eco-minima are determined according to the average annual inflow at the analogue point. They are compared with the threshold of 10% of the theoretical average discharge at the section, and the eco-minimum that should be observed is selected from the two values. The results of the calculation are shown in the following table

If facilities for regulating the outflow are constructed, the eco-minimums in the considered sections of the Biala River, Arpadere River and Yuren Dere River should be equal to the eco-minimum in Table 34.

TABLE 8-25: ECOLOGICAL MINIMUM IN THE RIVER SECTIONS UNDER CONSIDERATION

No	Section	95% in the analogue river	K_r	Q 95% . K_p	10% Q_{cp}	Eco-minimum
		m3/s		m3/s	m3/s	m3/s
1	p. Byala River before the Arpadere River	0.12	0.5374	0.0645	0.309	0.309
2	p. Byala River after the Arpadere River	0.12	0.7256	0.0871	0.417	0.417
3	p. Byala River after the Arpadere River, excluding the Yuren River	0.12	0.718	0.086	0.41	0.412
4	p. Arpadere before the Yuren Dere River	0.12	0.1711	0.02	0.09	0.09
5	Yuren Dere River	0.12	0.0077	0.0009	0.004	0.004
6	p. Arpadere after the Yuren Dere	0.12	0.1786	0.0214	0.10	0.10

	River					
7	p. Arpadere before the Biala River	0.12	0.18	0.0226	0.10	0.10
8	p. Arpadere before the Biala River without the Yuren River	0.12	0.18	0.02	0.10	0.103

8.7.2 Actual minimum water quantities

The data by year for the period 1963-1983 for the minimum monthly and annual water quantities in HMS 62800 on the Biala River near the village of Dolno Lukovo are shown in the following table.

TABLE 8-26: MINIMUM WATER QUANTITIES BY YEAR ON THE BIALA RIVER NEAR THE VILLAGE OF DOLNO LUKOVO IN HMS 62800

No	Chronological order		Descending order		Security P, %
	Year	Q_{avg} , m3/s	year	Q_{avg} , m3/s	
1	1963	0.180	1970	0.260	3.271
2	1964	0.074	1979	0.200	7.944
3	1965	0.130	1963	0.180	12.617
4	1966	0.06	1971	0.140	17.290
5	1967	0.130	1974	0.140	21.963
6	1968	0.00	1965	0.130	26.636
7	1969	0.090	1967	0.130	31.308
8	1970	0.260	1973	0.130	35.981
9	1971	0.140	1983	0.120	40.654
10	1972	0.02	1978	0.110	45.327
11	1973	0.130	1980	0.110	50,000
12	1974	0.140	1975	0.10	54.673
13	1975	0.100	1976	0.093	59.346
14	1976	0.093	1969	0.090	64.019
15	1977	0.068	1964	0.074	68.692
16	1978	0.110	1977	0.068	73.364
17	1979	0.200	1966	0.060	78.037
18	1980	0.11	1981	0.048	82.710
19	1981	0.048	1972	0.02	87.383
20	1982	0.001	1982	0.001	92.056
21	1983	0.12	1968	0.000	96.729
Qavg. min		**0.105**		**0.105**	
Cv min		**0.60389**		**0.60389**	
Cs min		**0.35393**		**0.35393**	

The curve of the minimum annual water quantities in the Biala River at HMS 62800 near the village of Dolno Lukovo is shown in the following figure.

The main characteristics of the minimum flow are: average annual minimum water quantity in the river $Q_{avg.\ min}$ = 0.105 m3/s, coefficient of variation of the minimum annual discharge C_{vmin} = 0.60389 and coefficient of asymmetry of the minimum annual discharge C_{smin} = 0.35393.

The analysis of the data in the table and the curve of the minimum annual water supply shows that there is a certain discrepancy for very dry periods. In practice, the minimum flow in the river in 1968 was zero. However, according to data on water consumers, it was precisely in that year that a pumping station for irrigation with a flow rate of 50 l/s began operating. Since there were no requirements to maintain an eco-minimum in the river during this period, it is most likely that all available water was used, and this is the reason for the occurrence of periods with zero flow in the river, as well as others with a flow of 1 to 20 l/s – (1972, 1981 and 1982).

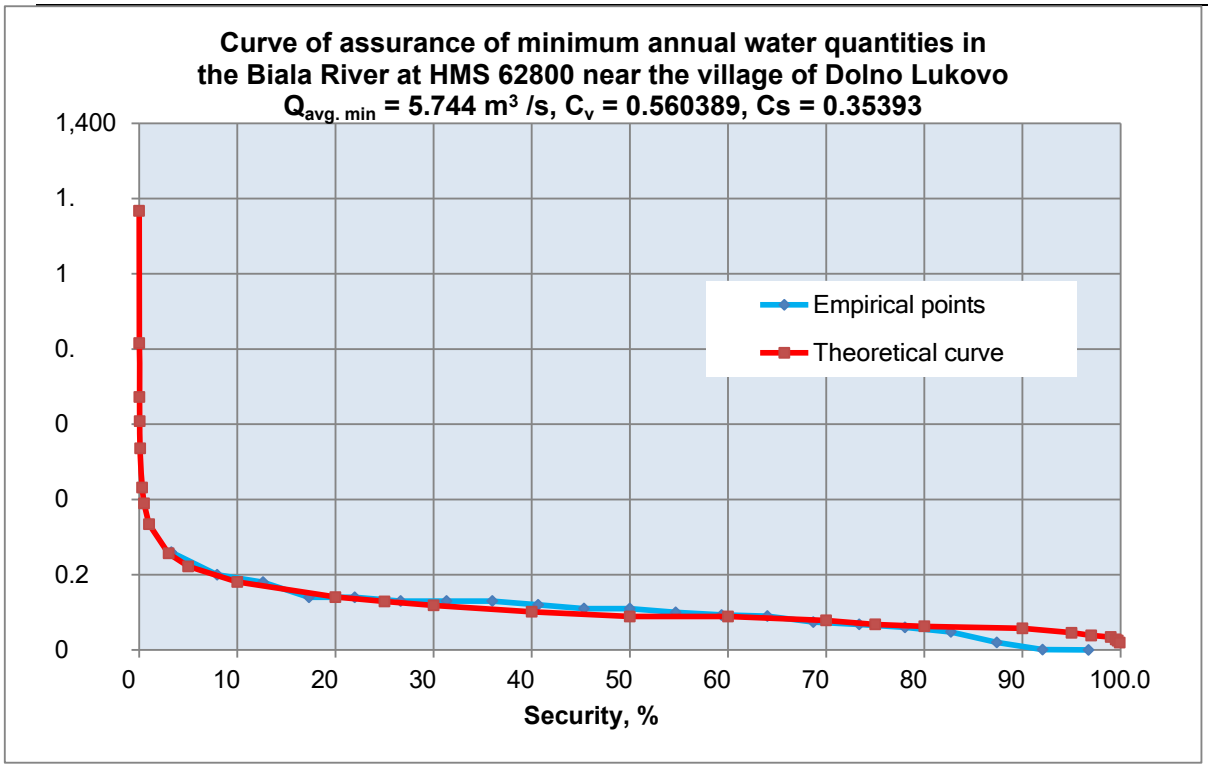

FIGURE 8-8 CURVE OF SECURITY OF MINIMUM ANNUAL WATER QUANTITIES IN THE BIALA RIVER AT THE HMS 62800 STATION NEAR THE VILLAGE OF DOLNO LUKOVO

Using the monthly and annual data from HMS 62800, the following years were determined as characteristic years for the minimum water quantities in the river: "average" with a security of 50% – 1980, "dry" with a security of 75% – 1977, "very dry" with a 90% probability – 1972, and "extremely dry" with a 95% probability – 1968.

The monthly distribution of the minimum flow at the HMP 62800 gauge in these characteristic years is given in Table 8-27.

TABLE 8-27: DISTRIBUTION OF MINIMUM FLOW IN M³/S BY MONTH FOR FOUR CHARACTERISTIC YEARS IN TERMS OF RELIABILITY ON THE BIALA RIVER, AT HMP 62800 NEAR THE VILLAGE OF D. LUKOVO

Characteristic year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Min.
Average annual 50%	2.847	1,951	2,100	3.271	2.455	0.524	0.123	0.11	0.118	0.118	0.160	1.253	0.110
Dry year... 75%	1.40	3.94	3.130	1.310	0.28	0.068	0.068	0.068	0.068	0.140	0.140	0.690	0.068
Very dry year 90%	0.930	1.520	1.520	1.030	0.850	0.160	0.032	0.02	0.032	0.460	0.46	0.230	0.020
Excluding dry year 95 %	2.90	3.540	2.47	0.730	0.28	0.120	0.032	0.000	0.035	0.05	0.075	0.24	0

The coefficients calculated for the respective sections yielded the following distributions of the minimum annual discharge – Table 8-28.

TABLE 8-28: DISTRIBUTION OF MINIMUM RUNOFF IN M³/S BY MONTH

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
Biala River before the confluence with the Arpadere River, K_r = 0.53743													
Average year 50 %	1.530	1.049	1.129	1.758	1.319	0.282	0.066	0.059	0.063	0.063	0.086	0.673	0.059

Dry year 75%	0.752	2.117	1.682	0.704	0.150	0.037	0.037	0.037	0.037	0.075	0.075	0.371	0.037
Very dry year 90%	0.500	0.817	0.817	0.554	0.457	0.086	0.017	0.01	0.017	0.247	0.247	0.124	0.011
Excluding dry year 95%	1.559	1.903	1.327	0.392	0.15	0.064	0.017	0.000	0.019	0.027	0.04	0.129	0.000
The Byala River after the confluence with the Arpadere River, K_r = 0.72563													
Average year 50%	2.066	1.416	1.524	2.37	1.781	0.380	0.089	0.08	0.086	0.086	0.116	0.909	0.080
Dry year 75%	1.016	2.859	2.271	0.951	0.203	0.049	0.049	0.049	0.049	0.102	0.102	0.501	0.049
Very dry year 90%	0.675	1.103	1.103	0.747	0.617	0.116	0.023	0.015	0.023	0.334	0.334	0.167	0.015
Excluding dry year 95%	2.104	2.569	1.792	0.53	0.203	0.087	0.023	0.000	0.025	0.036	0.054	0.174	0
Biala River after the confluence with the Arpadere River, excluding the Yurendere River, K_r = 0.71805													
Average year 50%	2.04	1.401	1.508	2.349	1.763	0.376	0.088	0.079	0.085	0.085	0.115	0.90	0.079
Dry year 75%	1.005	2.829	2.248	0.941	0.201	0.049	0.049	0.049	0.049	0.101	0.101	0.495	0.049
Very dry year 90%	0.668	1.091	1.091	0.740	0.610	0.115	0.023	0.014	0.023	0.330	0.330	0.165	0.014
Excluding dry year 95%	2.082	2.542	1.774	0.524	0.201	0.086	0.023	0.000	0.025	0.036	0.054	0.172	0
Arpadere River before flowing into the Yuren Dere River, K_r = 0.17114													
Average year 50%	0.	0.334	0.359	0	0.420	0.09	0.021	0.019	0.02	0.02	0.027	0.214	0.019
Dry year 75%	0.240	0.674	0.536	0.224	0.048	0.012	0.012	0.012	0.012	0.024	0.024	0.118	0.012
Very dry year 90%	0.159	0.260	0.260	0.176	0.145	0.027	0.005	0.003	0.005	0.079	0.079	0.039	0.003
Excluding dry year 95%	0.496	0.606	0.423	0.125	0.048	0.021	0.005	0.00	0.006	0.009	0.013	0.041	0.00
Yuren Dere River, K_r = 0.00766													
Average year 50%	0.02	0.015	0.016	0.	0.019	0.004	0.001	0.001	0.001	0.001	0.001	0.01	0.001
Dry year 75%	0.011	0.03	0.024	0.01	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.005	0.001
Very dry year 90%	0.007	0.012	0.01	0.008	0.007	0.001	0.00	0.00	0.000	0.004	0.004	0.002	0.00
Excluding dry year 95 %	0.022	0.027	0.019	0.006	0.002	0.001	0.00	0.00	0.00	0.00	0.001	0.002	0
Arpadere River after merging with the Yuren Dere River, K_r = 0.17862													
Average year 50 %	0.509	0.	0.375	0.584	0.439	0.094	0.022	0.02	0.021	0.021	0.029	0.224	0.020
Dry year 75%	0.25	0.704	0.559	0.234	0.05	0.012	0.012	0.012	0.012	0.025	0.025	0.123	0.012
Very dry year 90%	0.166	0.272	0.272	0.184	0.152	0.029	0.006	0.004	0.006	0.082	0.082	0.041	0.004
Excluding dry year 95%	0.51	0.632	0.441	0.130	0.05	0.021	0.006	0.00	0.006	0.009	0.013	0.043	0.00
Arpadere River before flowing into the Byala River, K_r = 0.18802													
Average year 50%	0.53	0.367	0.395	0	0.462	0.099	0.023	0.021	0.022	0.022	0.030	0.236	0.021
Dry year 75%	0.263	0.741	0.589	0.246	0.053	0.013	0.013	0.013	0.013	0.026	0.026	0.130	0.013
Very dry year 90%	0.175	0.286	0.286	0.194	0.160	0.03	0.006	0.004	0.006	0.086	0.086	0.043	0.004
Excluding dry year 95 %	0.545	0.666	0.464	0.137	0.053	0.023	0.006	0.00	0.007	0.009	0.014	0.045	0
Arpadere River before flowing into the Byala River, excluding the Yurendere River, K_r = 0.18056													
Average year 50 %	0.514	0.35	0.379	0.591	0.443	0.095	0.022	0.02	0.021	0.021	0.029	0.226	0.020

Dry year 75%	0.253	0.711	0.565	0.237	0.051	0.012	0.012	0.012	0.012	0.025	0.025	0.125	0.012
Very dry year 90%	0.168	0.274	0.274	0.186	0.153	0.029	0.006	0.004	0.006	0.083	0.083	0.042	0.004
Excluding dry year 95%	0.524	0.639	0.446	0.132	0.051	0.022	0.006	0.00	0.006	0.009	0.014	0.043	0.00

9 Sediment regime of the Yuren Dere River

Since there is no data on the sediment regime of the Byala River, the results of observations made on the neighbouring Krumovitsa River at HMS 61550, near the village of Gorna Kula, were used as an analogue for determining the sediments in the Yuren Dere River. Observations of floating sediments and river turbidity were also made at this point during the period 1958-1983. The data from these observations can be used to determine the amount of sediments deposited in neighbouring rivers in the region that have similar characteristics. Table 8-29 shows the annual sediment quantities for the period from 1960 to 1983.

The table shows the annual amount of sediment passing through the HMS weir, as well as the sediment discharge module. The average values for the period are also determined.

Due to the similar values of the average slope of the Krumovitsa River at HMS 61550, which is 19.641%, and the average slope of the Yuren Dere River, it can be assumed that the average sediment module obtained for the Krumovitsa River will be valid for the section of the Yuren Dere River up to its confluence with the Arpadere River. With this assumption, the following values are obtained for the characteristics of the sediment discharge, as shown in Table 8-30. Since there is no data on bottom sediments, which mainly move during "high" waves, it is assumed that their volume is 25% of the volume of floating sediments, a percentage accepted in the construction of dam walls.

TABLE 9-1: SEDIMENT QUANTITIES IN THE KRUMOVITSA RIVER NEAR GORNA KULA

Year	Average monthly sediment loads, kg/s												Average annual sediment load, kg/s	Sediment discharge	Sediment module	Average annual turbidity
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	kg/s	.10g t/year	t/km2/year	g/m
1958	3.940	39.300	2,140	4,410	1,270	1,180	0.006	0.004	0.004	0.070	0.350	4.040	4.730	149.00	300	567,000
1959	134,000	0.092	0.054	0.120	5,400	13,400	1.56	0.003	0.002	0.004	19.500	14,200	15.7	495	994,000	3,811,000
1960	170,000	1,030	0.21	0.17	0.12	64,800	0.093	0.002	0.002	0.001	8.310	12.90	21.5	679.882	1366.322	2,240,000
1961	0.640	4,570	0.051	3.00	9.970	0.130	0.011	0.003	0.004	0.005	0.02	6.18	2.05	64.649	129.921	340,000
1962	0.060	5.950	60,500	1,320	0.41	0.004	3.330	0.12	0.130	112.000	11	24,300	18,300	577,109	1,159,785	1,512,000
1965	3,880	9,250	2,380	0.510	9.640	0.800	5.000	0.00	0.00	0.007	0.15	41,700	6.1	192.37	386,595	656,000
1966	27,200	0.330	15,700	2,360	7,880	6.110	0.520	3,260	4,170	12,100	92.80	56,300	19,100	602,338	1,210,486	1,540,000
1968	22,000	21,600	0.086	0.028	0.01	0.004	0.003	0.540	0.089	0.013	7.49	3.020	4.570	144.514	290,423	738,000
1969	13,800	4,940	9,770	3,270	0.006	0.038	0.350	0.130	3.640	0.23	5.240	143.00	15,400	485,654	975,994	1,020,000
1970	14,700	7,170	14,600	6,790	9,400	0.023	4.310	0.009	0.006	60.600	2.060	56,400	14.7	463,579	931,630	1,455,000
1971	10,600	8,460	24,800	0.65	4,270	3,830	0.510	0.180	2.270	2.800	17.10	0.420	6.320	199,308	400,538	585,000
1972	0.840	20,000	1,020	2,750	15,200	1,850	1,370	12,600	0.490	28,600	0.087	0.027	7,070	223,570	449,297	1172
1973	4,100	65,500	24,400	3,870	0.47	0.990	0.580	0.002	0.130	7.760	0.079	15.30	10.3	324.821	652,775	1373
1974	0.042	9,900	3,340	0.750	1.20	0.180	2.670	0.010	1.70	4.210	18.10	40,700	6,900	217,598	437,296	1,423,000
1975	1,280	0.40	3,020	1,410	4.250	0.590	11,900	13,600	0.014	7.040	0.130	5.810	4.120	129.928	261,110	690,000
1976	1,060	4,750	0.067	0.47	0.21	2.200	0.240	6.790	0.045	7.670	6.480	17.80	3,980	125,857	252,928	740,000
1977	15,300	71,300	0.430	0.330	0.830	0.890	0.290	0.003	2.740	0.46	0.510	0.890	7.830	246.927	496,236	1179.00
1978	1,300	11,400	2,120	7,620	1,600	2,300	0.055	0.002	7.580	0.096	2.550	2.89	3.290	103.753	208,508	462,000
1979	40,300	35,500	0.210	0.690	17.40	2.350	0.470	0.220	0.170	1.380	11.00	7.370	9.760	307,791	618,552	850,000
1980	16,300	0.610	0.610	1,820	1.710	7.730	0.260	0.01	0.003	2.240	17.900	16.8	5.520	174,556	350,795	495,000
1981	22,500	14,600	16,200	0.360	2,340	0.540	0.140	0.077	0.79	1.050	1.120	11.50	5.88	185,432	372,652	576,000
1982	1,790	3,140	1,140	2,010	0.083	0.140	0.580	0.1	0.022	0.038	18.1	54.50	6.8	214,445	430,958	980,000
1983	0.190	28,000	3,660	0.26	0.24	30,300	2,950	0.14	0.15	0.077	0.400	4.490	5.90	186.062	373,920	904,000
Max	**170,000**	**71,300**	**60,500**	**7,620**	**17,400**	**64,800**	**11,900**	**13,600**	**7,580**	**112,000**	**92,800**	**143,000**	**21,500**			
Average	**17,518**	**15,638**	**8,777**	**1,926**	**4.154**	**5,990**	**1,697**	**1,800**	**1,150**	**11,827**	**10,506**	**24,871**	**8,828**	**278,403**	**559,491**	**996,667**

Min	**0.042**	**0.330**	**0.051**	**0.028**	**0.006**	**0.004**	**0.003**	**0.00**	**0.00**	**0.001**	**0.02**	**0.027**	**2.05**			

TABLE 9-2: CHARACTERISTICS OF THE SEDIMENT DISCHARGE OF THE YURENDERE RIVER BEFORE ITS CONFLUENCE WITH THE ARPA DERE RIVER

No	Characteristics	Measure	Value
1	Catchment area	km	3.5
2	Sediment module of floating sediments	t/km2/year	559.41
3	Annual sediment load of floating sediments	t/year	1957.935
4	Sediment module – bottom sediments 25% of floating sediments	t/km2/year	139,853
5	Annual sediment quantity of bottom sediments	t/year	489,484
6	Volume weight of sediment deposits	t/m3	1.5
7	Volume of annual sediments	m3/year	326.322

10 Conclusions

Based on the available data, the hydrographic characteristics of the catchment area, the average annual runoff, the minimum water quantities and the maximum design water quantities in the Biala River, the Arpa Dere River and its tributary, the Yuren Dere River, are as follows:

10.1 Biala River before the confluence with Arpa Dere

10.1.1 Hydrological characteristics

- Catchment area – 208.56 km^2 ;
- Average altitude of the catchment area – 499.52 m;

10.1.2 Average annual discharge

- Runoff module – 14.803 l/s/km^2;
- Runoff rate – 3.087 m^3/s;
- Annual discharge – 97.364 million m^3 ;

10.1.3 Minimum water quantities

- Eco-minimum – 0.309 m^3/s;
- Actual minimum water quantity with 90% reliability by analogy from station HMS62800 on the Byala River near the village of D. Lukovo – 0.011 m^3/s;

10.1.4 Maximum design water quantities

- Maximum water quantity with 0.1% reliability, $Q_{0.1\%}$ = 1309.139 m^3 /s;
- Maximum water quantity with 1% reliability, $Q_{1\%}$ = 804.764 m^3 /s;
- Maximum water quantity with 5% reliability, $Q_{5\%}$ = 537.543 m^3 /s;

10.2 The Byala River after the confluence with the Arpadere River

10.2.1 Hydrological characteristics

- Catchment area – 281.85 km^2;
- Average altitude of the catchment area – 498.51 m;

10.2.2 Average annual discharge

- Runoff module – 14.787 l/s/km^2;
- Runoff rate – 4.168 m^3/s;
- Annual discharge – 131.432 million m^3 ;

10.2.3 Minimum water quantities

- Eco-minimum – 0.417 m^3/s;
- Actual minimum water quantity with 90% reliability by analogy from station HMS62800 on the Byala River near the village of D. Lukovo – 0.015 m^3/s;

10.2.4 Maximum design water quantities

- Maximum water quantity with 0.1% reliability, $Q_{0.1\%}$ = 1648.653 m^3 /s;
- Maximum water quantity with 1% reliability, $Q_{1\%}$ = 1017.234 m^3 /s;
- Maximum water quantity with 5% reliability, $Q_{5\%}$ = 681.347 m^3 /s;

10.3 The Byala River after the confluence with the Arpadere River, excluding the Yuren Dere River

10.3.1 Hydrological characteristics

- Catchment area – 278.35 km^2;
- Average altitude of the catchment area – 500.40 m;

10.3.2 Average annual discharge

- Runoff module – 14.818 l/s/km^2;
- Outflow rate – 4.125 m^3 /s;
- Annual outflow – 130.071 million m^3;

10.3.3 Minimum water quantities

- Eco-minimum – 0.417 m^3 /s;
- Actual minimum water quantity with 90% reliability by analogy from station HMS62800 on the Byala River near the village of D. Lukovo – 0.014 m^3 /s;

10.3.4 Maximum design water quantities

- Maximum water quantity with 0.1% reliability, $Q_{0.1\%}$ = 1632.955 m^3 /s;
- Maximum water quantity with 0.1% reliability, $Q_{0.1\%}$ = 1007.393 m^3 /s;
- Maximum water quantity with 0.1% reliability, $Q_{0.1\%}$ = 674.636 m^3 /s;

10.4 Arpadere River before the confluence with the Yuren Dere River

10.4.1 Hydrological characteristics

- Catchment area – 65.08 km^2;
- Average altitude of the catchment area – 517.90 m;

10.4.2 Average annual runoff

- Runoff module – 15.106 l/s/km^2;
- Runoff rate – 0.983 m^3/s;
- Annual discharge – 31.002 million m^3 ;

10.4.3 Minimum water quantities

- Eco-minimum – 0.098 m^3/s;
- Actual minimum water quantity with 90% reliability by analogy from station HMS62800 on the Byala River near the village of D. Lukovo – 0.003 m^3/s;

10.4.4 Maximum design water quantities

- Maximum water quantity with 0.1% reliability, $Q_{0.1\%}$ = 536.670 m^3 /s;
- Maximum water quantity with 1% reliability, $Q_{1\%}$ = 325.214 m^3 /s;
- Maximum water quantity with 5% reliability, $Q_{5\%}$ = 214.912 m^3 /s;

10.5 R. Yuren Dere

10.5.1 Hydrological characteristics

- Catchment area – 3.50 km^2 ;
- Average altitude of the catchment area – 347.98 m;

10.5.2 Average annual runoff

- Runoff module – 12.530 l/s/km^2;
- Runoff rate – 0.044 m^3/s;
- Annual discharge – 1.383 million m^3 ;

10.5.3 Minimum water quantities

- Eco-minimum – 0.0044 m^3/s;
- Actual minimum water quantity with 90% reliability by analogy from station HMS62800 on the Byala River near the village of D. Lukovo – 0.0001 m^3/s;

10.5.4 Maximum design water quantities

- Maximum water quantity with 0.1% reliability, $Q_{0.1\%}$= 57.246 m^3/s;
- Maximum water quantity with 1% reliability, $Q_{1\%}$ = 33.466 m^3 /s;
- Maximum water quantity with 5% reliability, $Q_{5\%}$ = 21.528 m^3 /s;

10.5.5 Volume of sediments

- Annual sediment quantity – 1957.935 t/year
- Annual amount of bottom sediments – 489.484 t/year
- Annual volume of bottom sediments – 326,323 m^3 /year

10.6 Arpadere River after the confluence with the Yuren Dere River

10.6.1 Hydrographic characteristics

- Catchment area – 68.58 km²
- Average altitude of the catchment area – 509.23 m;

10.6.2 Average annual runoff

- Runoff module – 14.962 l/s/km²;
- Runoff rate – 1.026 m³/s;
- Annual discharge – 32.357 million m³ ;

10.6.3 Minimum water quantities

- Eco-minimum – 0.103 m³/s;
- Actual minimum water quantity with 90% reliability by analogy from station HMS62800 on the Byala River near the village of D. Lukovo – 0.004 m³ /s;

10.6.4 Maximum design water quantities

- Maximum water quantity with 0.1% reliability, $Q_{0.1\%}$= 558.602 m³/s;
- Maximum water quantity with 1% reliability, $Q_{01\%}$ = 338.723 m³ /s;
- Maximum water quantity with 5% reliability, $Q_{5\%}$ = 223.946 m³ /s;

10.7 Arpadere River before flowing into the Byala River

10.7.1 Hydrological characteristics

- Catchment area – 73.29 km²;
- Average altitude of the catchment area – 495.64 m;

10.7.2 Average annual discharge

- Runoff module – 14.740 l/s/km²;
- Runoff rate – 1.080 m³/s;
- Annual discharge – 34.069 million m³ ;

10.7.3 Minimum water quantities

- Eco-minimum – 0.108 m³/s;
- Actual minimum water quantity with 90% reliability by analogy from station HMS62800 on the Byala River near the village of D. Lukovo – 0.004 m³/s;

10.7.4 Maximum design water quantities

- Maximum water quantity with 0.1% reliability, $Q_{0.1\%}$ = 587.781 m³ /s;
- Maximum water quantity with 1% reliability, $Q_{1\%}$ = 356.707 m³ /s;
- Maximum water quantity with 5% reliability, $Q_{5\%}$ = 235.981 m³ /s;

10.8 Arpadere River before flowing into the Byala River, excluding the Yuren Dere River

10.8.1 Hydrological characteristics

- Catchment area – 69.79 km²;
- Average altitude of the catchment area – 503.05 m;

10.8.2 Average annual runoff

- Runoff module – 14.861 l/s/km² ;
- Runoff rate – 1.037 m³ /s;
- Annual discharge – 32.707 million m³ ;

10.8.3 Minimum water quantities

- Eco-minimum – 0.104 m³/s;
- Actual minimum water quantity with 90% reliability by analogy from station HMS62800 on the Byala River near the village of D. Lukovo – 0.004 m³/s;

10.8.4 Maximum design water quantities

- Maximum water quantity with 0.1% reliability, $Q_{0.1\%}$ = 566.165 m³ /s;
- Maximum water quantity with 1% reliability, $Q_{1\%}$ = 343.383 m³ /s;
- Maximum water quantity with 5% reliability, $Q_{5\%}$ = 227.065 m³ /s;

11 Analysis of the possibility of water abstraction from the Arpadere River at the pumping station for water supply to the village of Rozino

The possibility of water abstraction in the area of the water supply station for the village of Rozino is determined by the guarantee of the minimum water supply (ecological minimum), which for the Arpadere River before the confluence with the Yuren Dere River is 0.104 m³ /s – 10% of the average annual flow (the flow rate standard) and guaranteeing the water supply to the village.

The village of Rozino is supplied with water from the pumping station at Arpadere with a pump flow rate of 10 l/s, which operate until the reservoir above the village is filled or until the volume of the river lagoon at the pumping station is exhausted (during the dry season in summer).

The average water consumption of the flotation plant at the Rozino mine is 8 l/s. Water supply for the plant is planned to be provided by a pumping station, which will pump water at the following rate: 1 pump – 50 l/s, 2 pumps - 100 l/s, and will push the water to balancing reservoirs on the site.

Since in summer the water flow rates in average, average dry and very dry years are lower than the eco-minimum calculated above, it is necessary to define when the PS at the site can pump water at full capacity, when at partial capacity and when it cannot.

The following table shows the water pumping possibilities during the different months of an average year.

TABLE 11-1: BALANCE OF WATER QUANTITIES IN THE ARPADERE RIVER AT THE PS IN ROZINO, BEFORE THE REN DERE

Water quantities / Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Free river flow at average year p=50%, m3/s	0.514	0.35	0.379	0.591	0.443	0.095	0.022	0.02	0.021	0.021	0.029	0.226
Eco-minimum, m3/s	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104
Maximum water use for the Tintyava deposit, m3/s	0.10	0.10	0.10	0.10	0.10	0.008	0.008	0.008	0.008	0.008	0.008	0.100
Maximum water use for the village of Gugutka, m3/s	0.01	0.01	0.01	0.01	0.01	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Excess water in the river above the eco-minimum, m3/s	**0.3**	**0.138**	**0.165**	**0.37**	**0.229**	**-0.027**	**-0.100**	**-0.102**	**-0.101**	**-0.101**	**-0.093**	**0.01**

It shows that the PS at Arpadere can draw at full capacity during January-May and December, thus ensuring the eco-minimum and water supply to the village of Rozino. During the months of June-November, the flow rates through the river are lower than the eco-minimum (10% of the normal flow rate).

During these months, the pumping station can only draw water on days with rainfall that provides a momentary flow in the river above 164 l/s or 0.164 m3/s – the sum of the ecological minimum, the maximum amount for the village of Rozino and the capacity of one pump – 50 l/s from the pumping station at the mine. This water quantity is established when the PS pump is not switched off continuously, as the volume of the water-pumping lagoon on the river at the water intake – about 50 $m^{(3)}$ –does not allow a pump with a flow rate of 50 l/s to operate normally.

Water abstraction for the Rozino mine will not affect the communal and hygienic qualities of the water source, as mainly surface water will be abstracted, the qualities of which do not change.

The introduction of limited water use for the Rozino mine only during heavy rainfall between June and November, with a guaranteed river flow of over 164 l/s, will not create a shortage of water supply for the villages of Rozino and Gugutka, as the water supply system for the village of Gugutka draws water from the terrace of the Byala River, which is not connected to the waters of the Arpadere aquifer.

The abstraction of surface water from Arpadere will not lead to a deterioration in the chemical and physical condition of surface and groundwater in the area. The water accumulated during the spring-winter season at the site of the deposit will not come into contact with groundwater – it will be stored in isolated reservoirs.

Water abstraction will mainly take place during the winter-spring period of high water flow. The volumes drawn – 252,288 m3/year with an average daily water consumption of 8 l/s – are less than 1% of the total average multi-year flow in the Arpadere River and less than 1.5% of the flow even during the high-water period.