Analysis of flood and landslide risks for Montenegro

(with an emphasis on the catchment area of Bojana River and Skadar Lake)

Podgorica, November 2018

CONTENT:

1. POSITION AND SOCIAL CHARACTERISTICS OF MONTENEGRO

Montenegro is the Adriatic-Mediterranean, Dinaric country of the Southeastern Europe, situated between 41º39' and 43º32' north latitude and 18º26 'and 20º21' east longitude. On the west it borders Croatia (14 km of land border) and Bosnia and Herzegovina (225 km), on the north and northeast Serbia (203 km), the southeast and east Albania (172 km) and the southwest the Adriatic Sea. The length of the sea coast is 293.5 km. The surface of Montenegro is 13 812 km2 and the surface of the marine aquatic area is about 2540 km2.

Display 1. Position of Montenegro in Europe

According to the 2011 census, Montenegro has 620 029 inhabitants, 1307 settlements with a population density of 44.9 inhabitants per square kilometer. According to official estimates of the Bureau of Statistics of January 2018, Montenegro has 622 359 inhabitants. The main characteristics of the network of centers in Montenegro is the following: Podgorica as a state and Niksic as a regional center have 32% of the total population in their city zones.

According to the Law on Territorial Organization of Montenegro (*Official Gazette of Montenegro* no. 54/11, 27/13; 62/13; 12/14 and 22/17), Montenegro is divided into 24 municipalities: Nikšić 2065 km2, Podgorica 1441 km2, Pljevlja 1346 km2, Bijelo Polje 924 km2, Cetinje 910 km2, Kolašin 897 km2, Plužine 854 km2, Berane 497 km2, Bar 598 km2, Šavnik 553 km2, Danilovgrad 501 km2, Plav 486 km2, Žabljak 445 km2, Rožaje 432 km2, Mojkovac 367 km2, Kotor 335 km2, Andrijevica 283 km2, Ulcinj 255 km2, Herceg Novi 235 km2, Budva 122 km2, Tivat 46 km2, Petnjica 220 km2, Gusinje 157 km2[1] and Tuzi. Among Montenegrin municipalities there is a large disproportion in relation to surface area, population number and density –Tivat as the smallest one (46 km2) and Nikšić as the largest municipality (2 065 km2).

The Spatial Plan of Development of Montenegro defines three regions, which are distinguished according to their natural characteristics, manners of land usage and planning, economic activities and various comparative advantages for development: **1) south region** (Herceg Novi, Kotor, Tivat, Budva, Bar and Ulcinj municipalities);

[1] With the amendments to the Law on Territorial Organization of Montenegro in 2013 the following was established: the municipality of Petnjica in 2013, the municipality of Gusinje in 2014 followed by the municipality of Tuzi in 2017.

2) middle region (Capital City Podgorica, Danilovgrad, Nikšić, Tuzi and Old Royal Capital Cetinje); **3) north region** (Plužine, Petnjica, Gusinje, Šavnik, Žabljak, Pljevlja, Mojkovac, Kolašin, Bijelo Polje, Berane, Andrijevica, Plav and Rožaje municipalities).

2. NATURAL CHARACTERISTICS OF MONTENEGRO

2.1.Geological characteristics

Stratigraphic-lithological composition – the terrains of Montenegro are built by the rocks of the young Palaeozoic, Mesozoic and Cenozoic.

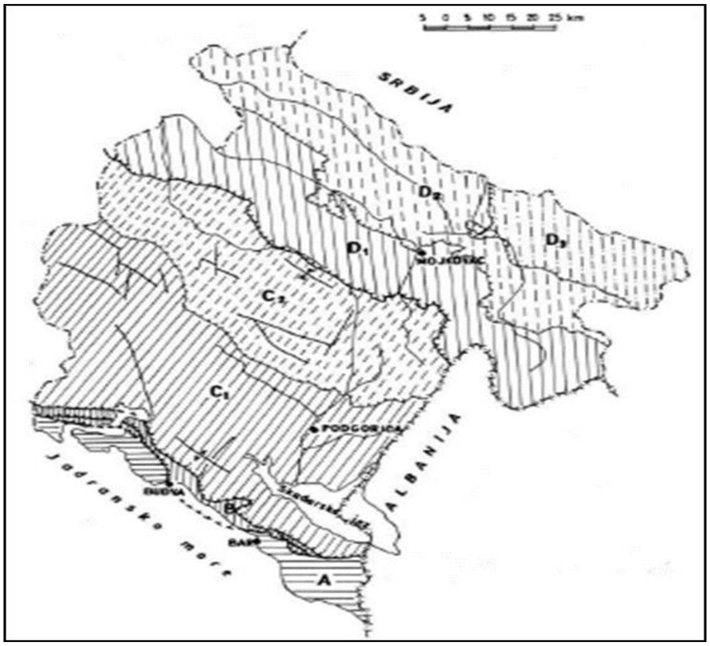
Young Paleozoic rocks are represented as more or less slate, clay-marly sandy layers and various slates with rare limestone and conglomerate lenses. These rocks are mostly a part of the northeastern composition of Montenegro.

Mesozoic rocks are represented by several known facies, among which are: carbonate, magmatic, volcanogenic-sedimentary, diabase-chert and flysch.
Carbonate facie is made of limestone and somewhat less dolomites. The rocks of this facie in the central belt of Montenegro builds a well-known geotectonic unit called the "High Karst Zone" and they may also be found in other parts of Montenegro.
Magmatic facie consists of numerous equivalents of eruptive rocks and their tuffs.
Volcanogenic-sedimentary facie is represented by cherts, tuffs, tuffites, bentonites, limestone with chert intercalation and nodules.
Diabase-chert facie consists of sedimentary, volcanic and intrusive magmatic rocks.
Flysch facie is made up of clays, marls, sandstones, limestones and transitional varieties of these lithological members with interlayers of breccias and conglomerates.

Cenozoic rocks are represented by carbonate and flysch facie of Paleogene; neogenic marine and freshwater sediments and quaternary unbound sand, gravel, larger blocks with and without clay, of glacial, fluvioglacial, limnoglacial, deluvial and alluvial origin.

2.1.1. Geotectonic composition of Montenegro

With regard to geotectonic composition of the terrain, Montenegro belongs to the southeastern Dinarides and it is characterized by a very complex tectonic structure. In the mainland of Montenegro, four structural-tectonic units are clearly defined and they are: Paraautohton, Budva-Cukali zone, High Karst and Durmitor tectonic unit. They are separated from each other by regional reverse dislocations stretching from northeast. **Paraautohton** includes coastal parts in the vicinity of Ulcinj and Boka Kotorska. It is characterized by a system of regional folds, overturned and reverse broken structures. **Budva-Cukali zone** includes a narrow belt of the Montenegrin coast from Sutorina north-west along the slopes of Orjen, Lovcen and Rumija to be continued through Albania. This tectonic unit is characterized by a system of squeezed and overturned isoclinial folds broken and separated by overthrust. **High Karst** encompasses the central and south-western parts of Montenegro, from Rumija, Lovcen and Orjen – in the southwest to Volujak, Durmitor, Semolj, Tresnjevica and Komovi in the northeast. This tectonic unit consists of two structural-tectonic units of the lower level: the *Old Montenegrin* and *Kučka Overthrust*. The first one consists of a complex anticlinorium in the Budva zone (with a number of complex and reverse broken folds) and also tectonically very complex synclinorium of the Zeta valley. Kuchka Overthrust is also made by a very complex anticline part built mainly of carbonate rocks and a syncline part – represented by Durmitor flysch. **Durmitor tectonic unit** includes the northeast parts of Montenegro. With relation to tectonics, special tectonic blocks are separated by flysch sediments, then diabase-chert formation and Paleozoic clastics. In the Neogene period, vertical tectonic movements caused the formation of basins and depressions in the area of this unit, in which lake sediments with coal were formed.



Display 2: Main tectonic units on the territory of Montenegro
(A – Paraautohton, B – Budva-Cukali zone, C – High Karst, C1 – Old Montenegrin tectonic unit, C2 – Kucka tectonic unit, D – Durmitor tectonic unit, D1 – Sinjajevina, Durmitor, Komovi tectonic unit, D2 – Cehotina tectonic unit; D3 – Lim tectonic unit).

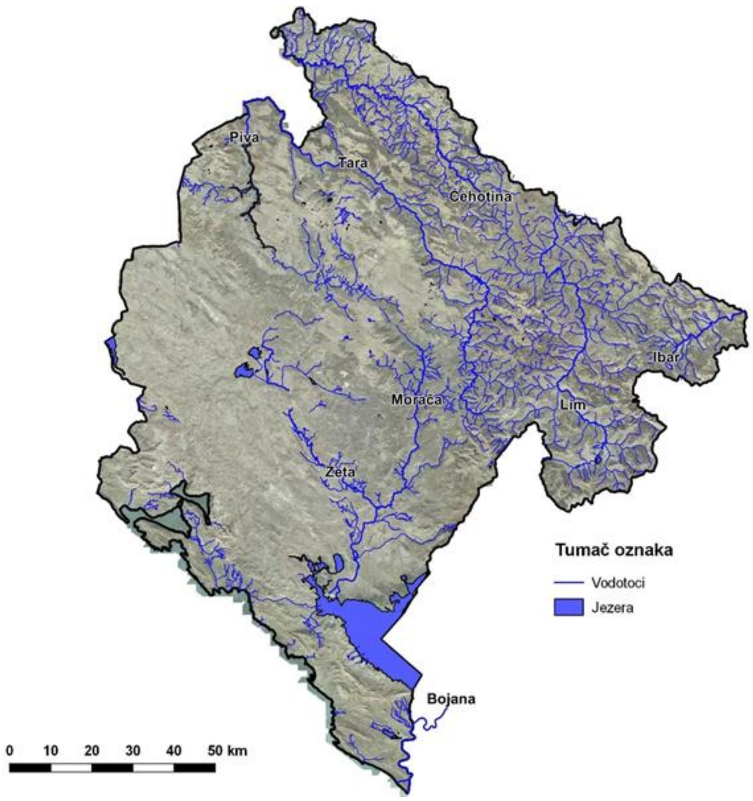
Neotectonics – Contemporary situation – the relief of the territory of Montenegro is largely shaped by neotectonic movements which have continued up to these days. These movements belong to the Alpine tectogenesis which began with the Montenegrin orogenic phase in the terrains of Montenegro and continued through the entire Mesozoic and Cenozoic with several orogenic phases which left visible traces. Among these orogenic phases, the laramide orogenic phase was the strongest and with the highest consequences. In the terrain of Montenegro, neogenic movements left, among other things, freshwater and marine Miocene sediments, numerous folds and disorders which form the basis (karst fields). These movements continue to this day, manifesting in earthquakes of intensity over 5o of Richter scale and movements of large blocks (and their denivelation) in the part of the southeastern Dinarides to which the territory of Montenegro belongs. Total knowledge on these neogenic movements indicates that, generally speaking, the territory of Montenegro is rising in level, except for Skadar Lake basin and a part of the basin of the Adriatic Sea opposite to it which are descending.

2.2.Hydrological characteristics

The main feature of the hydrography of Montenegro is the existence of two approximately equal catchment areas: the Black Sea and Adriatic Sea. The Adriatic basin covers cca 47.5% of the Republic, while the Black Sea covers around 52.5%.

The specificity is that the highest mountain peaks and wreaths are found within the Black Sea basin, while the watershed between the Black Sea and Adriatic basin are to the south compared with them. Generally, both catchment areas are rich in water, even according to the worldwide standards. However, a significant part of the territory of Montenegro belongs to the area of continental karst, which is without permanent effluents, with numerous sinkholes in which waters drain and then continue underground towards the watercourses or the sea.

Important rivers (main surface watercourses) of the Black Sea basin are: Piva, Tara, Cehotina, Lim, as well as watercourses from the Drina basin, and Ibar as a watercourse from the Zapadna Morava basin. Significant rivers (main surface watercourses) of the Adriatic basin are: Moraca, Zeta, Rijeka Crnojevica and Cijevna, which all gravitate towards Skadar Lake, from where they flow into the Bojana River and continue towards the Adriatic Sea. In the graph below the hydrographic network of Montenegro is displayed.



Display 3: Hidrographic network of Montenegro

Continental karst watercourses drain underground through sinkholes and efflux in the Adriatic and Black Sea river basins or under the sea surface. Part of these waters goes underground to neighboring territories (Trebišnjica, Konavle). The largest number of surface watercourses in Montenegro relates to torrents.

For the hydrography of Montenegro, artificial lakes are of great importance which can be found on: Piva, Cehotina, Zeta (Nikšićko polje) and Grahovo River (Grahovo). Part of the territory of the Republic was flooded with the construction of an artificial lake of the Hydropower plant Trebišnjica.

Natural lakes in Montenegro are relatively numerous, with the largest being located in the lowland areas of the southern part of the territory. Skadar Lake, formed in a spatial depression, is at the same time the largest lake in the Balkans. Three fifths of the surface of Skadar Lake belongs to Montenegro. This lake has an area of about 600 km2 at the highest water level of about 10.44 mnm. Šasko Lake is the second largest in Montenegro and it is located between Skadar Lake, Bojana River and the Adriatic Sea. Black, Plavsko and Biogradsko Lake are also nature reserves, as typical examples of glacial lakes. All these lakes, except Plavsko Lake, are located in national parks. In addition to these, there are also many smaller lakes, which are of glacial or karst origin.

The Adriatic Sea, between Montenegro and Italy, is around 200 km width and it forms part of the South Adriatic basin, in which the greatest depths of the Adriatic Sea are recorded – cca 1400 m. The total length of the coastline of Montenegro is around 300 km. About 80% of the coast is stony, with high water depths usually recorded along the coast, while the rest of shore is shallow with sand and gravel bottom.

The average ebb and flow amplitude is around 23 cm. The Adriatic Sea is a relatively warm sea. The dominant direction of sea currents is parallel with the sea shore towards northwest. Salinity of the water of the South Adriatic (38.6%o) is slightly lower than the average for waters of the Mediterranean Sea (39% o).

2.3.Climate characteristics

Montenegro is a very complex climate area characterized by marked variations in time and space due to its geographical location, vicinity of the sea, the morphological forms – mountain chains which prevent deeper penetration into the land of maritime influences as well as air currents.

There are two dominant influences on the climate of Montenegro. The first is the so-called Genovian cyclone, which causes high precipitation, and the other is the so-called Siberian anticyclone, which causes extreme values of air pressure and very low temperatures.

Coastal area and Zetsko-Bjelopavlicka plain are areas with the Mediterranean climate which is characterized by long, hot and dry summers and relatively mild and rainy winters. Places in the valleys, such as Podgorica, Danilovgrad and others, have lower temperatures in January compared to coastal ones in approximately the same latitude, whereas they have a slightly higher temperature in the summer. Zeta valley is particularly characterized by warm summers, and in this area the absolute maximum air temperature in Montenegro is registered with the highest average number of tropical days.

Karst fields are significantly sever in climate and they are located at higher altitudes, 20 to 60 km from the Adriatic. In winter, during anticyclonic situations, cold air is deposited in these fields, descending on the sides of the surrounding mountains, while in the summer, the ground air layer is significantly warmed up in them, resulting in an annual increase in air temperature fluctuations.

The only available data which analyzes a sufficiently long period on the basis of which climatological characteristics can be defined to be used as relevant in the preparation of the Spatial Plan of Montenegro until 2020, are for the period 1961-1990. These data are verified by the World Meteorological Organization as parameters which define the climatological characteristics of the specified area.[2]

Bearing in mind that precipitation represents the basic climate parameter in study and definition of floods, and to the large extent in the conditions of formation of landslides and other instability of the terrain, we considered it necessary to present the basic characteristics of precipitation in the area of Montenegro. The average annual rainfall due to orographic impacts is very uneven and ranges from about 800 l/m2, in the far north to about 5000 l/m2 in the far southwest (the slopes of the Orjen Mountain). Cyclone activities in the Mediterranean, i.e. wet

[2] WATER MANAGEMENT STRATEGY OF MONTENEGRO, Podgorica, January 2017

streams from the southern quadrant in the winter and orographic obstacles significantly affect the fact that the far south, southwest and southeast parts of Montenegro have considerably higher annual precipitation compared to the far northern parts. On the slopes of Orjen, during record years, cca 7000 l/m2 may fall, which makes this area the rainiest region of Europe.

As precipitation intensity is a particularly important factor in the area of flooding and the occurrence of terrain instability, the following table shows the calculated maximum daily precipitation for probability of occurrence. For a return period of 100 years (1% probability of occurrence), the calculated maximum daily precipitation ranges from 110 mm/day (continental part) to 480 mm/day (in the hinterland of the Adriatic Sea).

Station	Period	1%	2%	5%	10%	20%	50%
Bar	49-96	212	191	161	139	116	83
Berane	50-96	110	100	87	76	65	49
Bijelo Polje	51-96	145	127	104	87	70	48
Budva	49-96	237	210	174	146	118	78
Velimlje	70-96	205	184	157	136	114	84
Virpazar	70-96	214	205	192	180	166	138
Grahovo	53-96	351	328	296	270	240	190
Danilovgrad	70-96	250	234	211	192	171	136
Žabljak	54-96	199	180	153	133	111	80
Kolašin	49-96	258	233	198	172	144	105
Kotor	77-96	196	184	167	152	136	108
Krstac	71-96	166	155	140	127	113	91
Nikšić	49-96	264	240	206	180	151	109
Plav	70-96	193	164	127	102	79	56
Pljevlja	49-96	113	100	82	69	57	41
Podgorica	49-96	201	179	151	130	109	82
Rožaj	70-96	200	162	116	85	60	39
Tivat	70-96	187	173	154	139	122	96
Ulcinj	51-96	173	160	142	127	110	83
Herceg Novi-Igalo	49-96	307	277	235	203	168	118
Cetinje	49-96	293	279	259	241	220	182
Crkvice	53-96	485	452	406	368	327	258

3. HAZARD ANALYSIS – FLOODS

3.1. Floods – concept, types, causes of floods and frequency

Heavy rainfall, long-lasting heavy rains for several days in succession, combined with the melting of existing snow in mountainous regions in a certain period of the year are meteorological phenomena which are characteristics of the territory of Montenegro. Heavy rain series in extreme cases combined with snow melting or no snow (due to high temperatures) in mountainous areas in the cold part of the year, lead to a sudden rise in water levels in rivers and lakes (especially Skadar Lake) with extreme hydrological parameters, after which there are floods which cause material damage and endanger normal functioning of the infrastructure systems. Drastic examples are floods in 2010 and 2011 reaching half-century records for the status of water levels on the rivers, while Skadar Lake reached a historic maximum of water level of 10.44 mnv. In this situation, historically recorded rain series were noted – precipitation quantities. Three rainy series in November led to cca 1000 lit/ m2 which fell in some places.

Floods on the territory of Montenegro manifest differently depending on the characteristics of watercourses causing the floods.

For the territory of Montenegro, two categories of floods are characteristic: the first category includes floods which are result of abundant rain series of a few days with a large amount of rainfall, which in extreme cases can reach about 500~1000 lit/m2, covering larger space. They connect with river systems and lakes in such a way that water levels have extremely high values; they rarely occur, and when they occur, certain thresholds are reached and exceeded. The second category are typical meteorological floods (flash floods) which are local; they are more likely to occur and they are related to torrents and urban environments or a certain fragment of space. They are of short time span, but can be very aggressive, destructive and difficult to foresee and locate in time and space, because they are related to the formation of storm-thunder clouds which are very dynamic and capture only a certain locality from which, in a very short time, an abundant amount of rain is excreted, which in only a few hours can reach over 100 lit/m2 and thus very often exceeds the thresholds.

Along the valleys of most river courses, short-term waves of high waters endanger settlements, industrial plants and agricultural land. These courses are characterized by large longitudinal inclination, high velocities in case of flood waves, as well as significant amount of suspended and traction sediment. Canyons, sometimes very deep, with extensions – valleys can be found along the flow, where settlements, industrial facilities as well as traffic infrastructure are located. Agricultural areas are located in these valleys, although relatively modest, they have a great importance for agricultural production, since the total resources of agricultural land of Montenegro are very limited. They can be significant due to such a concentration of goods in the valleys and damage caused by floods, even of relatively smaller scope. Also, the consequences of floods along these courses are accompanied by changes in the riverbed, in particular with relation to its meandering. That is why the flooded surfaces change their position and size.

In the area of Skadar Lake, significant agricultural land was flooded for a long period of time, and the settlements along the edge of Skadar Lake are endangered. Considering the duration of floods, specific marshy areas have been established in this zone. Also, the high waters of Bojana also endanger the values in the area of Ulcinj field.

Smaller torrents, some of which are relatively short and discharge directly into the sea, flood relatively narrow valleys and cause significant damage by flooding and destroying the coast. For the territory of Montenegro, it is characteristic that due to the relatively small size of courses and large falls, the precipitation regime directly reflects the formation of flood waves and terrain flooding by the torrents.

In terms of significance i.e. by the size of damage, we cannot disregard damages in larger and smaller karst fields. In this respect, the most frequent floods are in Cetinje and Niksic fields.

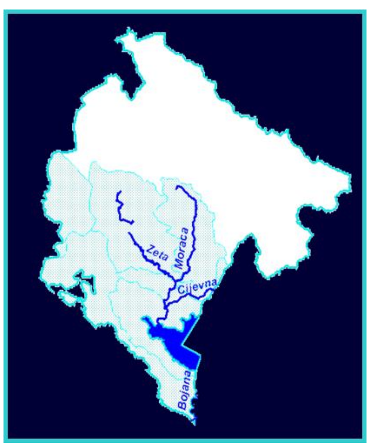
In addition to the floods which occur due to the occurrence of high waters at river courses and torrents, as well as very significant flooding caused by Skadar Lake, the occurrence of floods is caused by some specific causes as well, such as the combined effect of surface and ground waters, the effect of karst and water overflows from one underground basin into the other.

The largest floods in Montenegro since the half of the past century until now have occurred in: 1963, 1979, 1999, 2000, 2010 and 2011.

At the end of 2010, large floods have occurred caused by abundant precipitation on the territory of Albania and Montenegro in the basin of Skadar Lake and Drim and Bojana Rivers. They were manifested by flooding of the coastal part of Bojana in the municipality of Ulcinj and Skadar Lake, on the territory of Montenegro, as well as the wider zone of Shkodra in Albania. These were the largest floods since the catastrophic floods of January 1963, when the level of Skadar Lake reached the maximum recorded level of 9.86 meters. In December 2010, the highest lake level was recorded at 10.44 m.n.v. and since then the official hydrological measurements started.

3.1.1. Watercourses, lakes and reservoirs which may cause floods

In this part of the analysis, watercourses, lakes and reservoirs which may be the cause of floods in the area of the Adriatic basin (with an emphasis on the Bojana river basin) will be presented. In particular, the current situation will be analyzed, with a focus on the regulatory measures taken during the previous period.



Display 4: The Adriatic basin

Moraca River. In the past, the high waters of Moraca have endangered significant areas downstream from the exit from the canyon to the confluence into Skadar Lake. In addition, the most downstream part of the Moraca valley is flooded with waters from Skadar Lake as well. The superposition of these floods has had a very negative impact on the development of this area and the key problems have not been resolved to this day. Several facilities have been constructed in different periods along the Moraca River to protect against flooding and erosion of the coast. Unfortunately, works on protection from flooding were not performed systematically, nor to the full necessary extent.

The following embankments were performed:

- Cijevna-Vranjina embankment was constructed in 1950 on the left side of riverbed in the length of 16 000 meters. The embankment was originally envisaged as an integral part of the melioration system for the protection of Donja Zeta from floods of Moraca and Skadar Lake. Along the route of this embankment the railroad was built as well as Podgorica-Virpazar road. The construction of this embankment protects about 1 500 ha, and the frequency of flooding is here reduced. The settlements of Bistrica and Bijelo Polje are now in much more favorable situation, but the floods are not completely eliminated;
- Embankment on the right side of 3 000 meters by the village Vukovci. This embankment was built in 1952;
- Embankment on the right side of 1 500 meters by the village Ponari. This embankment was built in 1953.

In order to protect the river banks against erosion and stabilize the river bed, the following constructions were done:
- Coastal protection near village Goricani, 200 meters long. This facility was built in 1938;
- Coastal protection near village Grbavci, 200 meters long. This facility was built in 1958;
- Parallel facility near village Bijelo Polje, 170 meters long, built in 1950;
- Parallel facility near village Ponari, 200 meters long, built in 1953;
- Groyne in Lekići, 100 meters long, from 1977.

Reservoirs in Nikšić field:

Display 5: Hydropower scheme of HPP "Perućica" (flow hydroelectric power plant with water storage reservoirs)

Slano and Krupac reservoirs are built in the Zeta river basin, the largest tributary of Moraca River, which have a multiple impact on the protection of the Niksic field from floods. Due to the natural conditions which characterize this karst field, it is difficult to achieve further progress in flood protection with investment measures. Therefore, in order to reduce the damage, special attention should be paid to non-investment measures. Also, it is necessary to analyze and regulate in more detail the regime of operation of all reservoirs in the Niksic field zone.

Sitnica River. This river is the most watertight right tributary of Moraca. The flow is about 20 km and it flows into the Morača River at an altitude point of about 20 m. It dries in its lower part of the course during the dry season. For the protection against floods of the Ljeskopoljski lug, the regulation of Sitnica was carried out along around 3 kilometers. With this regulation, the level of high waters dropped by cca one meter. In this area a pond was built, so the works on melioration and area protection were no longer of its previous importance. As this pond was later abandoned, the flood protection works became again real.

Regulatory works in Ljeskopoljski Lug enabled faster discharge of high waters from the sector where intervention was carried out. Unfortunately, the downstream sector could not accept such increased flows. That is the reason why the area around the village Beri has been compromised. The main project of regulation of Sitnica River through the village Beri in 1986, regulates Sitnica in the length of 2800 meters. In 1987, the deepening of the river bed in a length of 1500 meters was performed. The work which was done did not fully protect the area from flooding.

Bojana River. For the protection of floods caused by high waters of Bojana River, the following facilities have been constructed:

- Sveti Nikola-Rec embankment in length of 6337 meters and the embankment Sutjel-Sveti Djordje of 1455 meters. These embankments protected the area of around 600 ha between Bojana and the old Solana embankment, as well as the Ulcinj field itself. After monitoring the embankment after the flood in 1963, it was concluded that Sutjel-Sveti Djordje embankment is not of a sufficient height in 40% of its length, and Sveti Nikola-Rec embankment is not of a sufficient height in 27% of its length. The embankments are not systematically maintained, they are covered with bushes and trees and it can not be said that they can perform their protective function when encountered with high waterwaves;
- Paratuk embankment was built in 1966 in the area between the embankments near Bojana and the old Bojana embankment. The embankment is 195 meters long and it divides the protected area into two parts;
- Gropat-Stodra embankment of 960 meters was built to protect Vladimir field from high waters of Bojana and it protects around 110 ha;
- Stodra-Sukobin embankment, 2900 meters long, protects around 360 ha of agricultural land in the Sukobin field from high waters of Bojana. Here, the embankment is constantly endangered by shifting of Bojana River banks.[3]

Sutorina River. In this river, unfortunately, there are no hydrological measurements that could be considered continuous. Earlier attempts to observe through the water gauge were not good due to the slowdown from the sea, so these data were rejected as unreliable. For the protection of Sutorina against floods, the regulation works were carried out at a length of 3500 meters, which included carving and stabilization of river bed, as well as the development of embankments.

Drenovstica River and Kucac. There is a regulation protecting Mrcevsko field from the high waters of Drenovstica and Kucac. Watercourses Drenmostica and Kucac are regulated watercourses in Mrčevsko field. There are no data on the measurements or observations on these watercourses.

[3] NATIONAL RESCUE AND PROTECTION PLAN IN CASE OF FLOODS, Podgorica, April 2014.

Crmnica with Orahovstica. The rivers Crmnica and Orahovstica are directly end their course into the Skadar Lake in the zone of Virpazar settlement. These are rivers that originate from the karst springs, with marked changes in flow. In the high waters of the Skadar Lake, the lower parts of the streams of these rivers are submerged by the waters of the lake.

There were no hydrological measurements and observations on the Crmnica River, the length of the stream is about 10 km and the surface of the catchment area is about 60 km2.

Rijeka Orahovstica has an area of about 80 km2, and the length of the stream is about 16 km. For a long period (since the 1990s) there are no hydrological measurements, but earlier observations have shown that the perennial value of the mean annual flow is 3.23 m3 / s. Maximum flows are about 50 m3 / s, while 100 year water is estimated at about 70 m3 / s.In the area of Crmnica, regulations of Bistrica, Orahovstica and Sutorman were done for protection against flooding of the coastal land. The works have achieved their goal in terms of protection against flooding, but they have adversely affected the levels of groundwaters due to laid out route which is too high.

Except for Sutorina River, which flows directly into the Adriatic Sea, all other watercourses belong to the hydrological complex of Skadar Lake and Bojana River.

Hydrological data on the watercourses mentioned in this chapter are given on the basis of the data of the Institute of Hydrometeorology and Seismology of Montenegro, as a table for those watercourses where continuous measurements and observations are carried out. The hydrological regime on the watercourses is given over the flow, because the water level analysis is only possible at the locations of hydrological stations, which does not necessarily reflect the condition on the parts of the flowing watercourses.

Data on discharge are given for Skadar Lake and the Bojana River.

Table: Hydrological parameters of the Adriatic river basin

No	**River \ Lake**	**Hydrological stations**	**River basin area (km^2)**	**Analyzed period**	**Characteristic discharge (m^3/s)**				
					Q_{min}	$Q_{min\ sr}$	Q_{sr}	Q_{maxsr}	Q_{max}
1	**Moraca**	Pernica	440,9	1956-2014	1,14	3,29	29,04	428,7	812
		Zlatica	985,3	1983-2012	0	1,619	59,64	885,6	1.369
		Podgorica	2.628	1948-2014	7,93	15,78	159	1.261	2.073
2	**Zeta**	Duklov Most	342,2	1955-2014	0,07	0,271	18,9	182,9	286
		Danilovgrad	1.215,8	1948-2000	4,68	7,99	77,9	278,2	577
3	**River Crnojevica**	Brodska Njiva	79,3	1987-2002	0,458	0,676	6,25	153,9	228
					Characteristic altitude points (mnm)				
					H_{min}	H_{minsr}	H_{sr}	H_{maxsr}	H_{max}
4	**Skadarsko Lake**	Plavnica	4.179	1948-2014	4,54	5,107	6,421	8,444	10,44
5	**Bojana**	Fraskanjel	16.520	1960-2014	0,019	0,469	1,816	4,764	6,359

According to our knowledge, permanent sources of public water supply in Montenegro do not float during extreme floods, but there are problems with water blur and breaks in the supply of consumers in that period or issuing warnings about the need for water purification. This is particularly the case in springs formed by the capture of karst springs.

Water supply of the urban population can be considered good. Of the total number of inhabitants of Montenegro, over 63% live in urban areas, and 99% of the city population is covered by public water supply systems, or about 387 thousand inhabitants of Montenegro (Source: Montenegro's Water Management Strategy, 2016).

Bearing in mind the large number of sources in the territory of Montenegro, their tabular presentation, with basic characteristics, would require a higher number of stations and significantly increased this document. All data on existing sources can be found in the document *Projection of long-term water supply in Montenegro*.

3.1.2. Torrents and erosions

Torrents and erosions are also processes which can potentially endanger lives of people, their property and natural resources. General exposure of the terrain in Montenegro to these processes, as well as the characteristic vertical stratification of vegetation, with distinct steep and very steep slopes, climate with 1 000 to 5 000 mm of water sediment per year, non-resistant soil due to often irrational and inadequate use of natural resources in these areas, are all the reasons for the occurrence of erosion processes on forest and agricultural land. Practically all the rivers in Montenegro in their upper course, and some of them at the entire length, are of torrent character. Each of these torrents threatens settlements and roads, as well as agricultural, forest and other lands.

The catchment area of Skadar Lake has a larger number of torrents, but we must point out that the territory of the Montenegrin coast has the largest number of torrents.

The Montenegrin coast represents a catchment area for about 70 torrents and channels, 40 of them being active. The surface of the torrent watercourses is about 350 km2. These are watercourses with the flow regime which is characterized by large amplitude of flows and water level, which is manifested by long period of water scarcity and lack of flows, as well as short-term large outflows due to heavy rainfall. Extreme precipitation causes the water to flow out of courses and to cause floods of local character. These floods fall into the category of sudden flooding (flash floods), and they are characterized by rapid flood wave of up to 6 hours since the occurrence of intensive rainfall.

3.1.3. Flooded areas

Floods in Montenegro mostly endanger large area of land along the edge of Skadar Lake, in zone of the lower flow of Moraca, as well as along Bojana River.

Floods on the territory of Montenegro manifest differently depending on the characteristics of the watercourse causing the floods. Along the valleys of most of the river flows with short-span waves of high waters, settlements, industrial plants and agricultural land are endangered. These courses are characterized by large longitudinal inclination, high velocities at floodwaves, as well as significant amounts of suspended and traction sediments. Canyons, sometimes very deep, are found with extensions – valleys, along the courses, where settlements and industrial facilities are located, as well as traffic infrastructure. Agricultural areas located in these valleys, although relatively modest, have a great importance for agricultural production, since the total resources of the agricultural land of Montenegro are very limited. Flood damage, even of relatively smaller scope, can be significant due to such concentration of goods in the basins. It should be noted that floods, which originate from high mainstream waters, often superimpose with floods which arise from torrential tributaries, and it is often very difficult and even impossible to separate these two phenomena. Also, the consequences of floods along these courses are accompanied by changes in the river bed, especially in relation to its meandering. That is the reason why the flooded areas change their position and size.

In the area of Skadar Lake, significant agricultural land was flooded for a long period of time, and the settlements along the edge of Skadar Lake are also endangered. The territory of 5 villages in Zeta (Bijelo Polje, Berislavci, Kurilo, Bistrica and Gostilj) cover about 700 residential units which are endangered by floods. Considering the duration of the flood, specific marshy areas have been formed in this zone. Also, the high waters of Bojana also endanger the values in the area of Ulcinj field.

In terms of significance, i.e. by the size of the damage, the damages which occur in the karst fields cannot be disregarded. In this respect, the most frequent floods are in Cetinje and Nikšić fields, which also belong to the Skadar Lake basin.

In addition to floods which occur due to the presence of high waters on river flows and torrents and the very significant flooding caused by Skadar Lake, the occurrence of floods is caused by some specific causes as well, such as the combined effects of surface and ground waters, the impact of tide and groundwater inflows.

In this document, we will review the flooded areas in the catchment area of Skadar Lake and Bojana River.

Moraca River. On the upstream part, the Moraca river bed is mostly deep-cut, with no significant flooded areas.

The following parts of the watercourse are exposed to floods:

- Downstream of the village Botun, the river valley is expanding and the high waters of Moraca flood agricultural area and a large number of rural settlements. The lower areas of villages Botun, Lajkovici and Mitrovici, on the left, and Grbavci and Lekici, on the right bank, are endangered in the direction towards the confluence of Cijevna;
- Parts downstream of the confluence of Sitnica River are exposed to flooding. The areas near Vukovci, Bistrica and Ponari are particularly vulnerable. Here Moraca flows through alluvial sediments, the river flow is meandering destroying the land and endangering the constructed facilities and traffic infrastructure. Meandering in areas from Botun to Ponari is evident. Excessive exploitation of gravel, especially in the area of merging Cijevna into Moraca, significantly contributes to meandering;
- Downstream of the village Ponari to the confluence, the Moraca valley is not endangered by its own waters, but also by the high waters of Skadar Lake. The Moraca river bed cannnot deal with high waters, the slowdown from the lake is significant, so the Moraca waters flood the area of Zabljak Crnojevic and Ceklinsko field.

Zeta River. On the territory of the Niksic field, larger areas were flooded. The flooded areas are mostly meadows, so the total damages from flooding are not high. The regime of flooding was altered by the construction of reservoirs in the Niksic field, but the overall volume of floods has not been significantly changed.

Along the lower flow of Zeta River, there are significant agricultural areas. However, owning to the relatively balanced hydrological regime and morphological and hydraulic characteristics of the bed, these areas are not significantly exposed to flooding. The exception are the areas directly upstream from the confluence in Moraca, which are flooded due to the slowdown of high waters of Moraca. Also, in the zone of Spuz, smaller areas are flooded by tributaries of Zeta.

Sitnica River. Until the implementation of regulatory work in the area of Ljeskopoljski lug, agricultural land of approximately 400 ha was endangered by floods. Regulatory works have not completely solved the problem of flooding so even today larger areas are flooded. Torrents of Crkovnica and Tresnica also have significant impact on the floods in this area.

In the area of the village Beri, high waters of Sitnica flood parts of the settlement, agricultural land and the road which connects Beri village with Podgorica and local roads. Although the floods are not of devastating character, the problem is the frequency of flooding. Another problem is that the occurrence of high waters of Sitnica coincides with high waters of its tributary – Golacki stream, which flows into the Sitnica downstream of the Berski Bridge.

Skadar Lake. The zone of the Skadar Lake and Bojana River, which leads the lake water towards the sea, is of special importance, since the largest area of agricultural land in Montenegro is affected by flooding in this area. The total flooded areas located on the edge of Skadar Lake above the 6.5 mnm ground level amount to 5 000 hectares.

The water levels of Skadar Lake are formed as a consequence of Moraca waters inflow into the lake and the inflow from the immediate basin, as well as from the conditions of discharging waters of the lake using Bojana River. In addition to the two mentioned watercourses, a number of smaller watercourses or torrents in Montenegro and Albania are being discharged into the lake.

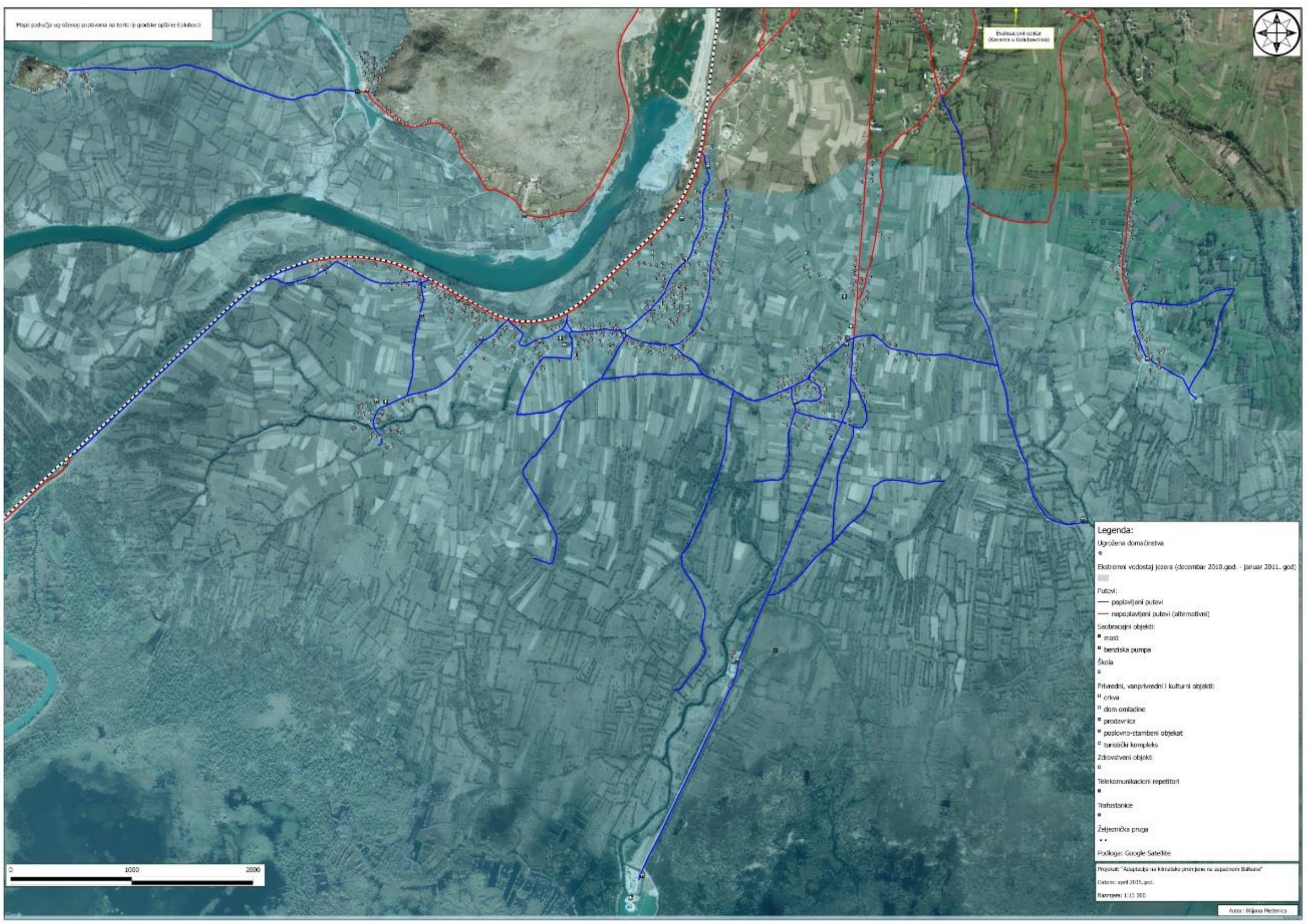
The surface of the Moraca river basin to the confluence of Skadar Lake (including the tributaries downstream of Podgorica) is about 3290 km2, with average inflows of around 200 m3/s. Drim River drains an area of cca 13 500 km2 (to Vaudejs the surface is about 12 100 km2) with an average inflow of cca 326 m3/s. The discharge of the lake water by means of Bojana River takes place in the period of high waters in very complex hydraulic conditions due to the influence of Drim River (in Shkodra, Albania) on this process. Drim River drains an area of cca 13 500 km2 with an average discharge of cca 320 m3/s. The average discharge of Bojana, at the confluence of the sea, is about 640 m3/s.

Bojana River. Bojana River discharges from Skadar Lake, and directly downstream (at a distance of 1.2 to 2 km) on the left it meets Drim River. After 18 km of flow through Albania, Bojana, about 25 km in length, represents the border between Montenegro and Albania. The Bojana regime at the exit from the lake is relatively balanced. However, during the occurrence of high waters on Drim, the water levels and discharges of Bojana increase rapidly. On the one hand this phenomenon causes floods along the Bojana flow, and on the other hand it slows down the discharge from the lake causing floods around the edge of Skadar Lake.

In the area along Bojana and in the basins of small watercourses representing its tributaries, some 2400 hectares of fertile land can be found, which represents a significant percentage of total agricultural land in the coastal part of Montenegro. The entire area along Bojana is endangered by the flood waters of Bojana River itself and waters of its tributaries. Before the embankments were constructed along Bojana, flood waters went deep into the land through the valleys of tributaries, which is especially characteristic for the most downstream area. In the event of a breakdown of defense lines, significant areas at a relatively large distance from the breakthrough site may be affected by the flood. Of particular importance are the following flooded zones: Vladimirsko-Sukobinsko field, Sasko Lake and Ulcinjsko field.

Cetinjsko field. Cetinjsko field represents a closed karst field. The length of the field is around 5 kilometers and the average width is around 800 meters. The average altitude of the field is 635 mnm, and the highest ground level of the terrain reaches 750 mnm. The Cetinje field basin is estimated at 46 km2. As it is a closed area of extreme precipitation, with intense snow melting in the basin, flooding of parts of the field occur. Namely, the sinks in the field, which serve for the discharge of waters through the geological medium, towards Skadar Lake, do not have the capacity for draining large quantities of water in such an extreme event. The main sink is located at the lowest ground level of the Cetinje field, and together with Cetinje cave and Cetinje fault, it is a system which drains most of the waters from the Cetinje field. Therefore, if the amount of water inflow exceeds the discharge capacities of the sink, the Cetinje field is flooded.

SPATIAL DISPLAY OF FLOODED AREAS ON THE TERITORY OF GOLUBOVCI



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[4] Source: Directorate for Emergency Situations in Montenegro. Map created through the project: Climate Change Adaptation in the Western Balkans CCAWB that implements GIZ

3.2. HAZARD ANALYSIS – LANSLIDES

The geological state of any part of the planet Earth surface reflects the evolutionary "moment" in its continuous development and change, as a result of the interplay of endogenous, exogenous and cosmic forces and processes. These dynamic processes belong to the most important factors of natural hazard, which is why knowing them is a prerequisite for rational behavior of a community and undertaking of long-term measures of adequate protection.

3.2.1. Geological factors as preconditions of natural hazard in Montenegro

The geographical area of Montenegro belongs to the Dinarides: Internal and Exterior. On its territory, four (some say five) structural-tectonic units are clearly expressed, which differ significantly among each other in terms of geological composition and tectonic structure. In the scientific and expert literature, these geotectonic units are known as: Durmitorska, High Karst, Budva-Cukali and Paraautohton (see picture 1). The geotectonic unit of the High Karst consists of the Old Montenegrin and Kucka tectonic units. The geological composition and tectonics give these units special natural features which reflect on: morphology of the terrain, layout of the hydrographic network, richness of springs, wells, aquifers of groundwaters, physical and geotechnical characteristics of the rocks, layout and type of agricultural areas and numerous other living conditions, i.e. development and land purpose.

3.2.2. Overview of engineering-geological properties of the terrain of Montenegro

The key factor in defining the hazard related to the occurrence of soil instability is the engineering-geological characteristics of the terrain which define physical-mechanical, resilient-deformable and structural characteristics of the rock mass. On the territory of Montenegro, based on the engineering-geological characteristics of the terrain, engineering-geological groups are formed and classified as follows:

- bound rocks,
- semi-bound to unbound rocks,
- unbound rocks.

Bound rocks – the common features of bound rocks are, above all, a solid intergrain connection, high resistance to pressure, high capacity and practical incompressibility. In terms of water permeability, porosity, resistance to atmospheric influences and chemical dissolution, they differ from one another and within this engineering-geological group of rocks we distinguish several lithological rock complexes which are:

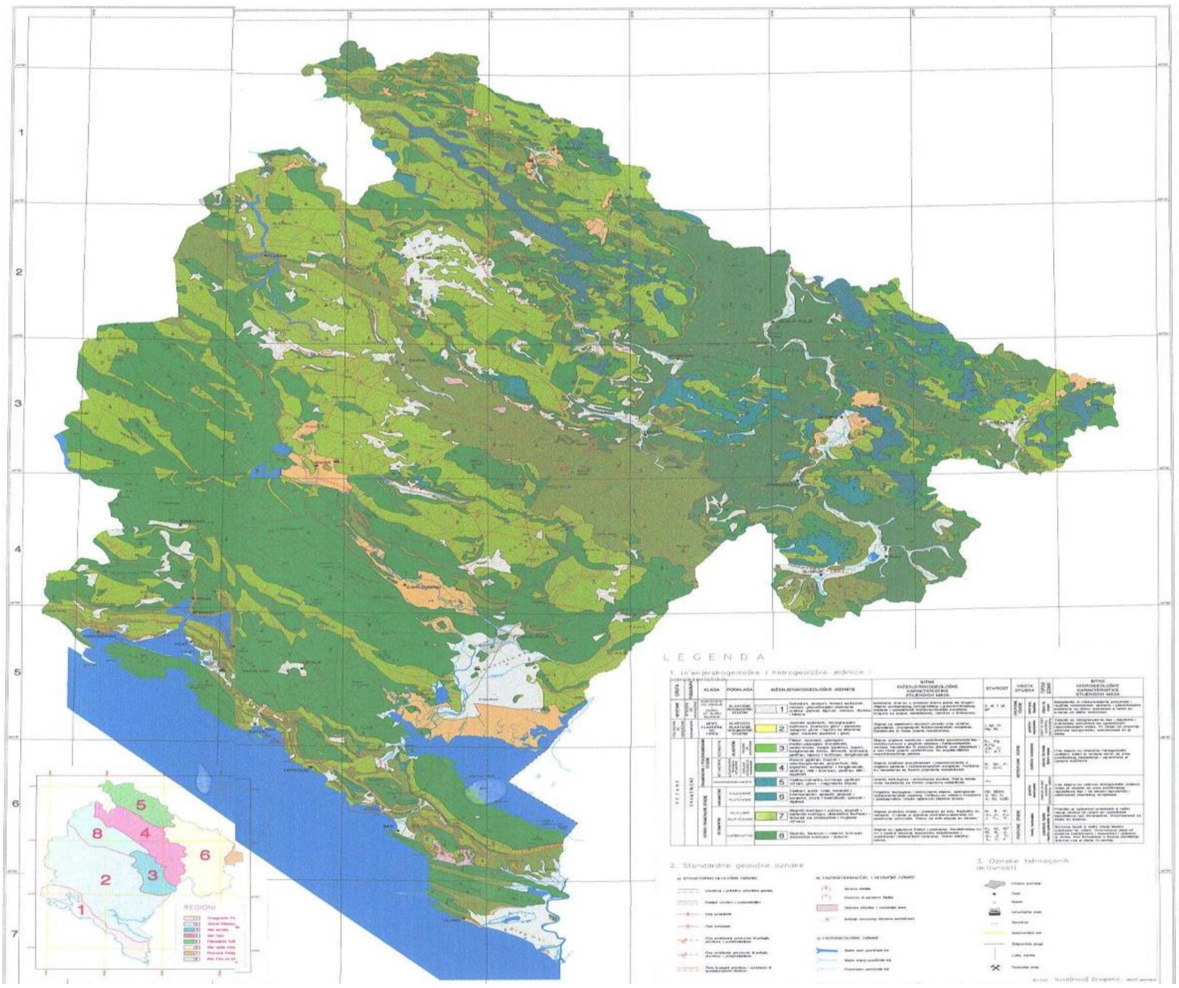
- ✓ complex of clay semi-petrified and clastic rocks with predominantly carbonate binder,
- ✓ complex of carbonate crystalline and cryptocrystalline rocks,
- ✓ complex of carbonate and silicate rocks,
- ✓ complex of siliceous massive, incompletely crystallized rocks.

Semi-bound to unbound rocks – in this engineering-geological group of rocks, in addition to clay, there are also deluvial and proluvial breccias, because they are not only carbonate-bound but also clay-bound. Also, this group includes more lithogenetic members of different origins and engineering-geological characteristics. They are characterized by the variable content of clay fractions, which is why they belong to the complex of unbound to semi-bound rocks.

Unbound rocks – we included in this group the loose rocks without cohesion. According to the engineering-geological characteristics we can divide them into two groups and they are:

- ✓ debris (talus) of a characteristic non-rounded grain,
- ✓ gravel and sand with more or less rounded grains.

Display 6 shows an engineering-geological map with the map of terrain landslide of Montenegro, A. Delibašić (2002), Map of landslides in Montenegro with an interpreter, scale 1:200 000, Republic Institute for Geological Research of Montenegro.



[5]

Display 6. Engineering-geological map of Montenegro with lanslide map

[5] Source of map: Republic Institute for Geological Research of Montenegro. The author: Vukasinovic Dragomir

3.2.3. Overview of the hydrogeological properties of the Montenegrin terrain

Knowledge of the hydrogeological characteristics of an area is of multiple significance from the aspect of determining the legitimacy of occurrence of terrain instability i.e. landslides and rock falls on the terrains of Montenegro. Landslide/Rock fall activation is most often due to changes in groundwater level in the field, which means that the hydrogeological characteristics of a particular geological environment significantly influence its stability.

From the hydrogeological aspect, rocks can be divided into **three groups**: water permeable rocks or hydrogeological collectors, water impermeable rocks or hydrogeological isolators and hydrogeological complexes.

- **The group of water permeable rocks – hydrogeological collectors** consists of two subgroups: water permeable rocks – hydrogeological collectors with intergrain porosity and water permeable rocks – hydrogeological collectors with cracking and cavernous porosity.

a) Water permeable rocks – hydrogeological collectors with intergrain porosity. Unbound and poorly bound clastic deposits are included in this group of rocks in Montenegro, such as: conglomerates of Permo-Triassic age (the surrounding area of Plav), marine sediments of Miocene age (the area of Ulcinj) and neogenic lake sediments discovered in the area of Pljevlja and Berane. Also, the whole range of quaternary structures belongs to this group: alluvial, lake, glacial, glaciofluvial, terraced and deluvial sediments related to the river beds and river valleys of: Ibar, Lim, Cehotina, Tara, Piva and Moraca, as well as for the flatland parts of the terrain near lakes and sea shores. The sediments of glacial origin have been developed mainly in the wider area of the high mountains of Vojnik, Maganik, Durmitor, Sinjajevina, Komovi and Prokletije, as well as along the riverbeds of surrounding rivers. In these deposits, compact aquifers are formed.

b) Water permeable rocks – hydrogeological collectors with cracking and cavernous porosity. This rock group includes hard rocks of carbonate composition which make around 60% of the territory of Montenegro. On the basis of intensity and degree of rock karstification in the karst terrains of Montenegro, the following is distinguished: medium to well karstified limestone rocks, cavernous-cracking porosity; poorly karstified limestone rocks of cracking and rare cavernous porosity and poorly to medium karstified dolomite rocks of cracking-cavernous porosity. Also, the following types of aquifers are also classified: karst type of aquifer in medium to well karstified rocks; karst type of aquifer in poorly karstified rocks and karst-cracking type of aquifer in poorly to medium karstified rocks.

Medium to well karstified limestone rocks of cavernous-cracking porosity. These rocks have the highest distribution on the territory of Montenegro. They create terrains of karst plateau (Sinjajevina, Drobnjacka lakes and Pivske mountains, Katunski krs, Rudine and Banjani, with Lovcensko-Orjenski massive and mountain ridge of Garc, Budos, Zla gora, Pusti Lisac and Njegoš), massifs of Prekornica, Golija, Durmitor, Maglic, Vojnik, Lola, Komovi, Prokletije and Zijova. Carbonate rocks which are separated into this group are represented by layered, banked and massive limestones, middle-Triassic, middle-Jurassic and Upper-Jurassic age and limestone of Cretaceous and Cretaceous-Paleogene age. The terrain built from these rocks is the area of holokarst, with numerous surface and underground karst forms, where the atmospheric precipitation falls directly into the interior of the limestone mass through numerous karst forms which permeate carbonate rocks to great depths and the surface discharge completely lacks.

Poorly karstified limestone rocks of cracking and rare cavernous porosity. The rocks from this group create part of the terrain of the geotectonic unit of Budva-Cukali zone, the lower edge parts of certain karst fields, certain anticline structures and often lower parts of certain canyons of watercourses in central and northern Montenegro. They are presented by the following: layered to platy limestones with intercalation and chert nodules, middle-Triassic age, which make part of the terrain of Budva-Cukali zone, Obzovica and the valley of Orahovska river; stratified limestones, dolomite limestones and limestones of Middle-Triassic and Upper-Triassic age, as well as stratified limestones and chert of Jurassic age; layered-marly limestones with chert intercalations and dolomites and limestones of Lower Jurassic age which are presented along the edge of the Njegusi field, in the canyon of Moraca, Zivsko razdolje, Njegos, Miljkovac and other localities; layered limestones with cherts of Cretaceous age and limestones of middle Eocene age; sandy and marly limestones, the youngest horizon of the Durmitor flysch, which are very karstified in certain parts of the terrain within the geotectonic unit of the Durmitor overthrust and can be included in the previous group of well karstified rocks.

Poorly to medium karstified dolomite rocks of cracking-cavernous porosity. Dolomites of the Upper-Triassic, Upper Jurassic, Jurassic-Cretaceous and Lower Cretaceous age are relatively largely distributed in Montenegro, and dolomites of Upper-Triassic age are characteristic especially in Skadar Lake basin. Many researches dealt with the hydrogeological properties of the dolomites in the Dinarides emphasizing their specific functions. Due to the lack of typical surface karst phenomena, greater susceptibility to mechanical decomposition than chemical corrosion and conversion into the dolomite dust which fill cracks, the relief in dolomites is considerably milder and more flat compared with limestones.

- **The group of water impermeable rocks – hydrogeological isolators** consists of two subgroups: practically impermeable rocks and mostly impermeable rocks.

a) Practically impermeable rocks in Montenegro are clay-marly, slaty sediments of Devonian-Carbonic and Permian age (sandstones, alevrolites and slates) which build terrains in the vicinity of Plav, Andrijevica, Kolašin, Mojkovac, Berane and Rozaje, and their largest distribution is in the wider area of Bijelo Polje. In addition to them, this group includes flysch sediments of different ages (Triassic, Jurassic-Cretaceous, Cretaceous-Paleogene, Paleogene and Eocene) and different composition: claystones, marls, sandstones, breccias, and conglomerates. Anisian flysch was discovered in the area of Crmnica and from Sutorina to Rumija on steep coastal sides. The Jurassic-Cretaceous flysch is discovered from the northern slopes of Ljubisnja, through Durdjevica Tara and Njegovudja to Gomila. The Durmitor Cretaceous-Paleogene flysch stretches to the northwest-southeast direction as a wide belt through Central Montenegro and it occupies a vast space. The paleogenic flysch of Budva zone appears as narrow zone along the whole Montenegrin coast, while the paleogenic flysch of the Zeta valley is in the form of narrow and interrupted zones from Kuce through Piperi, Bjelopavlici, Niksicko polje and Duga towards Gacko. Eocene flysch was developed around Herceg Novi, then in Grbaljsko polje and Ulcinj area. The surface degraded rock mass acts as a poorly water permeable environment, while a deeper preserved rock mass represents water impermeable rock masses, i.e. hydrogeological barrier.

b) Group *of mostly impermeable rocks* includes volcanic rocks of the Triassic age: andesites, dacites, diabase, spilites, keratophyres, quartz keratophyres and rhyolites which are developed in the northeast Montenegro, then in Niksicka Zupa, Pivska Zupa, Crmnica and on the southern slopes of Sozina and Rumija. This group also includes a diabase-chert formation consisting of clastic rocks with diabases and spilites, blocks and pieces of ultrabasic rocks and blocks of carbonate rocks, and it was discovered in the area of Pljevlja, in the area of Kosanica, Kovren, Sinjavina, in the vicinity of Berane and Rozaje. The main characteristics of these rocks is formation of a cracked type aquifers of limited distribution and abundance. Quaternary clays and sands are also classified as mostly impermebale rocks as well as limnoglacial sediments. Intergrain porosity is characteristics of these sediments, and a compact type aquifer of limited distribution is formed inside them.

- **Hydrogeological complexes** are made of groups of rocks of collector and isolating properties. Within this group the following is distinguished: a complex of water permeable and water impermeable rock(s) with alternating hydrogeological properties characterized by intergrain porosity in water permeable part and a complex of water permeable and water impermebale rock(s) with alternating hydrogeological properties characterized by cracking and cavernous porosity in the water permeable part.

3.2.4. Overview of geomorphological properties of the terrain of Montenegro

The geomorphological characteristics of the relief of Montenegro are essentially a prerequisite for the emergence of smaller or larger natural hazards and even disasters. The formation of landslides, rock falls, avalanches etc. are related to steep or canyon parts of the relief. On the other hand, the flat terrain, such as the Zeta plain, Niksic field etc. are subject to flooding with huge consequences. Canyons and gorges in Montenegro also pose a potential danger of large rock falls or large-scale landslides and restructuring of river flows, which would result in great damage. It should not be forgotten, however, that all geological factors, as causative agents of a natural hazard, are interconnected and they always have to be seen through that particular interaction i.e. cause-effect relations. An analysis of geomorphological factors in order to define their impact, as a prerequisite for the emergence of natural disasters makes sense only if seen as a part of geological factors as a whole. By the action of endogenous forces, whether it is a matter of magmatic activity, orogenic or epeirogenic movements, an uneven or very rugged relief, is formed on the surface. Contrary to them, exogenous forces, by destroying prominent parts on the Earth surface and disposing of them into the lower parts where they are accumulated, tend to flatten the terrain. The result of the continuous action of endogenous and exogenous forces is the constant change in the shape of the Earth crust and the permanent change in the appearance of its surface.

As part of the geomorphological studies in the area of Montenegro, the morphostructure analysis distinguishes the following elements: negative structures, positive structures, regional overthrust, deep regional overthurst and different types of reliefs (Glacial type of relief, Glaciofluvial and glaciolimnic relief type, Karst relief type, Fluvial type, Padina type, Lake-Bar type, Marine type and Anthropogenic type).

3.2.5. Contemporary exogeodynamic processes and phenomena

Contemporary exogeodynamic processes and phenomena are processes and phenomena which occur in natural conditions and those which are enhanced by anthropogenic influence. The representation and distribution of contemporary exogeodynamic processes is related to engineering-geological, hydrogeological, seismic, geomorphological and other properties of the terrain.

On the territory of Montenegro, the following exogeodynamic processes are registered: marine process, liquefaction process, planar and line erosion process, karstification process, rock fall and dispersion process and landslide process.

- ***Marine process***

The marine process has been developed on the sea coast itself and it is reflected in the formation of cliffs and beach sediments.

Considering the threat of process development, the sea coast is divided into the following **three zones**:

a) According to the general engineering-geological features, the first zone includes bound well-petrified carbonate rocks, primarily limestones and dolomite limestone of banked and layered textures, slightly tectonically damaged. Their firmness and slight cracking make the terrain resistant to the impact of the abrasion process, so the process of further development in terms of both erosion and accumulation is low.

b) The second zone consists of terrains built of bound, weakly and well-petrified clastic, carbonate and siliceous rocks. These rock masses are layered, thin-layered and of tabular texture, substantially cracked. Reduced rock firmness and increased cracking cause the increased degree of further development of the marine process; this applies both to abrasion i.e. the formation of cliffs and undermining of the coast as well as to contemporary marine deposits of beach sediments.

c) The third group consists of terrains along the southern edge of the Montenegrin coast where the contemporary marine deposits of beach sediments is exclusively present i.e. sandy-dusty sediments carried by sea currents as well as sediments carried by the Bojana River which are, in contact with salt water, deposited in the wider area of Ada Bojana. Sediments are mostly composed of gravel, sand and sandy clay. The average thickness of the sand cover is 17 m.

- ✓ ***Karstification process***

The process of karstification is a widespread process related to the carbonate rock masses which dominate in the construction of the terrain of Montenegro. The effect of karstification is significant on the surface of the terrain and also under the ground. On the basis of the effect of the karstification process, we can distinguish the areas of angry karst i.e. highly karstified terrain, medium karstified terrain and poorly karstified terrain.

Angry karst areas include areas of almost pure, tectonically damaged subshoal to layered limestones. This process is very well developed with banked and massive limestones and dolomite.

Medium karstified terrain was developed as an aureole, of spread diameter around the angry karst.

The rest of the terrain with carbonate rocks is poorly karstified terrain. Within the poorly karstified terrain in some areas, sub-surface karstification is evident, it is particularly shallow and frequent sliding of vaults in the caves and channels occur, which endanger stability of the terrain on the surface.

- ✓ **The process of landslide and dispersion**

According to the intensity of landslide and dispersion on the terrains of Montenegro, we distinguish **two zones**:

a) The first zone is made up of carbonate rock masses, limestones and dolomites, with landslides and dispersion occurring along steep slopes in the terrain parts which are cracked up to the dimensions of debris and blocks. In these terrains, thick debris-talus deposits are formed, up to 50 m thickness. Often larger slides and taluses are related to deeper canyons such as canyons of Tara, Moraca, Lim, Zeta, Cehotina etc.

b) In the second zone, dispersion dominates over landslides and it is most often accelerated by the engineering activity, i.e. terrain scribe and cutting. This zone is built by weakly and well-petrified rocks, then various clay deluvial debris represented on steep slopes, as well as deluvial debris partly bound in breccias. Talus and debris dimensions can be measured in meters, and talus material is of centimeter to decimeter dimensions. Remediation of slopes which are threatened by sliding or dispersion can be performed using standard methods, such as: easing the inclination of scribe or cuts, setting protective grids etc.

Landslides of different intensities in high mountainous and steep terrains are common and they occur in continuity as well as landslides in steep and canyon valleys of rivers Moraca, Piva, Tara, Lim and Ibar. These types of natural phenomena mostly have only local consequences. In deep canyons of Tara and Moraca, there may be larger slides with catastrophic consequences.

- ✓ ***Liquefaction process***

The terrain of coastal belt of Montenegro is characterized by the possibility of sudden loss of soil cohesion. This phenomenon is related exclusively to small-grain, water-saturated, dusty-sandy sediments and it is called liquefaction. It appears exclusively in terrains along the sea coast.

Based on granulometric composition, groundwater level, soil volume etc. in the terrain of Montenegro, we distinguish **two zones** of soil sensitivity related to occurrence of liquefaction.

a) The first zone includes proluvial and deluvial spectrum of unbound, medium compact and loose rocks with the increased content of sandy-dust component in the surface parts i.e. in the coastal belt, and the water level is high and corresponds to the sea level. In this zone, the loose sandy-dusty rock masses, which are mostly marine, belongs as well. Each construction of objects in this zone is accompanied by a high risk of collapse due to the possible occurrence of soil liquefaction. The process of liquefaction is very often initiated by seismic activity of the terrain. After a catastrophic earthquake in 1979, several buildings were identified to be demolished due to the liquefaction of the soil, as was the case in the municipality of Herceg Novi, in settlements Djenovici and Kamenari.

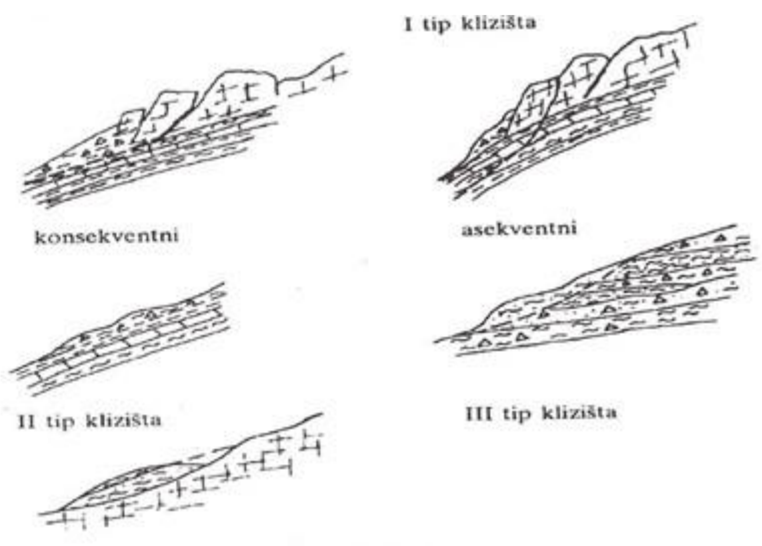
b) The second zone consists of bound unpetrified soft to plastic rocks of deluvial and alluvial origin. The likelihood of occurrence of liquefaction is the consequence of the increase of sandy-dust component in the narrow coastal belt due to marine influence. This second zone is extremely narrow and represents only a narrow coastal area and its sensitivity to liquefaction is lower.

- ✓ ***Planar wash-away and line erosion process***

On the terrain of Montenegro, a process of planar wash-away and line erosion has been developed, which is the most active in terrains built of poorly-petrified and unpetrified rocks of various consistencies, as well as in the volcanogenic-sediment complex. Line erosion is selectively developed. With poorly-petrified rocks, dredging is predisposed by increased content of claystones. Torrents of the intensity that depends on the amount of water sediment as well as easily moveable material in the basin are formed along the gullies and ravines during heavy rains. Almost all permanent and occasional watercourses are characterized by torrent activity, and the steep slopes of the terrain indirectly affect the depth of ravines. The density of the development of gullies in one area can be so great that they develop a common ridge. Along gullies and ravines, the terrain should be classified as conditionally stable to unstable, while closer to urban areas it is necessary to perform meliorative operations such as cascading barriers as a measure of flow channeling.

- ✓ ***Sliding process***

The sliding process is the most prominent contemporary process. In Montenegro, landslides are concentrated in the coastal belt of the Boka Kotorska Bay, hinterland of Budva, Becici, Sveti Stefan, Petrovac, Bar as well as Zeta, Moraca, Tara, Lim and Piva basins. Landslides affect terrains built of bounded unpetrified rocks of hard and plastic consistency and unbound largegrain poorly-complex rocks, and the basis for sliding are bound slightly petrified rocks of the flysch complex. The most common cause of the landslide is the high level of groundwater and unfavorable engineering-geological structure of the terrain. Depending on the engineering-geological structure of the terrain, several types of landslides are identified, which differ from each other according to their size and dimensions. Some characteristic types of landslides are shown in the display number 7.



Display number 7 Landslide types

a) The first type of landslide is in terrains the structure of which is made of different clay large-grain debris of predominantly deluvial origin with blocks of decametric dimensions (bound and unbound rocks). The floor consists of slightly petrified rocks, predominantly complexes of marls, sandstones, limestones or claystones. The infiltration of atmospheric precipitation and the penetration of water from the hinterland improves the degradation of poorly petrified rocks in the floor. Physico-chemical degradation is additionally enhanced by the loading of the roof debris, which then slides along the contact layer, if there is a critical inclination of the slope. This type of landslide is the most frequent in the terrain of Montenegro and it belongs to the consecutive type. The sliding plane is formed along the aforementioned contact with a poorly-petrified floor, with rare exceptions of sliding plane passing through semipetrified rocks, which is a consequence of the specific engineering-geological structure of the terrain and exceptionally steep terrain when deep landslide are usually formed with a sliding plane over 10m depth. The consequent type of landslide usually do not have a clear manifestation of sliding on the surface of the terrain with the absence of surface sliding of the terrain.

b) The second type of landslide results in forming relatively shallow landslides with a maximum depth of up to a few meters and a width of up to 10 meters. The engineering-geological structure of the terrain consists of the surface decomposition of semi-petrified rocks which slides along the floor consisting predominantly of claystones, marls, sandstones and limestones. The surface decomposition of semi-petrified rocks is most often of hard plasticity with uneven content of debris.

c) The third type of landslide is the landslides formed in the clay debris which belongs to the bound non-petrified rocks of medium to hard plasticity and they represent a complex of rocks of different clay content. Differently clayed debris, sandy debris and clay are mutually interchanged as lenses and layers, so that the waterpermeable elements lying on isolating clay units, with increased presence of underground waters and achieving critical inclination of the slope, slide with their overlays along the floor isolator layer. This type of landslide is mainly the result of the increased groundwater content, with additional slope loads or as a result of their scribing.

d) The fourth type of landslide is individual landslides, in terrains of specific structure, e.g. consolidated talus on clay sediments or red soil which are most often activated by anthropogenic influence.

If the conditions for remediation of all four types of landslides are considered through the characteristic remediation procedures: drainage, supporting walls etc. then it can be said that supporting walls are the basic remediation work of the second and fourth type of landslides, while the drainage interventions are the basic remediation work of the first and third type of landslide. Namely, **the first type of landslide**, requires foundation with a large volume of earthworks and an adequately large dimensions of supporting wall, which in most cases is not an economically rational remediation measure. On the other hand, the formation of a drainage network with a wide collection of groundwater for this type of landslide is economically rational, and in practice, the most effective remediation measure, so it is the most frequently the basic type of remediation.

In the case of **the second type of landslide**, drainage can be accomplished by a filtering blind on supporting walls. The foundation of the supporting walls does not require a large volume of earthwork, and relatively lean constructions do not burden the flysch floor.

The third type of landslide should also be remediated with the formation of a wide collector of groundwater. Foundation conditions in most cases are questionable due to the heterogeneity of the environment in which landslides occur and in which the supporting wall would be founded.

The fourth group of landslides has favorable conditions for the foundation of supporting walls, due to stability and good bearing capacity of the terrain floor.

On dozen locations across Montenegro, landslides of larger or smaller dimensions are identified, which in local proportions (and sometimes in regional ones) endanger the environment.

The south-west slopes of Rumija, Sutorman, Lovcen, Orjen and Vrmac represent geological and morphological "suitable" terrains for the formation of landslides of larger scale. The instability of these terrains is particularly affected by the areas of flysch plastic and waterimpermeable rocks over which, in most cases in the tectonic relation, are thick masses of rigid, well-petrified rocks, mainly limestones. These rigid masses pressurize and deform softer flysch formations, with detaching and slipping of blocks on the edges. This process is intensified during the rainy periods, especially during shakes i.e. earthquakes. In this manner, **large block landslides** have been created, such as **Vladimir, Ratac, Seoca and Savina**, which occupy a large area by surface and depth, they are very difficult to remediate and they belong to the first type of landslide.

In the flysch part of the upper and middle course of Moraca, landslides of different dimensions often occur, of which the **landslide beneath Crkvina (locality Dolovi)**, which is still not completely remediated, is particularly important, as well as the **landslide Djurdjevina**, which is the largest landslide in the terrain of Montenegro. The conditions for remediation of the landslide Djurdjevina affect the formation of the reservoir Andrijevo with slowdown level of 285mnv.

In the Moraca river basin, spacious horizons of terraced sediments are also present forming subvertical sections. These sediments are in a conditionally stable to unstable state of the boundary balance. The best example of instability of these sediments is the plateau on which the **Moraca Monastery** is located, at this locality an almost vertical sliding plane was formed, display number 8.

Display number 8 Landslide along the edge of the river terrace, the plateau on which the Moraca Monastery is located

In Skadarsko-Bjelopavlicka depression, landslides of smaller dimensions are found in Crmnica and along the north-eastern edge of the Zeta Depression, with the largest landslide in Povija, which threatens the stability of the railway Niksic-Podgorica.

Categorization of the terrain by degree of stability

The presence and intensity of the development of contemporary exogeodynamic processes condition the degree of stability, on the basis of which the terrain is categorized as stable, conditionally stable and unstable. The importance of a multidisciplinary, gradual and comprehensive approach to categorization of the terrain of Montenegro can best be illustrated by the fact that during the catastrophic earthquake in 1979, there were over 500 large and small landslides/rock falls, and the damage caused by them in the overall sum was equivalent to the damage from direct seismic impact.

According to the degree of stability, the terrain of Montenegro must be separated into **three categories: unstable terrains, conditionally stable terrains and stable terrains**. The categories of stability should be separated, both according to the threat to the terrain posed by contemporary exogeodynamic processes and phenomena as well as knowledge of the overall characteristics of rocks and terrain.

The category of **unstable terrains** includes the terrains where landslides occur, then the terrains of the first zone of the process of landslide and dispersion, the first zone of the process of liquefaction and the terrains affected by the process of washing away and line erosion. Planned engineering activities on the construction of the road network and hydroelectric plants in these terrains will lead to the activation of calmed landslides, the formation of new ones, as well as the large incidence of landslides along the canyons. Also, the narrow coastal belt will continue to be the subject of intensive urbanization with the expansion of urban centers. Consequently, further engineering-geological interventions in these terrains must inevitably be preceded by detailed engineering-geological research with a proposal for the method of foundation of the facility and remediation of the slope on which the objects are designed.

It is necessary to classify all the following terrains in the category of **conditionally stable terrains.** They are: terrains with sporadic occurrence of landslides, then terrains of the second category of landslide and dispersion, terrains of the second zone of the process of liquefaction, terrains of the first zone of the marine process and terrains in which dredging and rinsing processes occur sporadically.

In the **stable terrains** we must classify the remaining parts of the terrains of Montenegro built of well-petrified carbonate rocks. These are bound sediments of glacial and limnoglacial origin etc.

3.6 Hazard types caused by contemporary exogeodynamic processes and phenomena

Among the contemporary exogeodynamic processes and phenomena, the most devastating ones with regard to the effect on the territory of Montenegro are landslides and rock falls. As the most unfavorable ones, we identified the following scenarios of the effects of this natural hazard:

- blockage of traffic infrastructure due to the occurrence of larger landslides and rock falls,

- formation of larger landslides and rock falls caused by the construction of artificial reservoirs,

- formation of larger landslides within urban areas.

✓ **Blockage of traffic infrastructure due to larger landslides and rock falls**

The road network of Montenegro is mostly built in terrains with extremely complex topographic and geological conditions, so in relatively small area, there are sections of the road with numerous and deep active, fossil and calm landslides, sections along which the sides are prone to sliding, sections on poorly supporting ground, floating terrains etc. The degree of frequency of the occurrence of the terrain instability, as well as the intensity of these phenomena is increased by increasing the inclination of the soil, with the increased intensity of precipitation in a certain area, the increased degree of environmental damage due to engineering activity and the increased seismicity of the terrain. The falling, detaching and sliding of large amounts of rock mass is related to the instability of degraded sedimentary rocks, with larger landslides and rock falls primarily related to unstable geological contact zones between rocks of different physical-mechanical characteristics. Numerous occurrences of instability are also characteristic of surface degraded layers of younger sediments, the floor of which includes rock masses which can be characterized as hydrogeological isolators.

The occurrence of landslides and rock falls which block roads and railways in Montenegro is registered almost every year – displaz number 9.

Display number 9 Frequent occurrence of landslides in Montenegro along road and railway infrastructure

Bearing in mind the vulnerability of the main and regional road as well as railway network in Montenegro and already formed slides/rock falls along major roads, it is necessary to look at the scale and potential causes of possible new instabilities.

In the terrains of Montenegro, the canyons Tara and Moraca have been identified as sites with the largest number of falls of rock masses. Thus, in the Platija Canyon several landslides of rocks masses occurred. It is known that during the construction of this section of the main road, there were several larger landslides. The fracture on this section occurrs along unloading cracks, with the mentioned route being repeatedly interrupted. The unloading crack genesis is morphologically linked to deep canyons so that canyons of Tara, Piva, Moraca and partly Lim canyon stand out as zones of increased danger from the occurrence of larger slides. Important roads in Montenegro are also located along the mentioned canyons.

- The large landslides in the terrain of Montenegro are related to flysch terrains. Flysch rock masses build the terrain of a lighter inclination, so the road and rail infrastructure are located precisely in these rock masses.

Numerous active landslides along the railway infrastructure and roads are still present and we will mention only the most significant ones:

- Povija landslide on Niksic-Podgorica line,
- Mrcela landslide on Bar-Podgorica line,
- Ratac I, II, III and IV landslide along Sutomore-Bar road,
- Crkvine landslide, M-2 road of the section Podgorica-Kolasin.

The occurrence of the terrain instability undermines both the roadways as well as engineering facilities on them. It should be noted that due to morphology of the terrain, the number of facilities along the railway and road network in Montenegro is large, with the existence of engineering facilities the damage of which would cause a several month break in traffic. This increases the risk from the viewpoint of the traffic network exposure to natural exogeodynamic processes and phenomena.

Bearing this in mind, further engineering activities should perform security assessment of the facilities (bridges, tunnels) which are built or the construction of which is planned. Conclusions about the impact of these natural hazards on the vulnerability of infrastructure facilities must be considered in the context of local hydrogeological conditions, climate and terrain seismicity which are of great importance for the stability of sides, rock fall occurrence, landslides etc. The said factors vary widely across the territory of Montenegro, so in each specific case they need to be separately analyzed and considered.

- ✓ ***Formation of larger slides/rock falls caused by the construction of artificial reservoirs***

There are **two high concrete dams Mratinje and Otilovici** in Montenegro, and several artificial lakes on rivers Moraca, Komarnica and Lim are planned. It is believed that demolition or damage to these dams could have catastrophic consequences for downstream settlements. The construction of four dams: Andrijevo (160 m high), Raslovici, Milunovici and Zlatica of up to 60 m height are planned by the Draft detailed spatial plan for the area of multipurpose reservoirs on the Moraca river. The formation of artificial lakes raises the levels of groundwater for several dozen meters. Also, by constructing larger hydro accumulation lakes, the hydrostatic-voltage state of the rock mass changes in the narrow and even wider surrounding of the reservoir. Changing the groundwater level will cause an unfavorable change in physical-mechanical parameters, which can lead to the occurrence of larger landslides/rock falls. In the event of a soil breakdown and disturbance of the majority of terrain stability occurring suddenly, it is possible to create a flood wave with catastrophic consequences to the stability of the dam and downstream settlements. Bearing this in mind, when planning future reservoirs in Montenegro, great attention should be paid to the possibility of occurrence of larger slides/rock falls in the area of future reservoirs, and the devastation of the terrain along the reservoirs concerned. It should be noted that the area along the Moraca river course represents an impressive example of the development of glaciofluvial sediments which occupy large spaces along the said river course, constructing subvertical to vertical terraces on which numerous traffic, residential and religious facilities are built. The stability of these sediments in contemporary conditions can be assessed as conditionally stable to unstable, display number 10.

Display number 10 Disturbed stability of the large block of terraced sediments, the area of future reservoir Zlatica and larger blocks detached along the edge parts of the river terrace, the area of future reservoir Milunovici.

ANNEX NUMBER 3

TABULAR DISPLAY OF LANDSLIDES AND ROCK FALLS IN THE LOCAL SELF-GOVERNMENT UNITS WHICH ARE THE SUBJECT OF THIS ANALYSIS

NO.	*LANDSLIDE NAME*	*LOCATION*	*TYPE*	*DATE*	*RESEARCHER*	*RESEARCH LEVEL*	*RESEARCH TYPE AND SCOPE*
1.	Stanišići	Main road Cetinje-Budva	Fossil, old landslide	January 1979	Highway Institute, Belgrade	For the Main remediation design	Terrain mapping, drilling 17 wells (120m)
2.	Stanišići 2	Main road Cetinje-Budva, survey mark 22+334km	Fossil, old landslide	October-November 1979	Highway Institute, Belgrade	For the Main remediation design	Terrain mapping drilling (120m), laboratory geomechanical testing
3.	Slope Brbot-Stari Bar	Stari Bar, slope beneath the peak Špilja (375mnm)	Unstable slope	1980	Republic Institute for Geological Research, Podgorica	Expert report	Field tour, documentation analysis and report preparation
4.	Sutomore	Main road Petrovac – Bar, survey mark 45+000 to 45+700km	Old fossil landslide	1989	Institute for Design of the Yugoslavia Railway Community, Belgrade	For the Main remediation design	Researches in III phases: photogeology, terrain mapping, drilling 18 wells 579m, digging 2 exploration pits, laboratory testing
5.	Buko-vik	Jadranska main road M-2, Petrovac-Virpazar, location Bukovik, survey mark 939+080km	Landslide remediated	During 1977	Highway Institute, Belgrade	Main design	Terrain mapping (2ha), drilling 7 wells (60m) and laboratory testing.
6.	Kujava	Old road Podgorica-Nikšić, survey mark 48+080-48+220km, village Kujava, road Danilovgrad – Zagorak	Old landslide	20 December 1978	Republic Institute for Geological Research, Institute for Testing Construction Materials and Geotechnics Nikšič	For the Main remediation design	Engineering-geological terrain mapping, exploration drilling 6 wells (65m), laboratory testing
7.	Livero-vići	Nikšićka Župa, locality Liverovići	Active landslide	1980	Republic Institute for Geological Research, Podogorica	Regional Engineering-Geological Research of the north-west of Montenegro	Engineering-geological mapping
8.	Povija	Left side of valley of the river Zeta, locality Povija	Old fossil landslide, remedi	Early 70's	«Geosonda», Belgrade, 1970 and1979	1970 research for the development of geotechnical	1970 - 4 exploration wells, laboratory, 1779 - engineering-geological mapping of the slope and

			ated at the moment			substrates for landslide remediation; 1979 researches according to the Project for additional research works for landslide remediation	exploration drilling of several wells.
9.	Radov-če	Local road Podgorica-Radovče Polje, around 15km north of Podgorice, locality Gola Strana	Active landslide, activated during road reconstruction	Early 2002	Republic Institute for Geological Research, Podogorica	For the Main design, Podgorica	Terrain mapping, drilling 4 wells (35m), laboratory geomechanical testing
10.	Vasiljevići	Nikšićka Župa, locality Vasiljevići	Old fossil landslide	1980	Republic Institute for Geological Research, Podgorica	Regional engineering-geological research of the north-west of Montenegro	Geodetic survey, engineering-geological mapping and monitoring the landslide shift during research
11.	Vrelo	Main road Cetinje-Budva, survey mark 7+10 to 7+270km	Remediated landslide	1981	Institute for construction materials and geotechnics, Nikšić	For the Main remediation design	Terrain mapping, drilling 6 wells, laboratory testing
12.	Crkvi-ne	Jadranska main road, M-2, road Podgorica – Kolašin, km 1035+500km	Old active landslide	1981-1982	Institute for Design of the Yugoslav Railway Community, Bekgrade	Research for the Main remediation design	Terrain mapping, drilling 8 wells (120m), laboratory geomechanical testing
13.	Kući-šta	Left side of the valley of the river Morača, 12km south-west from Kolašin	Old fossil landslide	1980	Institute for Geological Research, Podgorica	Regional engineering-geological research of the north-east of Montenegro	Engineering-geological landslide mapping and monitoring the landslide shift during research
14.	Morača Monastery	Jadranska main road, road M-2, Podgorica – Kolašin, 1020+190km	Remediated lanslide	November 1979	Highway Institute, Belgrade	Research for the Main remediation design	Terrain mapping, drilling 6 wells (120m), digging 11 exploration pits and laboratory testing
15.	Morača Monastery	Jadranska main road, road M-2,	Remediated	November 1979	Highway Institute, Belgrade	Research for the Main	Terrain mapping, drilling 6 wells (120m), digging 11 exploration

		Podgorica – Kolašin, 1020+190km	landslide			remediation design	pits and laboratory testing
16.	Sinjac	Main road Nikšić-Plužine, around 8km south of Plužine	Remediated landslide	1980	Republic Institute for Geological Research, Podgorica	Engineering-geological landslide mapping	

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