Financed by European Union from IPA 2016,
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Support to Project Preparation for Environment and Climate Change Sector, Montenegro

EUROPEAID/139893/IH/SER/ME

Rehabilitation of Biogradsko Lake
Analysis of the existing condition and processes that may lead to its permanent devastation

[March 2022]

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PROJECT PREPARATION FACILITY
FOR ENVIRONMENT AND CLIMATE CHANGE SECTOR (PPF)

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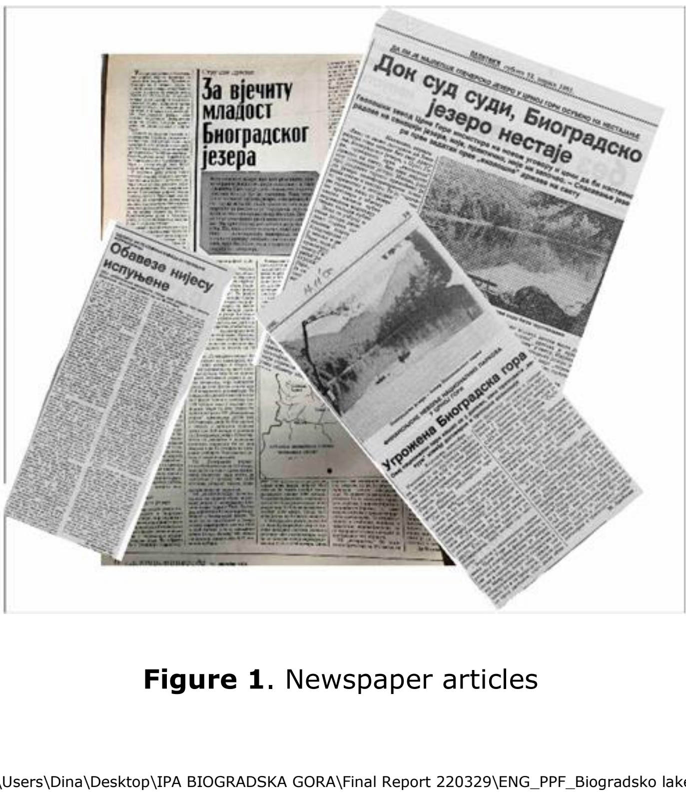
1. INTRODUCTION

The Project “Rehabilitation of Biogradsko Lake” has been one of the priorities in the environmental protection sector for years, and as such was also one of the priorities on the Single List of Infrastructure Projects.

The problem of erosion in the Jezerštica canyon, infiltration and loss from the Lake, as well as siltation of the Lake with river load sediments was recognized more than half a century ago and has always been linked to the possibility of permanent disappearance of Biogradsko Lake. The possibility of disappearance of the Lake was occasionally made a current matter, but the concern for this problem has never faded away.

The concern for the Lake and its fate has occupied the attention of newspaper articles and the public since the ‘90s and continues until today (Figure 1). Due to the increase in social responsibility towards the environment, and the ease of storing of digital information, nowadays it is not difficult to be informed about the problems faced by the National Park “Biogradska Gora”.


За вјечиту младост Биоградског језера

Док суд суди, Биоградско језеро нестаје

Обавезе нијесу испуњене

Угрожена Биоградска гора

Figure 1. Newspaper articles

Articles and feature stories about these matters can be accessed at the following links:

- https://youtu.be/gCrqJuA9wiE
- https://www.vijesti.me/vijesti/drustvo/573509/rnkovic-biogradsko-jezero-nije-presusilo-zbog-visednevne-suse-je-smanjen-vodostaj
- https://beraneonline.me/nevjerovatan-prizor-biogradsko-jezero-presusilo
- https://www.ucg.ac.me/objava/blog/1275/objava/127023-problemi-u-zivotnoj-sredini-biogradsko-jezero-nije-presusilo-ali-nestaje

In the previous period, several local authors, several institutions (Geological Survey from Podgorica, the Faculty of Forestry from Belgrade), as well as associations (the Greens of Montenegro), addressed the phenomenon of Biogradsko Lake. While some of these papers have undisputed, scientific and engineering credibility, the absence of dedicated research and surveys conducted in the systematized and analytical manner can still be noticed. Without data that would be acquired in this manner, it was not possible to start addressing all the problems on Biogradsko Lake in an integrated manner, while each of the problems can ultimately lead to its permanent devastation.

To this end, the Ministry of Ecology, Spatial Planning and Urbanism decided to complete the first phase, i.e. an analysis of the current situation through the current IPA Project "Support to Project Preparation for Environment and Climate Change Sector" (IPA 2016 –the Project is worth EUR 3.234 million), in order to collect all existing documents about Biogradsko Lake through a comprehensive approach, analyse them, prepare an overview of the current situation and define problems that need to be addressed, and prepare a proposal and a plan of further activities which should lead to lasting remediation and revitalization of Biogradsko Lake.

For the purpose of the Project implementation, an expert team was contracted comprising four local experts in geology, hydrogeology, hydrology and forestry. The task of the expert team was to collect and analyse the existing documents, define problems that may cause the loss of Biogradsko Lake and to plan future activities which could lead to the lasting protection of this pearl of nature.

Unlike many devastated natural and ambiental units in Montenegro, whose devastation is the consequence of anthropogenic factor, the possibility of permanent loss of Biogradsko Lake is the consequence of natural, evolutionary relief changes caused by various erosion processes. Future remediation solutions must be focused on changing natural processes that dominate in Biogradska Gora, whereby the solutions must be in full harmony and consistent with nature so as to avoid violating the uniqueness of Biogradsko Lake. While working on the Project, the expert team always took account of this.

The activities with the objective to review and analyse all relevant data, studies, documents and maps and plan further investigation works and studies, were implemented from October 2021 to January 2022, as per the Terms of Reference. The work was done both in the office and in the field.

The work results are synthetized in this Study.

2. OVERVIEW AND ANALYSIS OF THE EXISTING DOCUMENTS

SUMMARIES:

- **1976, JEZERŠTICA – MAIN DESIGN FOR REGULATION OF ERODED SLOPES IN THE JEZERŠTICA CANYON; (Institute for Water Management in Erosion Areas – Faculty of Forestry) Dr. Eng. Ljubiša Jevtić**

The reasons underlying drafting of the Main Design are defined by the Terms of Reference "Main Design for regulating eroded slopes in the Jezerštica canyon to prevent the process of undercutting of the basis of high riverbanks by periodically strong river water, as well as the requirements for further protection of these erosion sides".

The part of the text relating to the Description and Problems in the Basin states the following: "The basin of the Lake is built of schisty and broken green porphyry, with abundance of moraine material. In fact, moraine material of diverse composition and size remained behind in the process of subsidence of the glacier into the valley pushing everything in front of it thus gradually forming the Lake shell. Moraines are mainly formed of limestone material which arrived from the so-called limestone cap found on the catchment tops. . This material is not compact and healthy but contains clay and silicon, whereby it is also marly".

It also states that "Jezerštica is, therefore, formed based on lateral overflowing of water from the Lake, but also based on emerging of water from the loose material".

It further states: "During low tide of the Lake, numerous cracks are visible in the igneous rock, i.e. along the bottom of the Lake, which allow intense disappearance of water. When the water level is at its minimum, losses from the Lake are much higher than the water fed by Biogradska River with tributaries". The losses of water through ponors (sinkholes)s are estimated at about 25% of the possible water flow over the spillway amounting to 23.79 m3/s. ***In terms of relief, the entire catchment area of the Biogradska River is characterized by highly distinguished, steep terrains. With average inclination of lateral sides of up to 50% and a relative dip of the riverbed in terms of flow of***

$$J_t = 6.94\ \%,$$

it belongs to the category of terrains characterized by high energy potential of basins and a possible devastating flow, which may occur in the case of sudden and frequent precipitation."

Based on the existing topographic maps, the parameters presented in Table 1 are calculated.

Table 1. Characteristic values of the Biogradsko Lake basin

	Jezerštica	***Biogradska River***	***Lalev Stream***
Basin area	44 km²	29 km²	3.5 km²
Basin length	12 km	8.5 km	4 km
Difference in elevation	1286 m	1022 m	911 m
Forest cover	27.7 km²	16.9 km²	1.1 km²
Area under meadows	16.3 km²	12.1 km²	2.4 km²

The aim of the conceptual rehabilitation design refers to creating a stable slope with a natural inclination where conditions would be created for binding with vegetation or some other available measure. Developing an artificial "support " in the form of a gabion at the bottom of the slope side is proposed in order to stop erosion and washing out of denudation material.

The proposed manner of rehabilitation is presented on the Figure below.

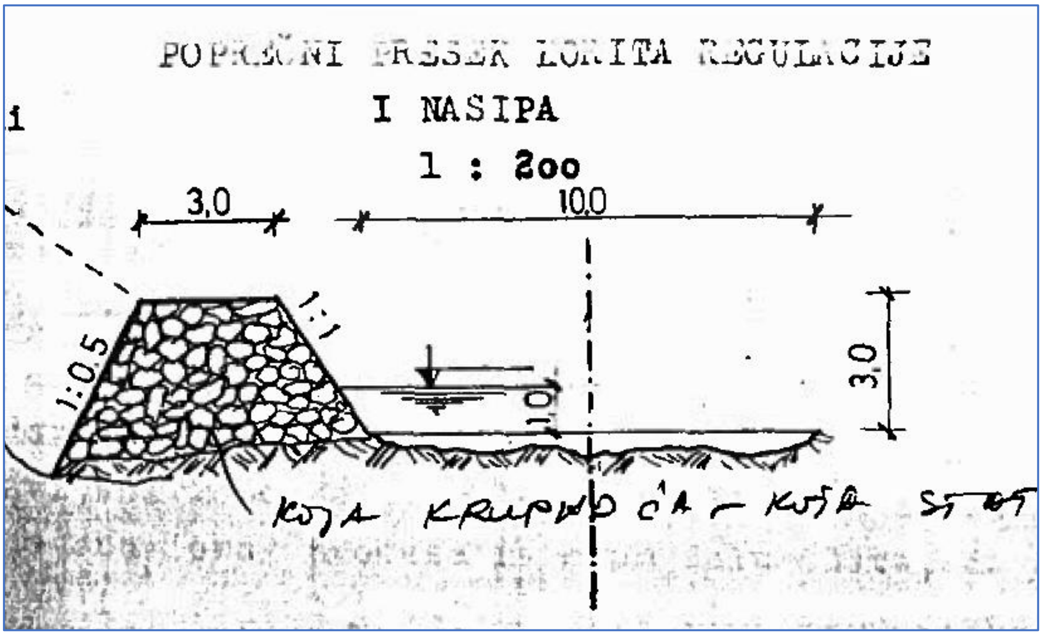


Figure 2. Cross-section of the regulation of Jezerštica riverbed with a protective embankment

- **1976, BIOGRADSKA RIVER AND LALEV STREAM – MAIN DESIGN FOR REGULATING BIOGRADSKA RIVER AND LALEV STREAM BEDS; (Institute for Water Management in Erosion Areas – Faculty of Forestry) Dr. Eng. Ljubiša Jevtić**

Biogradska River and Lalev Stream, as independent tributaries of Biogradsko Lake, bring abundant sediment to the Lake of the same name. The riverbed erosion processes, or fluvial erosion processes, are pronounced in downstream sections, just before the mouth into the Lake, i.e. at around 850 m of length of the riverbed in the former case, and 130 m of length in the latter case.

The Project objective is defined in the Terms of References, and it relates to regulation of Biogradska River and Lalev Stream beds to prevent river erosion by using the facilities that will guarantee full protection of the Lakebed.

The text states: ***"Due to frequent and sudden change in the flow power, and due to certain terrain, geological and other favourable conditions, there is also an adequate form of disbalance between aggressive forces and resistance forces in the riverbed, and as***

such, it became pronounced downstream Biogradska River. In fact, strong processes of river erosion expressed mostly as processes of the riverbed corrosion are observed in the length of around 900 m upstream from the mouth into the Lake. These are in fact processes of intense undercutting and caving of dilapidated and incoherent riverbanks built of moraine material which take place at the height of 1.5 to 2.0 m above the bed. As a result of the lasting destructive running of river water and due to high transport power of the upstream bed profile, downstream river and the river valley are largely silted with sediment as a consequence of a sudden change in the longitudinal drop of the bed, i.e. the occurrence of the so-called spillage drop. Erosion sediment deposited for decades silted practically the entire river valley giving it a convex form due to which the water course splits into numerous bayous or it is, however, in the phase of large meandering from one to the other riverbank".

Based on the estimation made at the time, it was considered that around 3.5-4 ha of the active surface of the Lake was silted with river load. It was also established that continuous destruction of the bed disrupted the flow regime of the Biogradska River. Similar processes as in the Biogradska River are present in the Lalev Stream, as an independent tributary of the Lake, whereby that process in the case of Lalev Stream is limited to the length of around 100 m upstream from the Lake.

The Main Design includes a calculation of maximum flow for high waters for basins of the Biogradska River and Lalev Stream:

- → maximum flow of high waters for the basin of the Biogradska River, occurrence p=1% (100-year waters), amounts to $\mathbf{Q_{max} = 123,70\ m^3/sec}$;
- → maximum flow of high waters for the basin of Lalev Stream, occurrence p=1% (100-year water), amounts to $\mathbf{Q_{max} = 29,60\ m^3/sec}$.

The calculations were obtained by computing and by applying three different types of calculations and, as such, they can be considered to be the relevant values for calculating a hydrograph.

Also, the chapter of the Main Design dealing with sediment hydrology includes a calculation of the probable annual sediment volume flowing into the Lake.

- → The average annual volume of bed load and suspended sediment that reached the Lake amounts to **W = 26 349 m³/year**.

Out of this sediment volume:

- → suspended sediment W_S = 19 590,41 m^3/year,
- → bed load W_v = 6 758,69 m^3/year.

The regulation concept. In order to protect Biogradsko Lake from deposit, the Main Design envisaged the regulation of the Biogradska River in the length of 855 m. The regulation is planned by regulating the bed profile and enclosing it with stone in cement mortar. Since stronger erosion processes are not identified in the middle course and upstream Biogradska River and since all the transported material originates from downstream river, it was deemed necessary to regulate it only in places of its spilling and meandering, due to a small drop and unpronounced bed, which is the last 855 m before the mouth of the Biogradska River into the Lake.

The same regulation method is foreseen for Lalev Stream, whereby a difference is that the regulation length is 132 m from the mouth of Lalev Stream into the Lake.

In order to avoid mud silting of the regulation downstream at the effluent, which is caused by rising of the water level in the Lake, the Main Design proposes tearing down of the spillway built on the natural lateral overflow of the Lake in Jezerštica, since it is considered that building of this spillway led to disruption of the balance between the Lake and the surrounding.

The Main Design includes, *inter alia*, the following useful Annexes:

1. Situation of the Biogradska River and Lalev Stream,
2. Longitudinal profile of the Biogradska River,
3. Longitudinal profile of Lalev Stream,
4. Cross-section of the Biogradska River,
5. Cross-section of Lalev Stream.

- **December 1987, TERMS OF REFERENCE FOR DEVELOPING THE PROJECT OF HYDROGEOLOGICAL AND ENGINEERING-GEOLOGICAL EXPLORATORY WORKS FOR THE PURPOSE OF ENSURING CORRESPONDING MAPS NECESSARY FOR REHABILITATION OF PONORS (SINKHOLES)S OF BIOGRADSKO LAKE which should serve for:**

Looking into hydrogeological characteristics of terrain, i.e. hydrogeological characteristics and functions of rock masses, the relations between ground and surface waters by geological composition andstructure of terrain.

- → Defining boundaries of the hydrogeological basin of Biogradsko Lake, courses and routes of circulation of surface waters.
- → Establishing balance of ground and surface waters.
- → Establishing dependence between precipitation, surface and ground waters, water redistribution regime throughout the year.
- → Establishing morphology of the Lake bottom.
- → Defining engineering-geological characteristics of terrain, with a special reference to cracks in rock masses from the aspect of supplying water to the basin.
- → Defining distribution and physical-mechanical characteristics of Quaternary sediments, their position relative to Paleo relief rocks.
- → Defining micro location of ponors (sinkholes)s (spatial position, dimensions, swallow capacity) of predisposed courses and routes of losing of aquifer water.

- Summary of the work carried put in the period between 11/08/1988 and 29/09/1988

- → Hydrogeological mapping on 1:25.000 maps.
- → **Hydrogeological mapping with preparation of the corresponding 1:5000 map.**
- → **Engineering-geological mapping with preparation of the corresponding 1:5000 map.**
- → Exploratory wells B1-10 m completed; B2-30 m; and drilling of the well B3 initiated.
- → **Dyeing of sinking water on the Lake's perimeter and dyeing of water in piezometers performed.**
- → Water gauging stations set-up on the Biogradska River, Lalevic Stream and two on Jezerštica.
- → Four staff gauges installed on water gauging stations on Biogradsko Lake.

- ❖ December 1987, Report of the "COMMISSION FOR A COMPLEX REVIEW OF THE PROBLEM OF WATER LOSS FROM THE BASIN OF BIOGRADSKO LAKE" states the following ***"Numerous ponors (sinkholes)s are visible along the northeast and southwest perimeter of the Lake. These sinkholes have been known for more than 20 years, and the surface of some of them is sealed with concrete. Such rehabilitation measure has not produced the desired and expected results".***

On 3 November 1987, the water level in the Lake was unprecedentedly low. It is stated that references included data on the Lake's fluctuation of even up to 9 m.

It is stated that the Biogradsko Lake basin is threatened by:

- → Infiltration of water in the basin itself, which increases over time,
- → siltation of the basin by deposits from the Biogradska River and Lalev Stream,
- → washing out, i.e. rise in the permeability of moraine masses between the Lake basin and the Jezerštica spring catchment area, and
- → regressive erosion of Jezerštica, towards the Biogradsko Lake weir.

The Commission states that "***infiltration of the Lake water is the strongest destructive cause, and it should be***

primarily learned about and stopped by adequate measures, i.e. bring it down to a tolerable level".

- **April 1988, ANNEX TO THE PROJECT OF HYDROGEOLOGICAL AND ENGINEERING-GEOLOGICAL SURVEYS FOR THE PURPOSE OF REHABILITATION OF BIOGRADSKO LAKE (PI Republic Geological Survey Institute), Z. Popović with associates**

The Annex to the Project includes the Revision Report for the Project of Hydrogeological and Engineering-Geological Surveys for the purpose of rehabilitation of Biogradsko Lake. Under number 2 of remarks and suggestions, the reviewers stated the following:

→ The ratio of Anisian limestone (T_2^1) and Middle Triassic keratophires and quartzkeratophires (T_2) on the Prognosis hydrogeological profile CD across Biogradsko Lake of 1:10.000 is not logical. The reason is that this ratio on other profiles is presented as a breakthrough. The remark indicates that even then there were dilemmas concerning geology on the large rockfall in the Jezerštica Riverbed. Namely, on geological maps 1:5000 prepared by the Geology Survey, Anisian limestone T_2^1 is singled out at the base of the slope where the rockfall is formed. On the profile presented on Figure 3, the Jezerštica Riverbed is cut into the moraine material. Hence the reviewer's remark that Anisian limestones T_2^1 occur on the surface as a breakthrough.

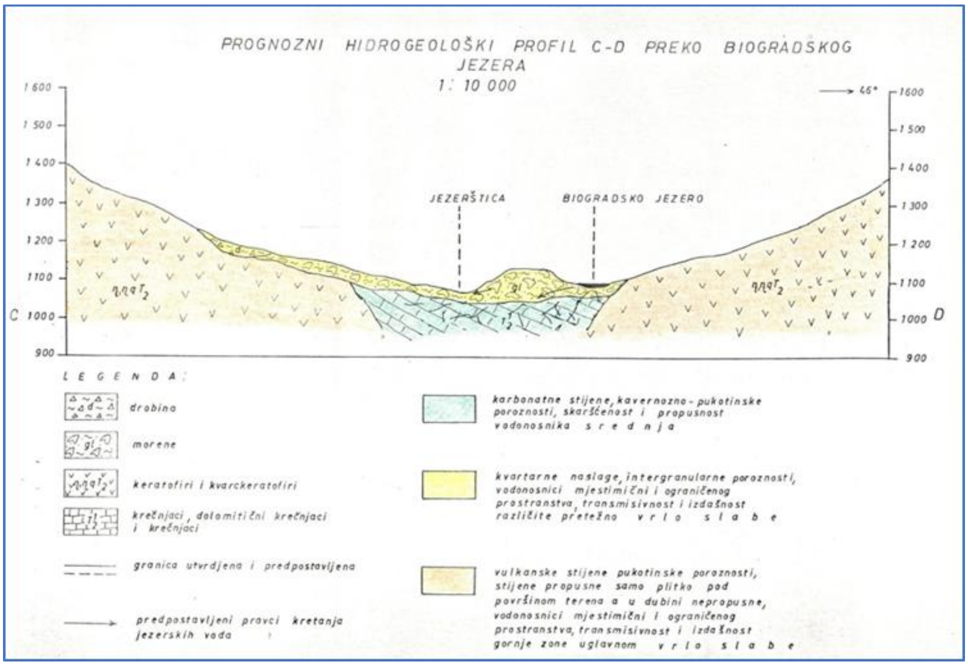


Figure 3. Designed hydrogeological profile CD

On the second profile found in the final Study (Figure 4), Anisian limestones are presented as a breakthrough.

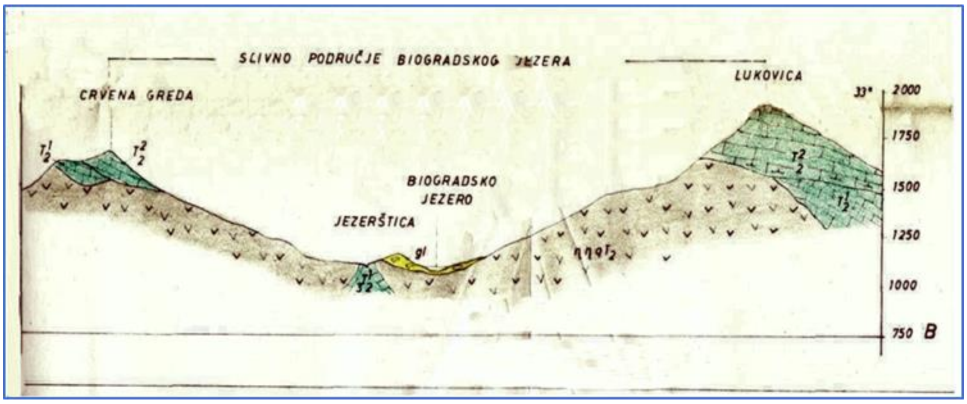


Figure 4. Hydrogeological profile from the Study

While visiting the terrain of the Jezerštica canyon, and by the insight into the geology of the open profile on the large rockfall, a dilemma occurred as to whether the underlying stratum of the moraine material includes Anisian limestone T_2^1, or whether those are quartzkeratophires and keratophires T_2. Our impression was that those were volcanic rocks. In any case, this dilemma must be addressed, since it may significantly influence the Conceptual Design for rehabilitation of the slope where the rockfall is located.

- **March 1989, ANNEX TO THE PROJECT OF HYDROGEOLOGICAL AND ENGINEERING-GEOLOGICAL SURVEYS FOR THE PURPOSE OF REHABILITATION OF BIOGRADSKO LAKE – PHASE II (Zorica Popović) Geology Survey**

The works executed in phase I are presented, by size and type, in the abovementioned Report, while works envisaged under this Annex constitute continuation of the works. The Annex envisages the following types of works:

→ Dyeing of groundwater

"It will be performed on the ponors (sinkholes)s of the bottom of Biogradsko Lake or in executed exploration piezometer wells. The surveys so far have not identified the presence of limestone or sinkholes, but if they exist, they will be dyed during the hydrological minimum when the Lake water level drops the most."

→ Hydrological works

"The remaining hydrogeological works are measurements of the flow on the water gauging stations already set-up on the Biogradska River, Lalev Stream, in two places on Jezerštica and on the sinkhole. Oscillations of the Lake will be measured in parallel with a view to determining the Lake oscillation amplitude and to determine dependence of oscillations in the level of the Lake water and the water running-off by underground routes, out of the basin and towards Jezerštica.

→ Meteorological works
→ Geodetic works
→ Long-term hydrogeological observations

- **March 1989, REPORT ON HYDROGEOLOGICAL AND ENGINEERING-GEOLOGICAL SURVEYS CONDUCTED**

SO FAR FOR THE PURPOSE OF REHABILITATION OF BIOGRADSKO LAKE. (Zorica Popović) Geology Survey

The Report included a short overview of the hydrogeological and engineering-geological surveys conducted until then for the purpose of rehabilitation of Biogradsko Lake (first phase). **"The aim of the survey was to determine hydrogeological conditions of the terrain of the Biogradsko Lake basin, the ratio of surface and ground waters depending on hydrogeological conditions of terrain, and identify, locate boundaries of movement of water in the Lake and routes of underground circulation, as well as places where they especially emerge".**

The purpose of preparing appropriate geological and hydrogeological data and maps is to prepare them for drafting project documents for rehabilitation of Biogradsko Lake from the aspect of infiltration of water in its basin.

The Report states the following **"Previous results of the executed exploratory drilling established the presence of a groove in the paleo relief which is silted by thick moraine material of a highly heterogenic composition, where a part of the groove is far below the Lake's bottom, which allows circulation of the Lake water through the moraine material out of the basin".**

- **1989, STUDY OF THE MORPHOLOGY OF THE BOTTOM OF BIOGRADSKO LAKE. Association of Young Researchers of the Faculty of Forestry in Belgrade. (Dr. Stevan Dožić with associates)**

The goal of the survey conducted in the field during August 1986 was to conduct a detailed survey of the Lake bottom and an immediate perimeter in a way to acquire a 1:500 scale map with equidistance of 1 m.

Since the Lake comprises two parts which can be presented separately, the narrower and longer part extending from northwest towards southeast, and the wider and shorter part extending approximately in the east-west direction, measurements are based on two interconnected networks. Thirty-four profiles are installed on the narrower section of the Lake, and 23 profiles on the wider section of the Lake.

A traverse line comprising the total of 22 points extending along the southern side of the Lake is set-up in the Lake's surrounding. Linking of the traverse line to the known mark was done also by an invert and the open mark on trigonometer located on the watershed towards Jezerštica was used.

The method of measuring by a probe with ribbon was used when measuring depths, whereby the reading accuracy was 1 cm.

After completion of field measurements and data processing, a 1:500 scale map of the Biogradsko Lake morphology was prepared, as well as a map showing the position of profiles. Also, each profile is presented individually in 1:500/1:100 scale, based on which the volume of Biogradsko Lake was calculated at the level of overflow into Jezerštica.

These data are very interesting since they provide a realistic picture of the condition of the Lake's bottom at the time of the survey. These data allow multiple further surveys, and one of them that especially stands out is the possibility to calculate the volume of sediments of the Biogradska River deposited in the Lake in the previous period. Usability of data is especially unquestionable when the proposal will be prepared for cleaning of the wider section of the Lake, in the place of merging of the Biogradska River and Lalev Stream, i.e. for rehabilitation of the Lake's condition.

The data presented with regards to the position of profiles and their transverse processes allow controlling sediments with respect to siltation. The total volume of water in the Biogradsko Lake to the afflux level (1.099,08 m.a.s.l.) amounts to 655.967,30 m^3, of which 490.353,95 m^3, which makes 25.21%, belongs to the narrower part of the Lake. The greatest recorded depth in the Lake at the time of the water level at the overflowing level at 1.099,08 m.a.s.l. amounted to 11.30 m.

- **22/06/1995, FINAL REPORT ON THE WORKS CONDUCTED SO FAR ON THE FACILITY "HYDROGEOLOGICAL AND ENGINEERING-GEOLOGICAL SURVEYS FOR THE PURPOSE OF REHABILITATION OF BIOGRADSKO LAKE" (V. Radulović with associates)**

The Reports presents the synthesis of exploratory works conducted in several (four) phases. The works started in 1988, it is not known when they were completed, but it is known that they were conducted with interruptions. As all designed works were not conducted, the Report cannot be considered complete.

- → **Hydrogeological mapping:** Field reconnaissance was performed in the total area of 40 km^2. The results are presented on the hydrological map 1:25.000.
- → **Detailed engineering-geological mapping:** The preliminary engineering-geological mapping was performed on the map R 1:100.000 in 1988, and it was amended in 1995 after acquiring the topographic map R 1:5000. The detailed engineering-geological mapping was performed on the total area of 4 km^2.
- → **Exploratory drilling:** Exploratory drilling in the total length of 106 m with 7 wells in total was performed in order to determine lithology composition and thickness of the moraine sediment, i.e. to determine the depth to paleo relief and rocks masses in the paleo relief, granulometric composition and permeability of the moraine material, determine the presence of ground waters, sinking zones, courses and routes of circulation of the Lake water out of the basin. Volcanic rocks (keratophires, quartzkeratophires) are drilled in all wells in the paleo relief. Based on the data acquired by drilling the authors established "***the presence of a groove in the paleo relief silted with thick deposits of moraine material of highly heterogenic composition, whereby a part of the groove is located far below the Lake bottom which allows circulation of the Lake water".***

- → **Taking samples from wells and laboratory testing:** Samples were taken for laboratory-based determination of permeability of separated lithology constituents. Testing was not performed.
- → **Geodetic works:** Geodetic works include instrument survey of levels and coordinates of exploratory-piezometer wells and water gauging stations.
- → **Dyeing of ground waters and observation:** Dyeing of ground waters was performed on two exploratory-piezometer wells B–2 and B-3. Dyeing of underground course was performed with sodium-fluorescein, B-2 with 2 kg of dye and B-3 with 3 kg. Observations were performed on the springs in the Jezerštica Riverbed. The observations lasted for 7 days, but there was no emergence of water. While controlling water in the well B-3, three days after dyeing, the presence of a high concentration of marker was established in the well.
- → **Hydrology works:** The total of 4 water gauging stations were set-up for the purpose of flow measurement: two on Jezerštica (one immediately on the outlet from the Lake, before flowing into Tara); one on Lalev Stream and one on the sinkhole north of the Lake. The total of 5 staff gauges are installed on water gauging stations (2 on Jezerštica, 1 on Lalev Stream, 1 on the sinkhole). As for hydrological works, flow measurements were conducted on already established water gauging stations: Biogradska River, Lalev Stream, two stations on Jezerštica and on the sinkhole.

  These works included measuring of oscillations of the Lake water level with a view to determine underground run-off. The measurements were conducted by a current meter on 5 flow profiles on 3 occasions. **Data processing is not completed due to missing data about the Lake volume which are acquired based on the data about the Lake level and the morphometric map of the Lake.**
- → **Meteorological works:** Meteorological works were only related to the processing of existing available data

on precipitation and evapotranspiration, primarily in the basin of Biogradsko Lake.

The part of the report addressing hydrography and hydrology data states the following: ***"Mapping of the Jezerštica riverbed identified places of discharge of groundwater in several places which are accurately located through geodetic works. Water is assumed to discharge in these places below steep sections in the Jezerštica Riverbed and under <u>red, very broken limestone</u> overlaid by moraine material".***

The chapter addressing the hydrogeological properties of rock masses, the part of the text concerning impermeable rocks, states the following: ***"Laboratory research of core samples taken from exploratory wells established that the transition coefficient of moraine material ranges between 1.9 x 10^{-5} cm/s and 6.0 x 10^{0} cm/s. Overall, given the high alteration of sediments by vertical profile, it can be said that the filtration characteristics of moraine sediments do not allow fast water circulation... Mapping of terrain established that springs do not emerge in the steep section on the southwest side of Biogradsko Lake, but that larger springs emerge in the Jezerštica Riverbed. Water of Biogradsko Lake is lost along the northwest perimeter of the Lake, through the <u>exposed outcrops of cracked volcanic rocks or limestones.</u>***

The Conclusion of the Study states that the following was accomplished through the executed exploratory works:

- → the geological composition of the immediate surrounding of the Lake was addressed, thickness of moraine material was determined by drilling, and the coefficient of their permeability was acquired by geomechanical survey;
- → the results were acquired with respect to hydrogeological characteristics of the terrain and rock masses in the immediate surrounding of Biogradsko Lake;

→ observation posts were set-up (piezometers, overflows etc.) for further observations.

It further lists the missing works that need to be completed in order to acquire maps for developing the rehabilitation project:

→ additional exploratory drilling,
→ **additional hydrological measurements with a view of identify underground run-off and water balance,**
→ since the place of water discharge was not identified by dyeing, the proposal is to implement geophysical method (MISSE A LA MASE) in order to identify the direction of water discharge.

❖ **1991, A POSSIBILITY TO PRESERVE BIOGRADSKO LAKE AS A NATURAL AND ECONOMIC JEWEL. Vladislav Vlahović (Natural and social values of the National Park Biogradska Gora), Montenegrin Academy of Sciences and Arts (CANU), Book 23**

The paper talks about a possibility to transfer overflowing and infiltrating waters of Biogradsko Lake into useful energy and a possibility to implement the idea for the Lake to be a natural and economic jewel.

The size of Biogradsko Lake basin was determined in the paper and according to Vlahović its size is 33 km^2. Also, it is underlined that around 72 (71.082) million cubic meters of water falls on the overall area of the basin a year. Given the impermeability of the basin, all that water, except the water retained by plants, and the water that evapotranspirates into the atmosphere, runs-off into Biogradsko Lake and Jezerštica. This volume of water constitutes 62.22% of the said precipitation.

During high waters the level of the Lake reaches 1.096 m.a.s.l. and captures the Biogradska River delta, and its size covers 273.333 m^2 at that time. The Lake oscillates 6 m at average, and the water oscillations in the Lake during the driest years reach the value of 9 m.

In order to remedy the losses of water from the Lake and eliminate the negative impact of backfilling of the Lake with material resulting from erosion processes, the author considers ***"the possibility of building facilities which would increase afflux of water to the Lake, eliminate the sinking and maintain a constant level of the Lake water. The facilities would serve the hydro power plants Biogradska River and Jezerštica".***

The HPP Biogradska River would be located at the mouth of the Biogradska River into the Lake, at 1096 m.a.s.l. The Lake would be at 1240 m.a.s.l., and its total volume would be 0.4 x 10^6 m^3. The planned production from this energy facility would amount to 12 x 10^6 kwh. The production in the HPP Jezerštica would amount to 56,67 x 10^6 kwh.

The author states the following in the paper: ***"If we leave the water of Biogradsko Lake to keep running-off freely through sinkholes and permeable moraine wall, it will disappear in the near future as many glacier lakes on the mountains of Montenegro have disappeared".***

With respect to the protection of the Lake from infiltrating water, the author states: ***"Biogradsko Lake would be secured from infiltrating waters by a grout curtain in order to intersect the moraine sediment and bond laterally and in depth to underlying moraine, but those which are practically impermeable".***

Also, the paper offers information that an attempt was made in 1950 to eliminate the Lake infiltrating waters by means of a concrete carpet along the bottom of the Lake. That attempt did not produce positive results.

- **January 2005, BIOGRADSKO LAKE, PRELIMINARY DESIGN OF ANTI-EROSION PROTECTION. Radosav Nikčević, Prof. Dr. Ratko Ristić. (Greens of Montenegro)**

The intention of the author of this document is to prepare the preliminary design for rehabilitation of the slope in the Jezerštica Riverbed which is exposed to progressive erosion which may lead to the disappearance of Biogradsko Lake.

According to the author, the Project would solve the erosion of the endangered frontal moraine which forms the natural dam of Biogradsko Lake on its northwest side. The presented solution is technical-biological one.

The following was prepared within the Study:

- → an analysis of erosion processes (magnitude, type and intensity),
- → an analysis of the manner of use of land in the basin,
- → pedological conditions in the basin,
- → meteorological-climate conditions in the basin,
- → calculation of the sediment yield,
- → the concept of protecting the Biogradsko Lake.

The part of the text dealing with the main natural characteristics of Biogradsko Lake states ***"At high water level, due to the effect of hydrostatic pressure, intense water inflow takes place whereby the smallest particles start moving. Thus, cohesion between the frontal moraine building material becomes increasingly weaker, as well as the stability".***

The author estimates that 30 to 50 l/s of water is lost by leaching through the moraine material and ends in the Jezerštica Riverbed.

In the Chapter relating to erosion processes in the Biogradska Riverbed, the authors state: ***"The inflow of erosion material caused the formation of a vast surface in the zone where the Biogradska River flows into the Lake. A large volume of material backfills the river valley, the flow loses the transport power thus often modifying the bed, channelling into bayous and creating meanders. Argillo-aranaceous material with a high content of humus is deposited in the zones closer to the Lake causing the development of abundant vegetation, which makes this part difficult to access. The surface of the Lake is reduced by 4-5 ha by sediment deposition processes. The flow introduces the finest particles to the Lake thus creating 2-3 m thick sludge in some depressions".*** The erosion coefficient is determined according to Gavrilović and equals Z=0.3.

The hydrological calculation was also prepared. The value of high water of Jezerštica was acquired based on the maximum recorded heights of the overflow nappe on the unsubmerged rectangular overflow amounts and equals 23.8 m^3/s. The value of maximum waters of 40 m^3/s is taken for the purpose of calculating the stability of the slope.

A calculation of the erosion production and sediment yield for the Biogradska River basin was also made:

- the overall annual production of erosion material amounts to W_{year}=25671,35 m^3. The hydrographic network receives Wp=21897.7 m^3 and expressed as a specific sediment yield (bed load and suspended), it amounts to W_{psp}=762,99 m^3/km^2/year.

For Lalev Stream:

- Total annual erosion production equals W_{year}=3130.6 m^3. The hydrographic network receives Wp=1922.2 m^3 and expressed as a specific sediment yield (bed load and suspended), it amounts to W_{psp}=549,21 m^3/km^2/year.

According to authors, protection of Biogradsko Lake includes:

- **protection of the right riverbank of Jezeršitca from undermining.** Three options are proposed for this activity:

  a) a retaining wall of large pieces of stones and relocation of Jezerštica Riverbed,
  b) building a retaining wall of stone stacks,
  c) developing a transversal facility (partition) at 20-30 m from the lowest point of the endangered riverbank.

- **Rehabilitation of colluvium debris and ravines on the moraine wall** for which stabilization walls are planned, as well as wooden braids for rehabilitation of ravines.

- → The authors plan to achieve the **protection of the Lake from siltation by erosion material** by applying:

    a) technical measures on slopes,
    b) technical measures in riverbeds.

- ❖ **1991, HISTORY OF THE NATIONAL PARK BIOGRADSKA GORA (Natural and social values of the National Park Biogradska Gora) Dragiša Dožić; Montenegrin Academy of Sciences and Arts (CANU), Book 23.**

National Park Biogradska Gora has its history and a turbulent past. The article highlights distinctive periods in the existence of Biogradska Gora so far. The periods are linked with political circumstances in Montenegro, which also dictated the attitude of the society towards this natural rarity.

Within the existence of Biogradska Gora, a reference was made to the following periods of its existence:

- → the period of the Ottoman Empire until 1978,
- → the period of the rule of the Petrović Dynasty until 1918,
- → the period between the two World Wars,
- → the period during the World War II,
- → the period after liberation, 1945 to 1952,
- → the period since 1952, when Biogradska Gora was declared the National Park, until 1965,
- → the period of work of the Administration for the Protection of the National Park Biogradska Gora, from 1965 to 1968,
- → National Park within the Tourism and Hospitality Enterprise (TUP) Bjelasica, from 1969 to 1978,
- → The period since 1978 when Biogradska Gora was established as a separate interest group (enterprise) under the Law on National Parks.

Each of the above periods had its own characteristics, and some of them were crucial to further survival and status of Biogradska Gora.

The part of the article relating to the period between 1965 and 1968 states the following ***"The project for grout injecting of sinkholes in Biogradsko Lake was prepared but not implemented due to the lack of funds, and it burned in a fire with other Administration documents in the building of the Municipal Assembly in 1975."***

The paper was written in 1991 and it also states: ***"Drying of trees in Biogradska Gora is observed in recent years, as well as an increased number of sinkholes in Biogradsko Lake, which are especially visible during dry summers, from the end of August to the end of October".***

- **1991, GEOLOGY OF THE BJELASICA MOUNTAIN (Natural and social values of the National Park Biogradska Gora) R. Mihajlović; V. Radulović; Montenegrin Academy of Sciences and Arts (CANU), Book 23.**

The paper presents geological structure (stratigraphic-lithology-facial composition and tectonic composition), geomorphological, hydrogeological and engineering-geological characteristics of the terrain of the Bjelasica Mountain which makes the National Park Biogradska Gora.

The overview itself is at the level required for developing spatial-planning documents that should ensure rational use of natural resources from the National Park, with adequate protection and optimum development.

The paper provides an overview of the geological structure of terrain from Early Palaeozoic to Quaternary, followed by a reflection on the tectonic composition of the terrain.

The Chapter on geomorphological characteristics of the terrain provides zoning of the terrain relative to their morphometric characteristics and dominant geomorphological processes, and the following have been singled out:

- → terrains prone to washing, gullyng, rupture and sliding,
- → terrains prone to karstification,
- → terrains resistant to denudation and karstification processes.

Special attention is paid to hydrogeological features of terrain. From the hydrogeological aspect, and taking into account the behaviour of rocks that build the area of Bjelasica with respect to surface and ground waters, i.e. their dominant type of porosity, they are divided into:

- → hydrogeological insulators,
- → hydrogeological complexes,
- → hydrogeological collectors.

As a hydrogeological phenomenon, Biogradsko Lake is described as the lake located at 1094 m.a.s.l., with average surface of around 228.500 m^2, maximum depth of 12.1 m and the volume of around 1052760 m^3. The basin of the Jezerštica River, with Biogradsko Lake and the Biogradska River, is said to have the surface of around 38 km^2.

The paper states the following: ***"The territory of the Bjelasica Mountain comprises sinkholes with intermittent and continuous swallowing of water. It is clear that these waters occur in terrains built of rocks belonging to the group of hydrogeological collectors and hydrogeological complexes. Among these phenomena, especially important are those along the perimeter and at the bottom of Biogradsko Lake. Sinkholes occur along the northern and north-western perimeter of the Lake, in moraine debris, which seemingly lie on permeable Middle Triassic limestone. The infiltrating waters of Biogradsko Lake emerge west from the Lake, on permanent karst spring in the Jezerštica Riverbed".***

In addition to the reference sources presented here, the more recent documents have also been reviewed, such as for instance:

- → Radulović M., Pejović R., Tomanović Z. Sekulić G (2007) Report on the visit to erosion-threatened slope in the

Jezerštica canyon in the zone of the National Park Biogradska Gora. Civil Engineering Faculty (UMNE), Podgorica;

→ Čađenović N., Blečić V., Radulović M.M. (2012) Possibility of rehabilitation of Biogradsko Lake by anti-filtration works. Proceedings of XIV Symposium of engineering geology and geotechnics with international participation, 27-28 September 2012, Belgrade, pp. 519-528; ISBN 987-86-89337-01-3.

3. MAIN NATURAL CHARACTERISTICS OF THE BIOGRADSKO LAKE BASIN

The National Park Biogradska Gora belongs to the region of northeast Montenegro, located between Tara and Lim rivers, in the central part of the Mountain Bjelasica. It is situated between 42°50′5" and 42°56′7" latitude north and 19°34′7" and 19°42′3" longitude east. Parts of the NP Biogradska Gora are situated in Kolašin, Mojkovac and Berane municipalities. The NP Biogradska Gora is located in the most beautiful part of Bjelasica and, with respect to tourism development, it has a very favourable geographic position.

The Park's boundary starts with the River Tara, extends through Jarčeve Strane and gradually rises to the Crna Glava top (2.137 m), and then goes down to the Lumerski Stream and the River Tara (Radojičić, 2002).

The central part of the Park comprises: Biogradska River, Biogradsko Lake that the Biogradska River discharges into, and Jezerštica, a distributary of Biogradsko Lake and a tributary of Tara. The area of Biogradsko Lake with Biogradska Gora and the Jezerštica Valley occupies around 1.600 ha, of which around 85% is under dense forest of rainforest type (Radojičić, 2002). In addition to Biogradska Gora, the National Park includes mountain tops Jarčeva Strana, Crna Glava (2.139 m), Zekova Glava (2117 m), Troglava (2072 m), Ogorela Glava and Donji Lumer. The total territory of the Park equals 5.650 ha. The protection belt or the Park's contact zone is almost three times larger.

3.1. Geographic position

Biogradsko Lake is situated on the southwest side of Bjelasica, at a height of 1.094 meters. It was created in the terminal basin of the glacier behind the frontal moraine dividing former glacial through. The Lake is of an irregular shape, and the length of the shoreline is about 3.3 km. Steep wooded slope Jarčeve Strane is found in the northern part of the shore. The eastern riparian belt about 500 meters long is a plain created by sand and gravel. The shoreline moves in that part depending on the water level. At the water level of 650 cm, it reaches the length of 857 meters and width of 410 meters. The average width of the Lake is 261 meters, and the largest surface is 228.500 m^2. The maximum depth at this water level is 12.1 meters, and the average depth is 4.5 meters (Stanković, 1975).

Biogradsko Lake has a favourable position since it is situated in the lowest part of Bjelasica, and there is the main road in its immediate vicinity that connects north and south of Montenegro. It is 16 km away from Kolašin, and 12 km away from Mojkovac. About 3 km long asphalt road leads from the main road to the Lake. The Lake water temperature during summer exceeds 18°C, and in addition to the conditions for other forms of recreation, the Lake also offers bathing opportunities in this period.

Biogradska Gora is a rainforest area surrounding the basin of Biogradsko Lake. It is characterised by a highly diverse wildlife, a great wealth of flora and fauna, and the presence of plant communities which are very rare. Due to accessibility and passability of the rainforest, it represents a true outdoor laboratory for biologists, ecologists, geographers and all nature lovers.

3.2. Climate characteristics

The geo-spatial specificity of the territory of Montenegro is expressed also by its position, which causes a pronounced thermal asymmetry between cold northern Europe and extremely hot Northern Africa. These air masses very often collide and mix (occlusions) in the territory of Montenegro, followed by extremely diverse physical and meteorological characteristics. These systems strongly affect the weather conditions and define the types of climate, from harsh to very favourable (in all seasons).

Direct and indirect links between climate and relief are very much present in the studied area, so the climate characteristics of the catchment area of Biogradsko Lake have the characteristics of the alpine climate, but there is also an evident influence of the Mediterranean Sea which is reflected through the precipitation regime and a somewhat higher mean temperature in the coldest month.

As per Köppen classification (Burić et al, Climate Atlas of Montenegro, 2012), the area of the respective location, and its complementary hinterland, belongs to the following climate types:

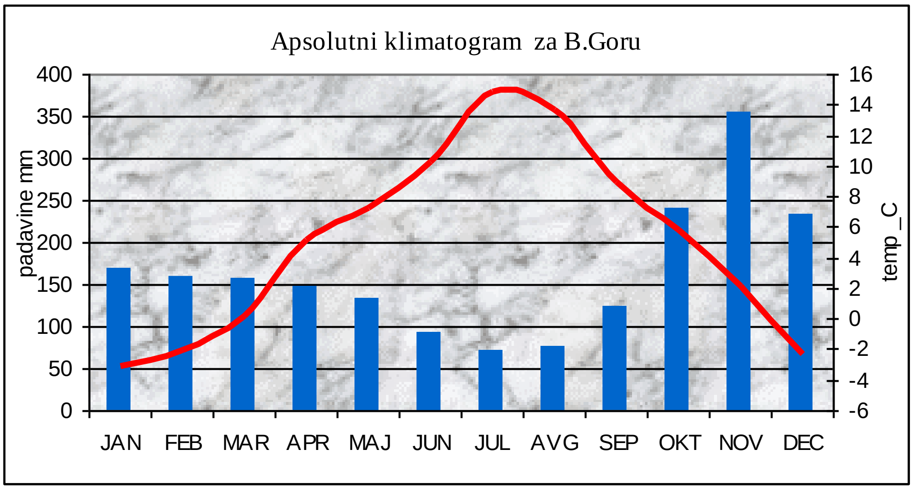
- Cfws’’bx" (moderately warm climate without pronounced dry period during the year, with lower precipitation in the winter period of the year. Summers are relatively warm. Maximum precipitation occurs in early summer and late autumn), and
- Dfbx’’ (snow forest (boreal) climate without pronounced dry period during the year. The average temperature in the coldest month is below -3 °C. The precipitation has a pronounced maximum at the end of autumn).

Mean annual temperature is around 2ºC, 0ºC in the highest areas, around 2ºC in mountainous areas and around 4ºC in lower areas. The isotherms of mean annual temperatures extend in the north-south direction, indicating the fact that that there is a drop in temperature from west towards east, with the concentration of low temperatures at the tops of mountain masiffs. The mean air temperature for the vegetation period is around 6ºC (mountain areas) to 12ºC (lower areas-Tara valley). The average temperature in December is around -4ºC (the highest mountain areas) to around -1 ºC in lower areas. Maximum mean temperature in July is around 16ºC (higher areas) to around 22ºC (lower areas). The number of icy days is around 40-50, i.e. that is the number of days in a year when the temperature remains below zero throughout the day.

The period with positive temperatures lasts around 220 days (mountain areas) to 280 days (the lowest areas in the Tara valley).

Table 2. Absolute climatogram for Biogradska Gora

	1	2	3	4	5	6	7	8	9	10	11	12	G
T (mm)	-3.1	-2.1	0.2	5.1	7.2	10.3	14.8	13.7	8.9	5.8	2.1	-2.3	5.05
RR (°C)	170	160	158	148	134	92	71	77	124	240	354	234	1962



Source: *Čurović M, PhD Thesis*

The average annual precipitation in the studied area ranges from around 1750 mm (lower areas) to around 2000 mm (higher and eastern areas). The precipitation for the vegetation period ranges from around 500 mm to around 700 mm. The average precipitation in January is around 150 mm to 200 mm, while the average precipitation in August is around 70 mm to 80 mm. The number of days with precipitation above 10 mm is around 55 to 70 days a year.

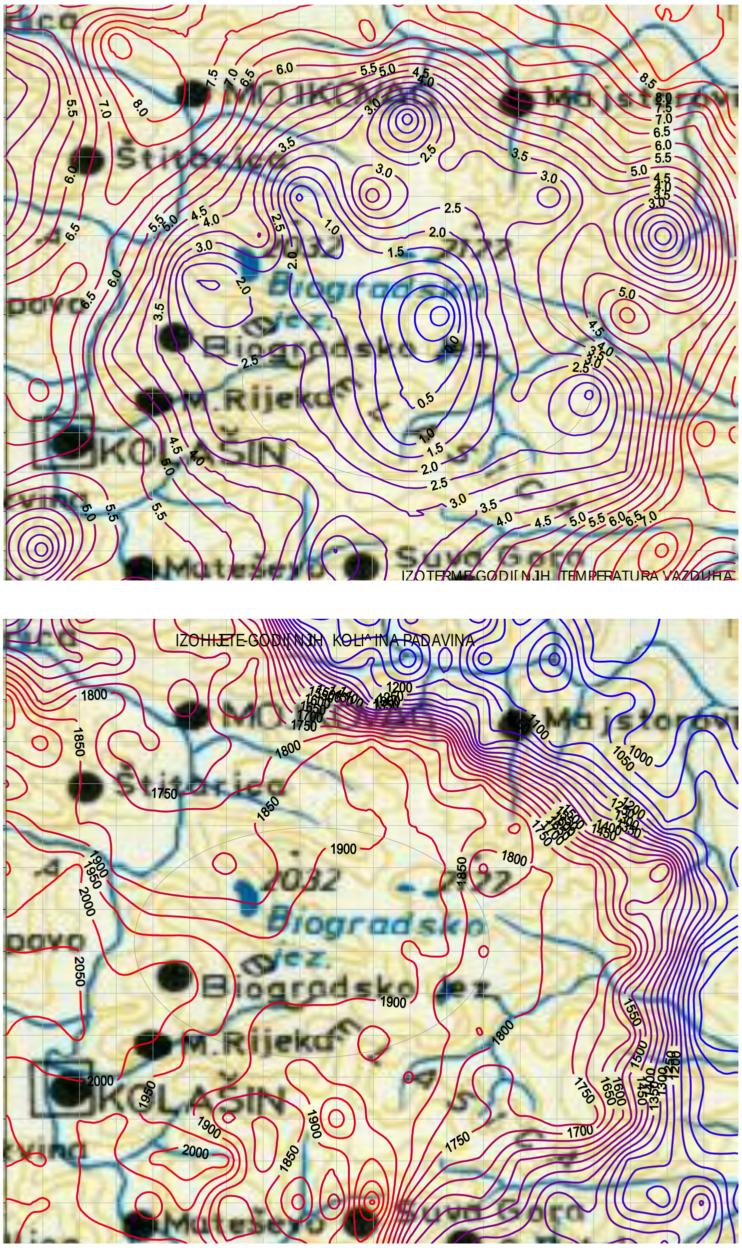


Figure 5. Maps of isotherms and isolines for the studied area
(Source: Čurović M, PhD Thesis)

Figure 5 shows a disposition of isotherms for air temperature and a disposition of isolines for annual precipitation for the area of Biogradska Gora. The air temperature isolines are drawn by a half-degree step, while precipitation isolines were drawn by a 50 mm step. The highest gradients-concentration of isotherms is found in the zones with sudden changes in altitude. There are two centres with temperature below 2ºC in the territory of Bjelasica, one of which occupies a significantly larger territory. Isotherms have a highly pronounced concentration west or east from these centres.

Mean maximum height of snow cover is around 110 cm to 200 cm. Western areas have the lowest height of the snow cover of around 110 cm, while eastern-mountainous and southern areas have the average maximum snow height of around 200 cm. The number of days with the snow cover exceeding 50 cm is around 20 days in western areas to 100 days in eastern and southern areas-mountain tops.

Extending of isotherms in the south-north direction indicates the fact that temperature changes very quickly and intensively in the west-east direction and very slowly in the south-north direction. Consequently, the average mean annual air temperature in the studied area of monodominant beech forests equals to 3.5-4ºC, 3-3.5ºC in valuable broadleaved stands, 2-2.5ºC in the area under beech-fir forests, which applies also to the sites under three-dominant fir and spruce communities.

In the territory of Biogradska Gora, isolines (Figure 5) have a very weak spatial change in the entire territory. Although this is a high mountainous zone, there is a reduced amount of precipitation compared to lower areas in the south, the reason being the generation of the precipitation process in the mountainous zones before Bjelasica. Since there is a significantly lower precipitation in eastern parts of Bjelasica, there is a very strong concentration of isolines with extreme gradients in those parts. This zone occupies the entire eastern side with a linear arc of 180 degrees around Bjelasica where precipitation is lower for a whole 1.000 mm a year and amounts to around 1.850 mm a year.

3.3. Geological characteristics

The geological structure of the studied terrain, which was a subject of this Study and relates to a wider coverage of the Biogradsko Lake basin, comprises Permian, Triassic and Quaternary sediment formations, where special importance and significance is attributed to the volcanic rocks created as a consequence of a strong volcanic activity that took place during Early and Middle Triassic, in parallel with sedimentation of Dogger and Malm carbonate sediments, as well as Quaternary sediments that frame Biogradsko Lake through the prominent frontal and lateral moraines, and alluvial deposit.

While being relatively widespread on Bjelasica, **Permian** sediments are not significantly represented in the Biogradsko Lake basin. The age of the sandy-schist series, which has a dominant share in the Permian lithological composition, is determined indirectly through fossil-bearing limestone lens found sporadically in that series. Lithologically, Permian sediments on the indicated part of the terrain are represented by sandstones, schists, alevrolites, marls, conglomerates, quartzites and dolomite limestone.

Figure 6. Permian sediments
(Photo: Dubljevic V., 2021)

The largest part of the Permian terrain is built by sandstone and schist. Out of the listed lithological components, the most represented are mica, quartz and conglomeratic sandstone.

Mica sandstones occur mainly as layers or as intercalations in marly-clay sediments. Their colour is light grey to dark grey. They are built of quartz grains (40-60%), plagioclase, muscovite, sericite and chlorite (15-20%). Cement is silicic or silicic iron. They are hard and compact. Quartz sandstone occurs also in the form of layers and banks. They are very hard and compact. Their colour is grey to dark grey. Quartz is a dominant constituent (up to 95%) and occurs in the form of grains. In addition to quartz, plagioclase and muscovite occur in a smaller percentage. Cement is of silicon type.

From the very complex composition of Permian sediments, considering also their age, it is clear that they are highly homogenized compact rock masses characterized by water impermeability and must be singled out on hydrogeological maps and in profiles as insulating rocks.

The catchment area of the Biogradsko Lake spring is built of various Middle **Triassic** rocks. The volcanogenic sediment formation T_2^2 should be described primarily due to its distribution in the catchment area.

Limestone T_2^2. Massive crystal limestones are represented by folded stratified limestone on intercalations and cherts nodes. Based on sedimentology surveys, the following were identified in this limestone series: oosparite, biosparite, micrite, pelmicrite, intrabiomicrite, intrabiosparite, microsparite, arenaceous oosparites and arenaceous calcarenite.

We think it is not necessary to describe individual types of sedimentology components of crystal limestone. It is more important to underline that crystal limestones are not highly karstified and typical karst forms are not observed on the surface. This indicates that ground water circulation through this type of rocks primarily does not take place through caverns which are the consequence of karstification, but they find their way through small and numerous cracks which were created by strong, dynamic and continuous tectonic processes which also caused a highly complex geological structure of the terrain.

Figure 7. Triassic massive crystal limestones
(Photo: Dubljevic V., 2021)

Ladinian massive crystal limestones of Bjelasica have magmatic rocks in the underlying stratum, which is very important for hydrogeology, overthrusted by Permian sediments, which is especially visible on the southern side of the Ključ masiff. Thickness of massive crystal limestones is around 450 m, as estimated by the author of the Basic Geological Map 1:100000, sheet Ivangrad.

Volcanogenic – sediment formation T_2^2. This formation occurs in zones next to large eruptive effluent, as the case is with locations in the wider surrounding of Biogradsko Lake.

In addition to vulcanite, the composition of this formation includes tuffs, tuffites, marls, chert and limestone. Tuffs and tuffites that occur in this series appear as precipitated rocks formed by volcanic and volcanoclastic material. Those are usually green, brown, grey-green, and sometimes completely modified rocks. They are usually massive, and rarely of schisty and striped texture.

Most frequently, they belong to crystaloclastic tuffs and tuffites. It is characteristic for them that plagioclase grains in fragments are fully kaolinized. The binder with these series is most often built of cericite, chlorite and silicic matter. Marls are rather frequent in this formation. The colour is grey, brown or green, massive but stripped texture. The composition largely varies.

Figure 8. Vulcanogenic sediment series of tuffs with marls
(Photo: Dubljevic V., 2021)

By increasing of the carbonate component (calcite) they turn into sandy and marly limestone, and by increasing of clastic fraction (quartz, feldspad, chlorite) they turn into sandstone or tuffaceous sandstone.

Cherts are mainly dark red, grey, light grey and dark grey. They occur as intercalations, groups of layers and rarely as lens. They usually follow silicic-sericite schists argilophytes and alternate with them. Tuffites, limestone and other constituents occur together with them. Thickness of structures of this formation is variable, from a few tens of meters to 250 m.

Magmatic rocks belong to Triassic volcanism and represent typical submarine effluents. They alternate on various sediments (limestone, cherts, marls, clayey schists etc.) created during dormancy of submarine volcanoes.

The cycle of creation of these rocks starts in the Anisian. At the beginning, those were calm plate lava effluents interrupted by explosive phases when volcanic breccias, and later tuffs, were created. The volcanism in this terrain ends in the Ladinian with typical lava basins which alternate with tuffs and volcanic breccias. At the same time, the end of the Triassic volcanism is marked with the said volcanogenic-sediment series where tuffs, tuffites and volcanic breccias alternate with limestones, marls, sandy marls, clayey schists and cherts. Volcanoclastic material especially dominates over volcanic material on Bjelasica, which indicates that volcanism in some phases was highly explosive.

Figure 9. Magmatic rocks
(Photo: Dubljevic V., 2021)

The rocks studied in the area that is important for preparing this Study belong to keratophires and quartzkeratophires, and their tuffs, while andesites occur very rarely.

Keratophires and quartzkeratophires are rocks of almost completely massive appearance, weaker or better pronounced schistosity is occasionally observed. The colour is light green to dark green, rarely grey and dark grey.

There are no significant fluctuations in the mineral composition, other than varying of the quartz content. In addition to quartz, plagioclases occur in these rocks as phenocrystals, followed by potassium feldspars in alkaline keratophires, sometimes micropertites and fully modified coloured constituents. Apatite, zircon and metallic minerals are secondary constituents.

When considering chemism of rocks, it must be borne in mind that alternation processes that affected these rocks have caused, to a lower or higher extent, changes in the primary chemical composition of the rocks.

Based on the large number of chemical analyses of these rocks, it can be concluded that SiO_2 content in most keratophires fluctuates between 57% and 62%, while some varieties contain only 52-54%. The content of SiO_2 in quartzkeratophires ranges between 65% and 72%. The volume of total iron varies most often between 4% and 5%, and MgO between 0.30 and 2%. The content of CaO is regularly low and ranges between 1% and 3%. The high content of Na_2O and low content of K_2O are particularly characteristic. Increased content of potassium is observed in quartzkeratophires.

Chemical composition of quartzkeratophires of Bjelasica is presented in Table 2.

Table 2. Chemical composition of samples of quartzkeratophires of Bjelasica

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	Cao
71.81	0.33	13.41	2.60	1.97	0.06	0.30	1.12

Na_2O	K_2O	P_2O_5	CO_2	S	H_2O	%
6.75	0.44	0,01	0,32	0.03	0.73	100

The importance of underlining chemism of volcanic rocks of Bjelasica is reflected in their contribution to the structure of the catchment area of Biogradsko Lake whereby they constitute lateral and underlying barrier for circulation of ground waters.

Quaternary sediments in the area which Biogradsko Lake gravitates towards are represented in a form of moraine material created as a consequence of the glacial erosion, by alluvial sediments the products of fluvial erosion of the Biogradska River, Lalev Stream and Jezerštica River, and by deluvial sediments created by decomposition of the surface rock material and its gravity subsidence, washing-off and accumulating at the foot of slope sides.

Moraines occur as a consequence of the glacial erosion or movements of glaciers during the last Ice Age (Pleistocene). The moraine material is represented by rock blocks, gravel, sandy clay and pebbles of various mineralogical and petrographic composition resulting from a diverse geological composition of the foundation along which the glacier moved eroding thereby the rock mass on its route and accumulating it in the area of reduced energy in the form of frontal moraine partitioning the glacial through, and lateral moraines. Rocks belonging to vulcanites, volcanogeno-sediment formation T_2^2, limestones T_2^2 can be found in the composition of the moraine material, and a smaller amount of Permian sediments can also be encountered in the material. Thickness of the moraine material can range from several meters to 50 m.

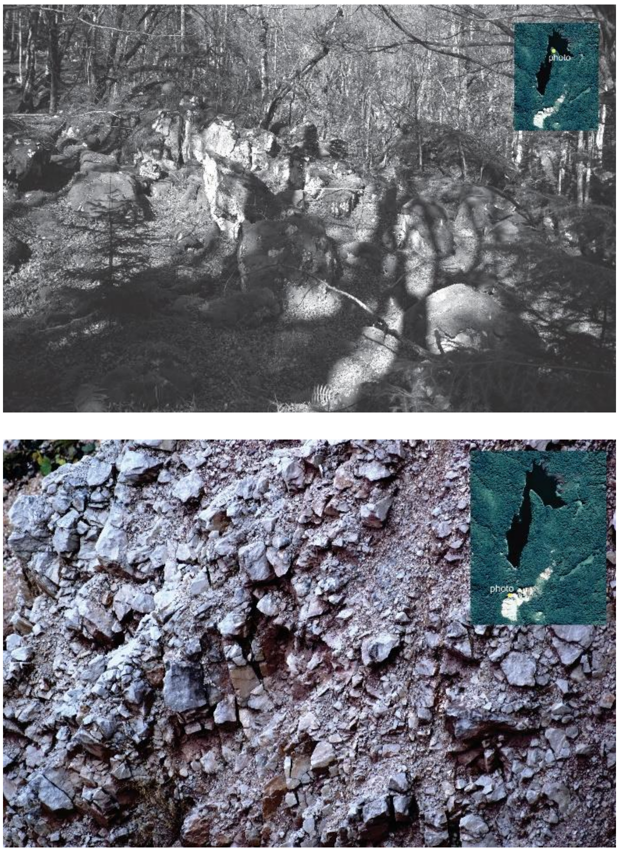


Figure 10. Limestone blocks in lateral moraine (a) and moraine material (b).
(Photo: Dubljevic V., 2021)

Alluvial sediments are deposited in riverbeds of the Biogradska River, Lalev Stream and the River Jezerštica. Sediments contain gravel, sand and sandy clay. Thickness of alluvial sediments ranges up to 10 m. (Geological Survey, 1995). The material is well-rounded and heterogenic by composition, both in mineralogical and petrographic terms.

Alluvial sediments in the Biogradska River delta are flooded by Biogradsko Lake during most of the year resulting in the occurrence of crossed sedimentation due to deposition of finer particles in the Lake conditions and coarse particles brought by the Biogradska River.

Figure 11. Fine lake sediments covering alluvial sediments
(Photo: Dubljevic V., 2021)

Going upstream the Biogradska Riverbed, increasingly large material is encountered in the alluvial sediment as a consequence of increased erosion energy of the river course. Considering that the estimated maximum, hundred-year flow of the Biogradska River amounts to 127.70 m^3/s, and of the Lalev Stream amounts to 29. 60 m^3/s, finding boulders which may be even one meter in size in the riverbed is logical. Due to lasting destructive effect of the River, downstream section of the riverbed is completely silted with sediment in the length of around 900 m, from the mouth of the Biogradska River into the Lake, as a consequence of a sudden change in the longitudinal inclination of the bed.

Figure 12. Coarse alluvial sediments in the Biogradska Riverbed
(Photo: Dubljevic V., 2021)

The River Jezerštica is formed due to lateral overflow from the Lake and based on emerging of water through unconsolidated source area at the foot of the large erosion shell. Based on the calculation (Nikčević, Ristić 2005), the value of high water of Jezerštica at the overflow amounts to 23.8 m^3/s. The large inclination of the river course caused Jezerštica to be characterized with high energy potential so alluvial sediments ranging from smaller to multi-meter large blocks are accumulated in its course.

Figure 13. Jezerštica bed at the place of continuous emergence of water
(Photo: Dubljevic V., 2021)

Deluvial sediment occurs on slopes as a consequence of surface decomposition of the bedrock and transporting of decomposed material by washing-off and gravitation to the foot of the slope. Therefore, rocks in the area of Biogradsko Lake are of varying petrographic and granulometric composition and are predominantly of eruptive and carbonate origin. Grains are semi-spherical, and it is not easy to separate them from glacial sediment in the field. The border between them is very often unclear. This inability of breaking them down is especially present in lateral moraines around Biogradsko Lake. In some places, along the Lake shore, material belonging to glacial sediment is masked (covered) by deluvial sediment of small thickness, which is eroded and accumulated there in the period after completion of movement and melting of glaciers.

Figure 14. Deluvial sediment
(Photo: Dubljevic V., 2021)

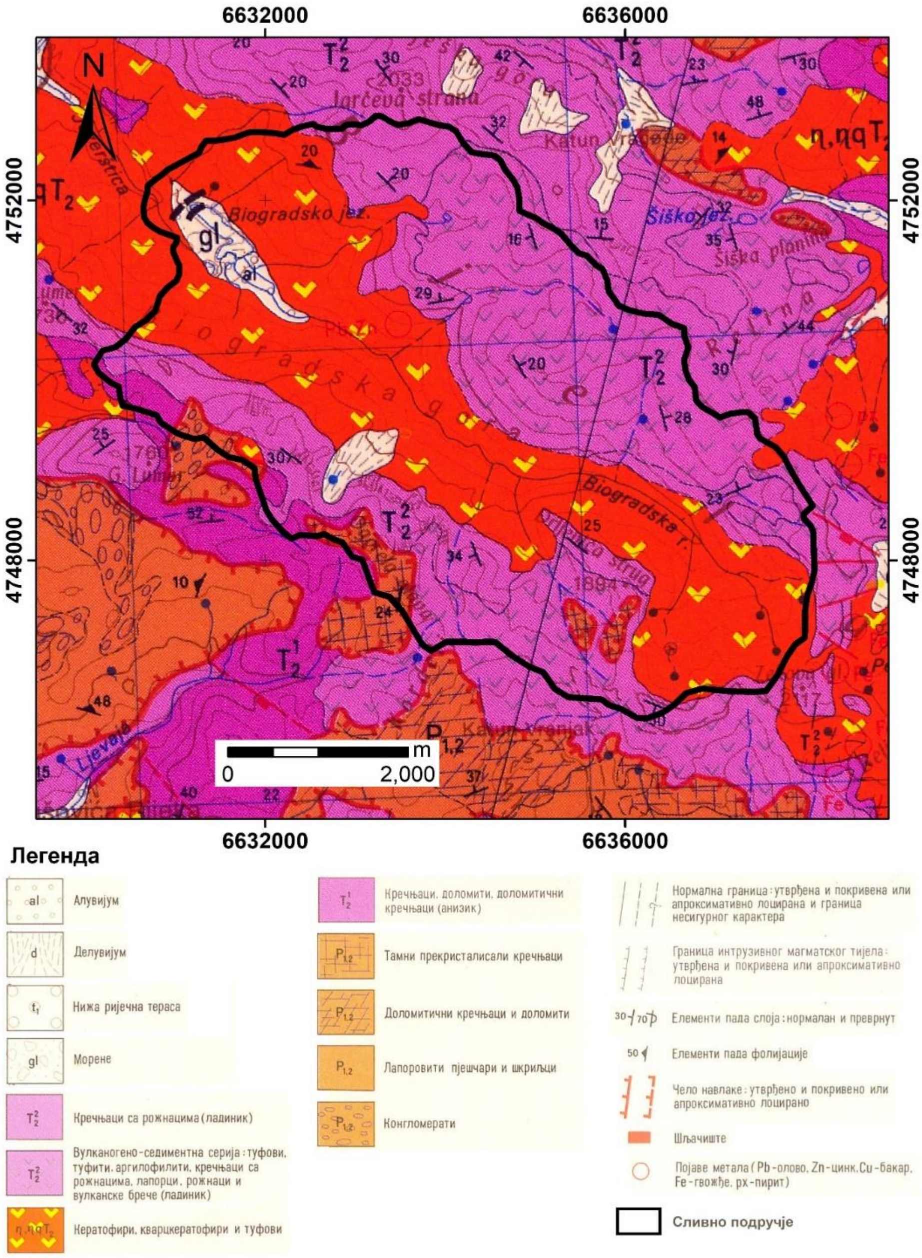


Figure 15. Excerpt from the Basic Geological Map 1:100000, sheet "Ivangrad" (Source: Živaljević et al. 1978)

Tectonics

There are several different opinions concerning tectonic structure of the area of Bjelasica. The opinion expressed by M. Živaljević 1970, V. Đokić and M. Živaljević (1970) is accepted for the purpose of this paper (research).

Later research confirmed the opinion presented by these authors. Namely, Palaeozoic of this area is in tectonic relation with Triassic sediments and magmatic rocks of the Bjelasica territory. Therefore, compared to Palaeozoic sediments, the Triassic of the Bjelasica territory occurs in the position of a relatively large tectonic window, with a rather complicated internal tectonic structure.

Triassic magmatic and sediment rocks contribute to the geological structure of the tectonic window of Bjelasica. Magmatic rocks and volcanogeno-sediment formations have the largest share in their structure. These terrains are completely covered by vegetation which we verified during the field visit for the purpose of drafting of this Study, which made studying and reconstruction of larger and smaller disjunctive and plicative tectonic forms more difficult.

According to the data of the Basic Geological Map, sheet "Ivangrad" 1:100000, the studied area belongs to the *Durmitor tectonic unit and Triassic windows of Bjelasica* (Živaljević et al. 1978). Triassic magmatic and sediment rocks contribute to the geological structure the tectonic window of Bjelasica. Magmatic rocks and volcanogeno-sediment formations have the largest share in its structure. Bedding is expressed best in crystal limestones which are occasionally intensively folded.

The Triassic complex of Bjelasica is overthrusted by the Durmitor tectonic unit with Permian sediments.

3.4. Engineering-geological characteristics

From engineering-geological aspect, the rocks that contribute to the structure of the terrain of the catchment area of Biogradsko Lake and upstream Jezerštica can be divided into three groups:

- incoherent rocks,
- incoherent and semi-coherent rocks, and
- coherent rocks.

The alluvial and glacial sediments represented in the basin of Biogradsko Lake and its immediate vicinity can be classified as incoherent rocks. Alluvial sediments are mainly represented by sandy-gravel deposits and larger semi-spherical pebbles, while glacial sediments are mainly composed of sand, detritus, clay and blocks of rocks of varying composition.

Estimated physical-mechanical properties of the said loose sediments are:

- bulk density $\gamma = 18 - 20$ kN/m^3
- specific gravity $\gamma_s = 26 - 27$ kN/m^3
- angle of internal friction $\varphi = 30 - 32^o$
- filtration coefficient $K_f = 1{,}0 \times 10^o - 1 \times 10^{-3}$ cm/s
- velocity of distribution of longitudinal waves $V_p = 300 - 500$ m/s
- velocity of distribution of lateral waves $V_s = 150 - 200$ m/s
- according to GN-200, they belong to category I and II

Clayey detritus of deluvial origin and pulverulent-clayey Lake sediments can be classified as coherent and semi-coherent rocks. The estimated values of parameters of physical-mechanical properties of deluvial sediments are the following:

- bulk density $\gamma = 19 - 21$ kN/m^3
- cohesion $c = 10 - 50$ kN/m^2
- angle of internal friction $\varphi = 20 - 32^o$

Limestones, dolomite limestones and dolomites, limestones with cherts, as well as volcanic rocks keratophires and quartzkeratophires can be classified into the group of coherent well-petrified rocks.

The estimated values of parameters of physical-mechanical properties for cracked layered limestone are within the following limits:

- bulk density γ = 24 – 25 kN/m^3
- angle of internal friction φ = 35 – 38^o
- cohesion c = 0,20 – 0,30 Mpa
- deformation modulus D = 1500 – 2000 Mpa
- elasticity modulus E_{dyn}= 3000 – 4000 Mpa
- Poisson's ratio η = 0,26
- As per GN-200, they belong to category V and VI of excavation

The estimated values of parameters for physical-mechanical characteristics of volcanic rocks keratophires and quartzkeratophires are as follows:

- bulk density γ = 25 kN/m^3
- angle of internal friction φ = 35^o
- cohesion c = 0,30 Mpa
- uniaxial compressive strength σ = 90 MPa

Volcanogeno-sediment Middle Triassic formation (T_2^2) can be classified as coherent, poorly petrified to well-petrified rocks.

The estimated values of parameters for volcanogeno-sediment formation are:

- bulk density γ = 20 – 23 kN/m^3
- angle of internal friction φ = 25-28^o
- cohesion c = 0,10 – 0,15 Mpa
- deformation modulus D = 500 – 1500 Mpa
- elasticity modulus E = 1000 – 3000 Mpa
- uniaxial compressive strength σ = 4 – 30 MPa

3.5. Geomorphological characteristics

Geomorphological characteristics of the terrain of the basin of the Biogradska River and Jezerštica are directly conditioned by the lithological composition of terrain and highly complex climate conditions that existed in the past. Height differences within the observed region exceed 1.200 m.a.s.l. and indicate a high vertical relief dissection.

The highest parts of the terrain are tops of ridges rising above 2.000 m.a.s.l. (Troglava, Zekova Glava, Crna Lokva), while a part of the Biogradska River Valley is at around 1.000 m.a.s.l., and the section of the Tara River at the point of merging with Jezerštica is situated at around 850 m.a.s.l. Deeply cut-in valleys and high ridges constitute an important geomorphological characteristic of the studied terrain.

Dominant processes that contributed to shaping of the terrain and creating the relief as it is today are glacial, fluvial, deluvial, colluvial and proluvial processes, while mild to moderate karstification occurs in some parts built of carbonate rocks.

The genesis of the origin of Biogradsko Lake is dominantly linked to glacial erosion. As per Milanković's Canon of Insolation and the results of surveys of remains of glacial processes in the field, the territory of Montenegro, including the territory of Bjelasica, underwent four great glaciations in the last 600.000 years. Smaller regional coolings that are considered little Ice Ages occurred periodically in-between.

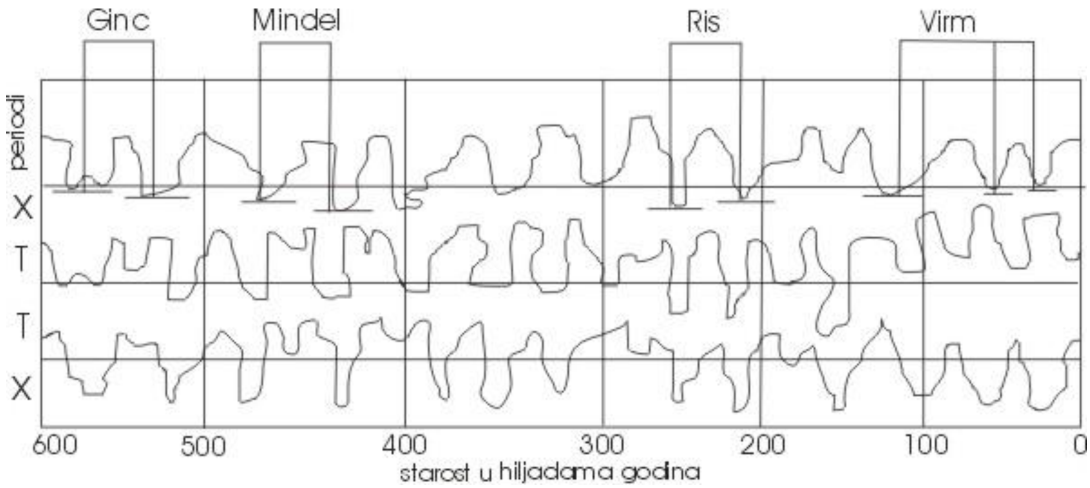


Figure 16. Distribution of Ice Ages as per M. Milanković

Every large regional cooling on the Northern Hemisphere influenced the formation of the relief of Biogradska Gora and Biogradsko Lake. Intense glaciation of the highest sections of Bjelasica is of the greatest importance for the formation of the Lake basin. The relief conditions during Ice Ages in Prepleistocene and Pleistocene periods did not allow creating of a single glacier on Bjelasica, but they were formed in source sections of Prepleistocene river courses and valleys.

Western sides of Zekova Glava and Crna Glava were centres of glaciation. Northern slopes of Zekova Glava, Troglava and the spring catchment area of the Biogradska River were the centre of the Biogradski glacier. The glacier moved from there towards the valley transforming the preglacial river valley into the glacier through, travelling thereby around 8 km.

Biogradski glacier received smaller glaciers on the sides. They are formed in the highest parts of valley, in smaller and bigger caves – cirques (Figure 17).

Existence of intense and lasting glacial erosion is confirmed by the existence of deeply cut-in Biogradska Riverbed and the moraine material that is accumulated around Biogradsko Lake in the form of frontal and lateral moraines. The glacier descended to the height of approximately 1.000 m.a.s.l. where moraine material sedimented. Moraine material separated the glacier valley and created conditions for keeping the glacier and for its melting thus creating Biogradsko Lake as we know it today.

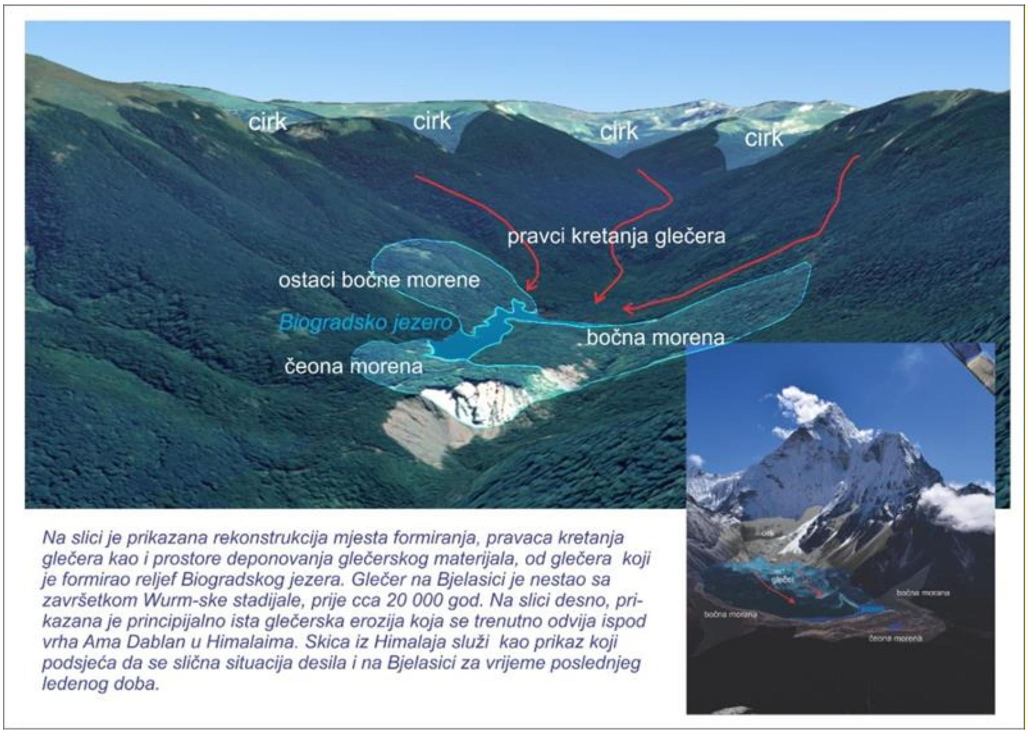


Figure 17. Reconstruction of glacier movement
(Source: Dubljevic V., 2021)

Based on detailed geological researches conducted by the Geological Survey, it is established that the thickness of the moraine material along the southwestern shore of the Lake is 30 m and that **the existence of a groove was identified in paleo relief** in that place, **which is silted by thick moraine material of highly heterogenic composition and whose groove is far below the bottom of the Lake, which allows circulation of the Lake water through the moraine basin and out of the basin".** The geological profile across boreholes is presented in Figure 18.

Moraine material in that place is accumulated in a form of a wall. Fluvial erosion of the Jezerštica River has cut through this powerful moraine wall which rises above the Lake surface even up to 30 m and has cut its bed into it.

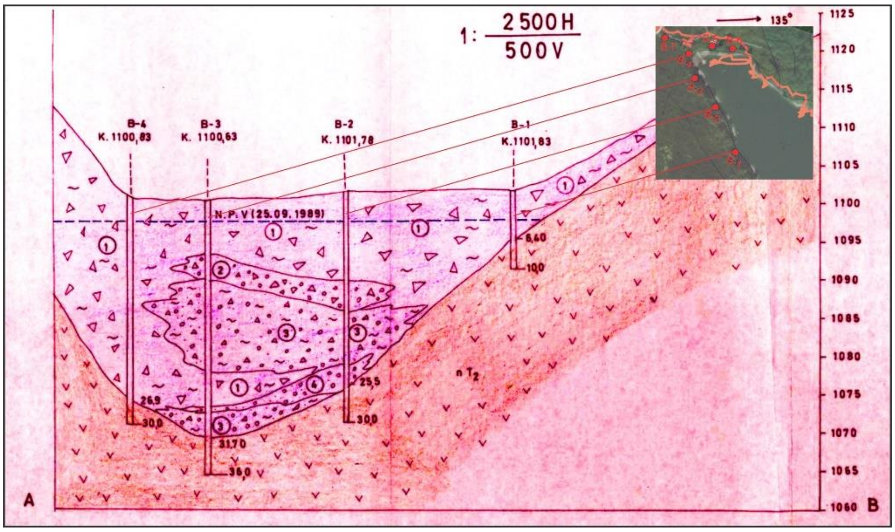


Figure 18. Geological profiles of boreholes on the southwestern side of the Lake

Lithostratigraphic and petrologic description of the moraine material is provided in Chapter 3.3. Geological characteristics.

In addition to the glacial process, the relief formation was also highly influenced by fluvial erosion. Deep river valleys of permanent and intermittent water courses are the most visible traces of the fluvial process. The lithology composition is such that it conditioned the development of a branched and dense hydrographic network, and disposal of river erosion products created alluvial sediments along the courses of the Biogradska River, Lalev Stream, Jezerštica and Tara, as the main drainage flow which serves as an erosion basis for all ground waters of Bjelasica.

A huge shell-like erosion scar more than 120 m high and around 650 m wide is found in the Jezerštica riverbed (Figure 19). The formation of this erosion scar is a consequence of intense geomorphological processes. However, its genesis is not linked with any separate, special, geomorphological process. Several geomorphological processes or types of erosion contributed to creating the large erosion scar and they are permanently alternating:

- fluvial erosion,
- deluvial erosion,

- proluvial erosion, and
- colluvial erosion.

The fluvial process caused by waters of the Jezerštica River was definitely the initial process that disrupted the natural conditions and stability of the slope.

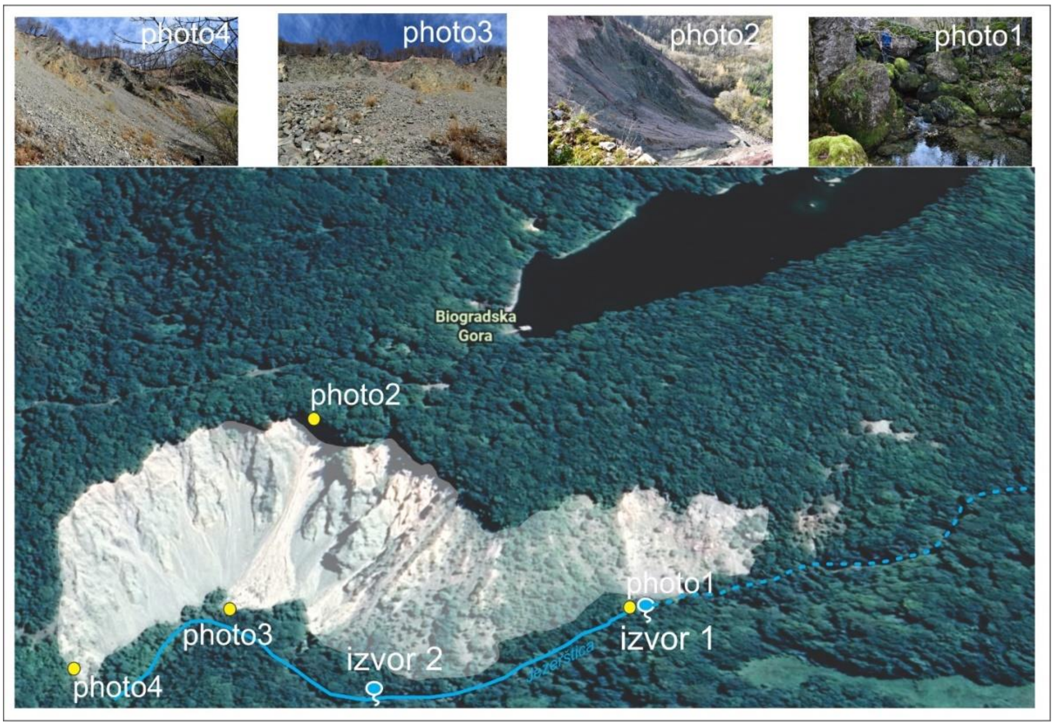


Figure 19. Erosion scar on the right riverbank of Jezerštica as the consequence of fluvial, deluvial, proluvial and colluvial erosion.
(Source: Dubljevic V., 2021)

The water of the Jezerštica River which can reach the maximum of more than 20 m^3/s are characterized by huge energy capable of carrying blocks of several meters in size. On the right riverbank of Jezerštica, where the river suddenly changes its course, there has been undercutting of the underlying rocks and disruption of stability of the slope and the change to the primary natural stress notation. *(Based on available data, magmatic Ladinian rocks T_2^2 should be in its underlying stratum. However, due to the terrain inaccessibility, this information was not confirmed during field surveys. This dilemma is intensified by the fact that, based on available 1:5000 geology maps, the left side of Jezerštica is built of Triassic limestone.)*

Disrupted stability of the slope has led to the beginning of a colluvial process or to sliding of the slope as a consequence of the influence of gravity force. A progressive and joint influence of fluvial and colluvial erosions created the initial scar on the right side of the canyon, removed the vegetation cover and exposed the open unprotected slope to the influence of deluvial erosion. Under the influence of weathering, especially melting and freezing in winter and spring months, and intense warming in summer months, there has been intense decomposition of surface rocks and transporting of eroded material into the Jezerštica Riverbed, which carried it further towards its erosion basis, the Tara River. Widening of the erosion scar continued over time.

Under the syngenetic influence of fluvial and colluvial erosion, the slope was becoming increasingly open over time, so the cumulative deluvial and colluvial erosion, stimulated by fluvial process, reached the slope section built of moraine material. The immediate roof of the erosion scar is mainly built of moraine material of varying granulometric composition and variable lithostratigraphic and petrological origin.

Moraine material, loose or poorly compact and heterogeneous, presented ideal conditions for the occurrence of proluvial processes reflected in the formation of line water courses in the slope. A larger volume of water accumulates in such relief forms causing the increase of its kinetic energy, which results in deepening of the caves. The line water courses resulting from proluvial erosion are seen on Figure 19.

3.6. Pedological conditions and vegetation cover

According to Fuštić and Đuretić (2000), the wider area of Biogradska Gora is dominated by:

- Brown forest soil on basic igneous rocks, immediately along the Biogradska River banks – upstream from Biogradsko Lake almost to Zekova Glava (2116 m.a.s.l.);
- Brown forest soil on calcareous-silicate material, on panels at 1400-1600 m.a.s.l. – section from Katun Goleš to Katun Rupe on the left bank and from Bendovac to Katun Riva on the right bank;
- Brown soil on calcareous-silicate material, on the right bank of the Biogradska River, offsets of Bjelasica above the forest belt of the previously mentioned mapped unit to the watershed with the Berane depression – Bistrica basin;
- Alluvial calcareous gravely soil on the mouth of the Biogradska River into Biogradsko Lake.

In small and negligible areas of the wider territory of Biogradska Gora, on terrains above 1800 do 2000 m.a.s.l., we also encounter in a form of a mosaic:

- Rendzine on hard limestone (Buavitza), very shallow;
- Rendzine on hard limestone (Buavitza), shallow from Jarčeve Strane along the watershed to the Mountain Šiška;
- Rendzine brownized on hard limestones (Buavitza), shallow in the area of Kriještolska Rupa.

The dominant type of soil on the studied area is brown acid soil – dystric cambisol on igneous rocks.

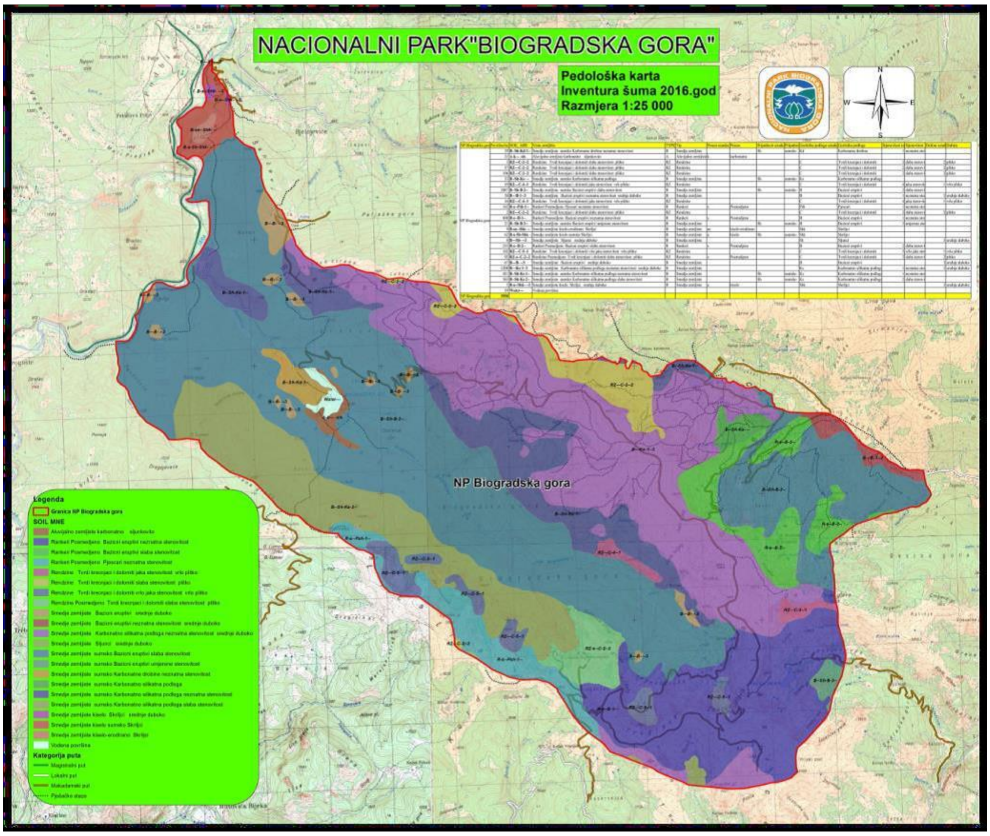


Figure 20. Pedological map of the studied area
(Baseline Study on Forests in the NP Biogradska Gora, 2017)

The occurrence of individual types of soil is conditioned primarily by the characteristics of the parent substrate, climate and relief, and to a lesser extent by the influence of the vegetation cover (Fuštić 1991). The soil on the igneous rocks was formed on the terrain with a strongly pronounced and dynamic configuration. Rarely, it is found on calmer forms of relief, and there is a particularly small number of plateaus. Therefore, this soil in various positions is quite uneven in morphological terms. Generally, it is shallow since it is mostly found on ridges and steep slopes.

Washing-off and erosion of soil from these relief forms occurs and it becomes shallow. When the relief is coupled with the resistance of compact igneous rocks and their weaker decomposition which is, by default, more pronounced on these relief elements, it is clear why soil remains long in the initial development stage. Igneous rocks are sometimes observed also on the soil surface on such relief. The content of larger fragments of rocks in soil is then higher, and it is mainly skeletoid.

As shown, relief and the stratum are important components that the soil depth and thickness of individual horizons depend on. Vegetation also has some influence. Vegetation is well-structured since we have a hilly-mountainous area with somewhat more humid climate.

To acquire more precise data on soils, 19 pedological profiles were opened and 39 soil samples were processed (Čurović M. 2011). The data about physical and chemical characteristics of soil were acquired based on the analyses performed in the laboratory of the Centre for Soil Research of the Biotechnical Faculty in Podgorica.

Soil on igneous rocks is more often characterized by A-(B)-C profile composition, although transitive A(B) and (B)C horizons may occur. Organic (O) horizon occurs regularly in the forest. What it observed in morphological terms is somewhat less expressed differentiation to horizons A and B, both with respect to colour and the mechanical composition, and other characteristics and properties as well. The soil colour is most often dark brown, but in some profiles in areas at higher altitudes, it can be brown in A, and dark brown in (B) horizon. The occurrence of such colour is the consequence of hydrothermal conditions in which the soil is formed. Namely, higher altitude followed by relative dryness during summer, and low temperatures and humidity during the rest of the year, prevent good mineralization of humus and it accumulates in soil giving it darker or brown shade or brown shade in A, and dark brown in (B) horizon.

Soil on igneous rocks mostly has a light and sandy composition and, in addition, it is skeletoid. The fraction of the skeleton is composed of smaller or larger fragments or pieces of rocks of various shapes and gruss resulting from decomposition. Fragments and pieces of rocks often have sharp-crested edges, they are rather hard and resistant to decomposition thus remaining for a long time as a skeleton in soil.

Forest ecosystems of Biogradska Gora undoubtedly belong to the most important forest facilities due to exceptional diversity and a high level of preservation. Due to mainly completely altered primary forest ecosystems, the rainforests of Europe are becoming increasingly important both as the safest indicator of the production potential of individual tree species (achievable dimensions and volumes) and the most important segment of the Planet's genetic heritage (Tomanić, L. 1991). Due to the absence of impact of human factors, these ecosystems are especially interesting from the professional and scientific point of view and rewarding study facilities, since management at sufficiently high biodiversity level within forest ecosystems requires learning about the development process taking place in intact forests (Medarevic et al. 2004).

The total of 86 determined woody species in the territory of the NP "Biogradska Gora" also indicates the wealth of biodiversity, with the highest share of beech and fir (Stešević et al. 2004). The ecosystems of the reserve NP "Biogradska Gora" are dominantly characterized by structurally uneven-aged rainforests. In addition to beech, fir and spruce, which constitute main edificators of polydominant communities, highly valuable broadleaved trees are often encountered (Balkan maple and sycamore, white ash and scotch elm). Also, the values of main production indicators are extremely high in these communities. All this indicates the exceptional ecological (biodiversity) and economic value of forests of the NP "Biogradska Gora".

Based on intense multi-year studies of phytocenoses or ecosystems of the Mountain Bjelasica (Blečić, V. 1960; Blečić, V., Lakušić, R. 1970 et al.), preconditions are created for building the ecosystem model of this highly complex mountain, whose upper forest boundary is formed by six different ecosystem belts, which is incomparably more than on any other mountain of the Balkan Peninsula, i.e. Europe (Lakušić, R. et al. 1991).

Twenty-six plant communities have been identified in the wider area of the NP “Biogradska Gora”:

- typical mountainous beech forest (*Fagetum montanum typicum*),
- montane beech forest with sesleria (*Fagetum montanum seslerietosum*),
- beech-fir forest (*Fageto – Abietetosum*),
- subalpine fir forest (*Abietum sulbalpinum*),
- hop hornbeam forest (*Seslerio – Ostryetum*),
- maple and ash forest (*Acero fraxinetum*),
- oak and hornbeam forest (*Querco- Carpinetum montenegrinum*),
- black alder forest (*Oxali – Alnetum*),
- spruce forest (*Deschampsio-Piceetum excelsae*),
- typical subalpine beech forest (*Fagetum subalpinum typicum*),
- subalpine beech forest (*Fagetum subalpinum lusulosum*),
- subalpine beech forest with maple (*Fagetum subalpinum acerosum*),
- subalpine spruce forest (*Picetum subalpinum*),
- large-leaved willow forest (*Salicetum grandifoliae*),
- willow forest (*Salicetum*),
- *Nardetum montenegrinum*,
- *Cynosuretum cristate*,
- *Festucetum variae montenegrinum*,
- mountain rose and dwarf juniper community (*Roso-Juniperetum nanae*),
- *Seslerietum giganteae*,
- *Edraiathi– Heliianthemetum montenegrinum*,
- rigid buckler fern community (*Dryopyeridetum Villarsii*),
- *Seslerietum tenuifiliaemontenegrinum*,
- *Ranunculetum crenati*,
- *Genisto – Festucetum*,
- mugho pine community, *Pinetum mughi montenegrinum*.

Eighty-six woody species in total and more than 220 plants inhabiting the forest communities of this Park have been identified. The high number of endemic forms in the high-mountainous flora of Bjelasica can be explained by the link of Bjelasica with Prokletije and other mountains of the southeast Dinarides. On the other hand, strong influence of the Mediterranean climate on Bjelasica, which comes from southwest along the Morača Valley, allowed the high mountainous regions of Bjelasica to be a significant refugium for ancient oromediterranean flora.

Based on the analysis and comparison of high-mountainous endemic flora of Kopaonik in Serbia and the Bjelasica Mountain, Lakušić D. and associates (1991) indicate the presence of 67 common endemic species and as many as 86 specific endemic taxa of the Bjelasica Mountain.

The ecosystems of the reserve NP "Biogradska Gora" are dominantly characterized by structurally uneven-aged rainforests. In addition to beech, fir and spruce, which constitute main edificators of polydominant communities, highly valuable trees of valuable broadleaves are often encountered (Balkan maple and sycamore, white ash and scotch elm).

According to Vučković (1989), the following belong to high forests in the wider area of Biogradska Gora:

- mixed sessile-flowered oak and white hornbeam forests (*Querco-Carpinetum montenegrinum*);
- mixed fir and beech forests (*Abieti–Fagetum moesiacae*);
- montane beech forest (*Fagetum montanum*);
- parts of montane spruce forest (*Luzulo-Piceetum abietis*);
- spruce forest (*Blechno-Piceetum abietis*);
- lower belt of subalpine beech forest with maple (*Aceri-Fagetum subalpinum*);
- sycamore and white ash community (*Aceri-Fraxinetum montenegrinum*).

The area of Biogradska Gora, its genetic, ecosystem diversity is classified as one of the centres of biodiversity of the

European continent. The large number of diverse, dynamic and complex ecosystems, the wealth of flora and fauna species of diverse origin and age, as well as the substantial number of endemic and relict plant species are the result of biogeographic position of the Bjelasica Mountain, complex geomorphological, hydrological, orographic structure, diverse climate influences, as well as all historical specificities since Tertiary, through the Ice Age, to the present day.

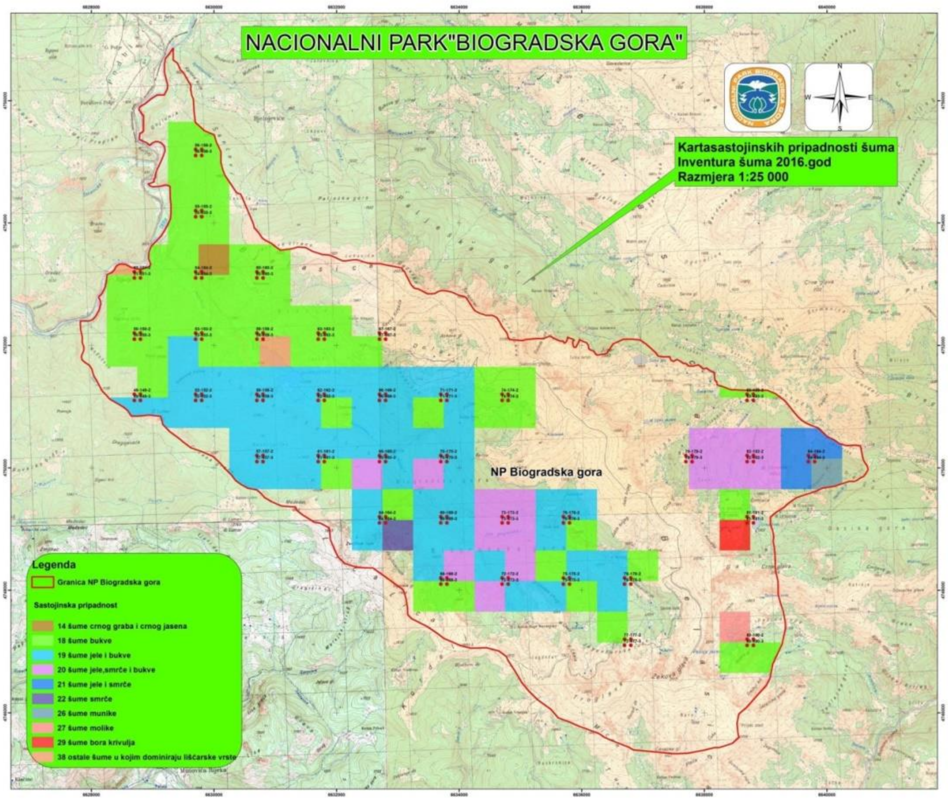
In addition to already mentioned number of defined phitocenoses (26) and more than 220 plant species inhabitating forest communities, which include numerous endemic, relict and protected plant species, flora of aquatic systems should be mentioned as well, and 514 algoflora species identified so far. Moss and linchen flora in this area is not studied sufficiently. Only around ten species have been identified.

The macromycete research so far have not been systematic and extensive. However, their wealth is undoubtedly large, diverse and specific.

According to the data of the First Forest Inventory of NP Biogradska Gora (2017), the following types of forest communities were registered in the territory of the rainforest reserve:

Beech forests including:

- beech and sycamore community (*Fageto-Aceretum visianii*),
- beech and nuts community (*Asyneumo-Fagetum moesiacae*),
- beech forest (*Seslerio-Fagetum moesiaceae*),
- beech communities connecting beech with fir forests (*Elimo-Fagetum moesiacae*).



Forest 21. Forest stands as per the Forest Inventory
NP Biogradska Gora

Beech and fir forests including:

- fir and beech community (*Abieto-Fagetum moesiaceae*).

Fir, spruce and beech forests including:

- *Luzulo-Piceetum montanum,*
- *Blechno-Piceetum abietis.*

Other forests dominated by broadleaved tree species:

- maple and ash community (*Aceri-Fraxinetum montenegrinum*),
- communities of flooded alder and willow forests (*Oxali-Alnetum incanae*).

Mugho pine forests (*Pinetum mughi*).

In addition to fir and sycamore trees, dwarf juniper (*Juniperus nana*) is found on the very boundary of the reserve, in the ground layer.

4. HYDROGEOLOGICAL AND HYDROLOGICAL CHARACTERISTICS

Based on hydrogeological properties and functions of rock masses, the structural type of porosity and spatial position of hydrogeological phenomena, the following can be singled out in the studied catchment area:

- well-permeable rocks of cavernous-cracked porosity, represented by Middle Triassic (T^2_2, T^1_2, $_3T^1_2$) limestone and dolomites;
- poorly permeable to impermeable rocks represented by keratophires and quartzkeratophires (η,ηq,T_2) and volcanogenic-sediment formation of Middle Triassic age (T^2_2); and
- a complex of poorly permeable to well-permeable rocks of intergranular porosity, represented by glacial, alluvial and deluvial sediments.

Poorly permeable to impermeable rocks are widely distributed in the catchment area of Biogradsko Lake and Jezerštica, and they are overlayed by a rather dense river network comprising Biogradska River, Lalev Stream, Jezerštica River and their tributaries.

Intergranular aquifers of heterogenic filtering characteristics are represented within glacial, alluvial and deluvial sediments of intergranular porosity.

The most important hydrogeological phenomena in this area are sinkholes along the bottom of Biogradsko Lake and springs along the Jezerštica course, which will be addressed in more detail in Chapter 5.

Smaller springs creating Biogradska River, Lalev Stream and other shorter watercourses (intermittent) are frequent in higher parts of the catchment area of Biogradsko Lake.

4.1. Biogradsko Lake

According to its dimensions (in the spring), Biogradsko Lake belongs to larger mountainous lakes in Montenegro. Created by water accumulation in the terminal basin of the lowest part of the glacier of the Biogradska River, Biogradsko Lake has a complex evolution and a number of specificities of the water balance regime, and by its function belongs to the group of flow lakes. The Lake in today's form is the geolimnological rudiment of the glacial lake which used to extend in the northwest-southeast direction.

The Lake is elongated in the southeast-northwest direction and has an irregular shape. It comprises an enlarged southeast section and an elongated northwest section lying one to another under the right angle. At the water level of 650 cm, the Lake is 875 m long. Maximum width is 410 m, and average width is 261 m. The area of the Lake's basin is 31.25 km^2. The size of the basin is 136.7 times larger than the size of the Lake (according to data from 1975). Out of the total area of the basin, 18.55 km^2 is under forest vegetation, and 12.70 km^2 under meadows, pastures and bareland. The afforestation coefficient of the basin is 0.59. The shoreline is scattered and prone to oscillations, subject to changes in the water level. Water level fluctuations are very frequent and directly linked to the inflow (by surface and underground routes), evaporation from the water surface and losing water by infiltration.

The northern part of the Lake shore is characterized by steep and well-forested slopes of Brežje and Jarčeve Strane, which are built of limestone. The slope inclination is intersected by several intermittent water courses cutting deeply into the Bjelasica masiff. The eastern part of the riparian belt is the lowest and the least accessible one. It is represented by the Biogradska River delta which branches into several effluents (in the early autumn). The eastern riparian belt 400–500 m long and 100-200 m wide is represented by sediment plain built by sand and gravel of variable granulometric composition.

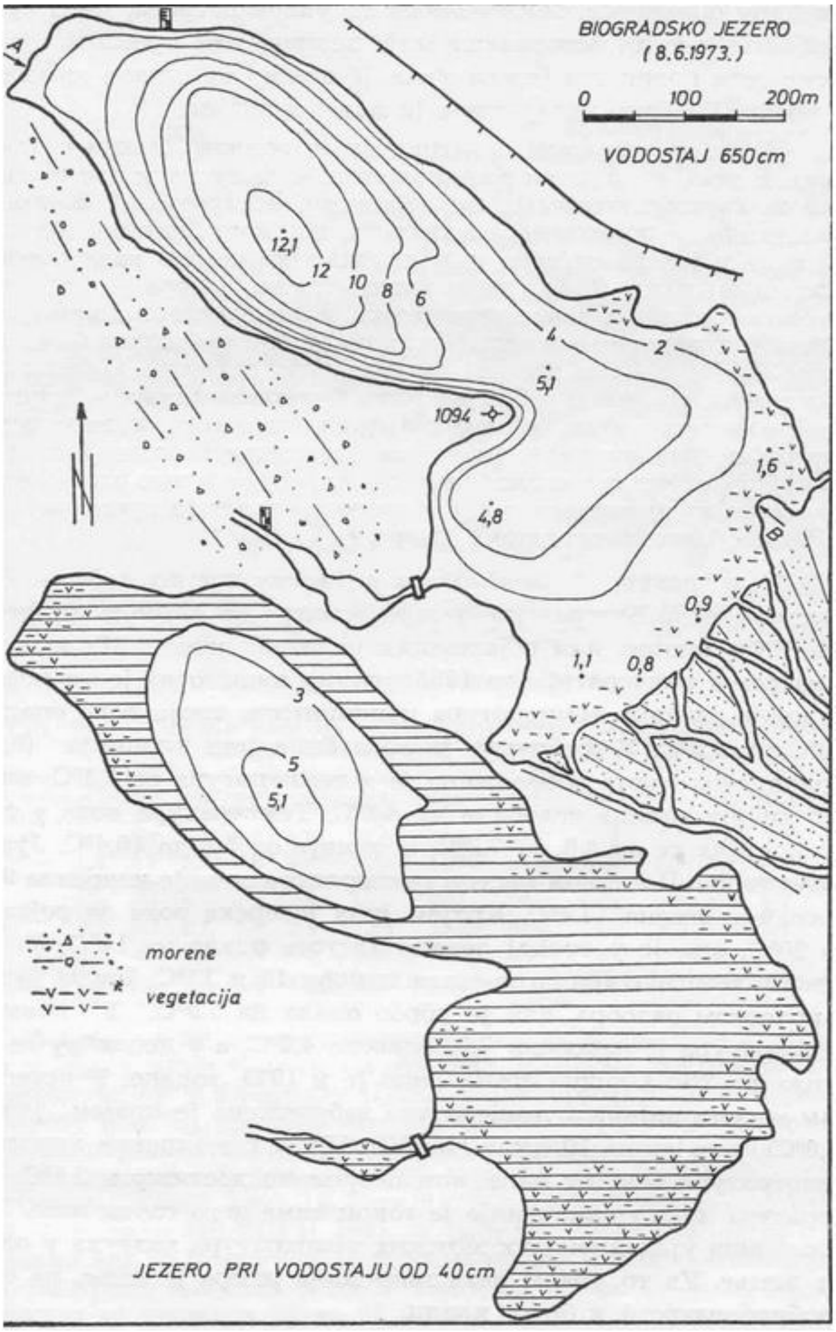


Figure 22. Bathymetry of Biogradsko Lake
(Source: Stanković S., 1975)

Effluents, abandoned riverbeds, abundant vegetation and high soil humidity make this part of the riparian belt inaccessible. Impassability is even higher closer to the Lake. This part of the terrain is flooded during medium and high waters, and the shoreline itself is not stable.

The southwest part of the shore, along the foot of the steep section, is silted in several places by moraine material. Horizontal and vertical dissection of the shore in this section is the highest since Jezerštica is here deeply cut in. The shore is less ragged in the northwest direction, and even has a rectilinear direction in some sections. Situated in the terminal basin, Biogradsko Lake is characterized not only by unusual appearance, but a complex configuration of the bottom. This is best seen in the distribution of depth or in the position of isobaths, the ratio of maximum and average depth and the depths in the north-western and south-eastern sections of the basin.

According to data of S. Stanković (1975), maximum depth of the Lake at the water level of 650 cm is 12.1 m. The zone of the greatest depths is situated in the elongated north-western section, closer to the southwestern than to the north-eastern shore. Unlike the isobath of 10 m of somewhat larger size, the isobath of 12 m occupies only a negligible section of the Lake. Depth increases rapidly from the southwestern and the north-eastern shore towards the central section of the basin. Depth reaches 6 to 7 m already at the distance of 5 to 10 m from the coast. Such distribution of depths indicates large inclination of the sides of the basin, and they correspond to the inclination of slopes of Jarčeve Strane and Crvena Greda. The south-eastern section of the Lake is rather shallow. In some places 100-150 m away from the coast, depths do not exceed 2 m. Depth in the west-eastern direction of this section of the Lake gradually drops, and the volume of sediment material transported by the Biogradska River increases. The angle of inclination of sides of the basin opposite the Biogradska River delta is 5°. Due to low depths and the inclination, the bottom is under hydrophilic vegetation, and some woody plants (willow) set deep into the Lake. Maximum depth of the eastern section of the Lake is 4.8 m. The average depth of Biogradsko Lake as a whole is 4.5 m. The morphometric indicators vary due to the high amplitude of the water level. During dry summer months when the level of the Lake drops by 4 to 6 m compared to the spring water level, the Lake water fills only the deepest section of the basin in the north-western section. The depth of the Lake drops to 5 to 6 m, length drops to 400 m, and width drops to 200 m. At such low water levels, the south-eastern section of the Lake and the wide riparian belt of other sections of the Lake become marshy soil and land. The surface of the Lake drops to 58.000 m^2, and the volume to 210.000 m^3 (Stanković S, 1975).

High amplitudes of the water level fluctuations pose a special problem to tourism valuation of the Lake, even more so that low water levels occur in and correspond to the period of the most intense tourism trends (July, August, September). The high amplitudes of the water level fluctuations affect adversely the wildlife of the Lake as well. Biogradsko Lake loses water through the distributary (Jezerštica), by infiltration and evaporation.

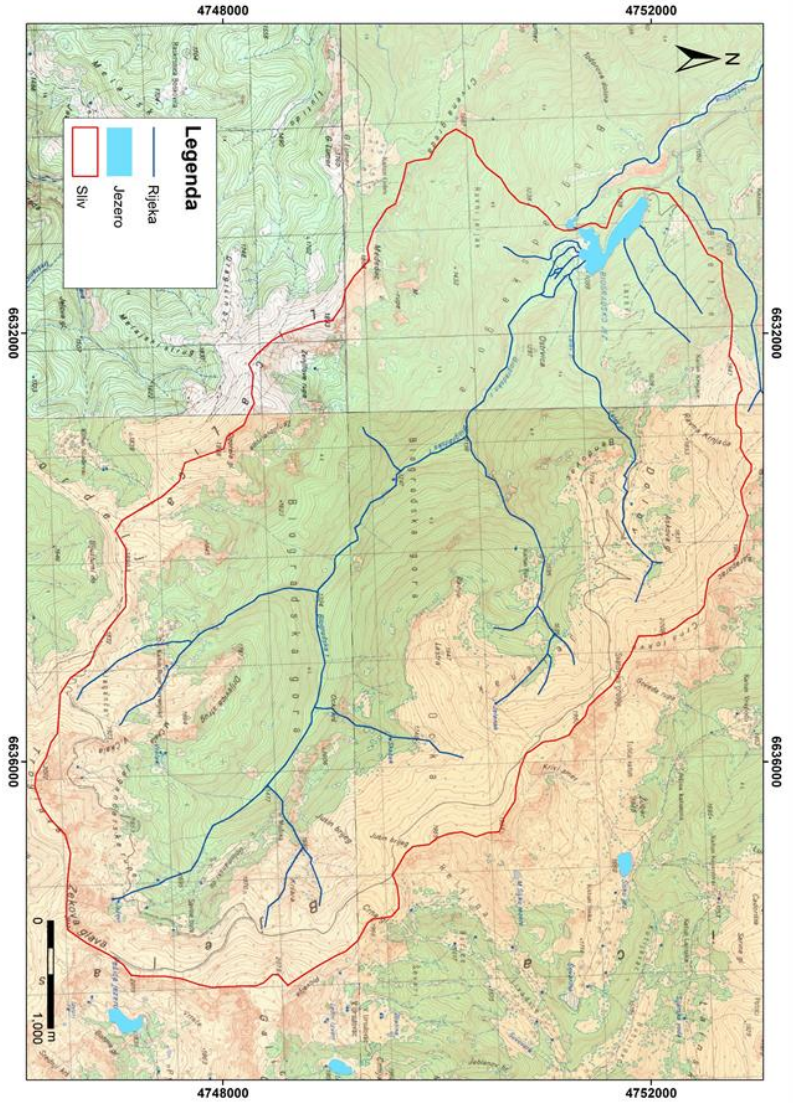


Figure 23. Catchment area of Biogradsko Lake

3.2. Biogradska River

Biogradska River is the Lake's main tributary. It is 7.960 m long. It is created by merging of several source arms on slopes of Zekova Glava and Turjak. The source of the longer component is situated at 1.860 m of altitude. Since the Biogradska River mouth is at 1.094 m, the overall inclination is 766 m, and average inclination is 96.2‰. Biogradska River occupies 25.97 km^2 of the catchment area.

Due to its morphometric characteristics, it is rather fast and torrent and never dries up. The data of short-term, periodic measurements and observations performed by the IHMS (www.meteo.co.me) in the period 1957 – 1989 show that there are two distinct maximums and minimums of the water regime. The first maximum occurs in May. It is caused by spring rainfall and melting of snow caused by the increase in the air temperature. The secondary maximum usually occurs at the end of November, and it is a consequence of autumn rainfall. The former water level minimum occurs in October (where this period has moved even to mid-November in recent years) as the consequence of the summer period characterized by the precipitation deficit, high temperatures and higher evaporation. The latter minimum usually occurs during January and is caused by snow followed by rather low temperatures, and there is no melting and feeding of watercourses.

Figure 24 (Graph) shows the measurements conducted in the period 1957 – 1989, during September and October for the purpose of provisional insight and comparisons with the current situation.

As already stated, continuous measurements and observations on the Biogradska River, and on other hydrological facilities in the catchment area of Biogradsko Lake, are not performed and, therefore, the water balance cannot be reliably determined. Judging by the size of the basin (topographic) and the precipitation volume, it can be assumed that at the maximum water flow, approximately 3-

5 m^3/s of water flows to the basin, while at the minimum flow this volume drops to approximately 100 l/s.

Figure 24. Values of water flows on the Biogradska River – historical data
(IHMS)

Table 3. Characteristic values

Biogradska River			***Measuring profiles***				
			HM 1		**HM 2**	**HM 3**	**HM 4**
Date			**07.11**	**13.11.**	**13.11**	**13.11**	**13.11**
Profile surface	F	m^2		0,20	0,09	0,15	0,47
Profile width	B	m		1,8	0,9	1,4	3,7
Mean depth	T_m	m		0,11	0,10	0,11	0,13
Maximum depth	T_{max}	m		0,16	0,15	0,14	0,20
Mean velocity	V_{sr}	m/s		0,593	0,359	0,544	0,229
Mean sur. vel.	Vo	m/s		0,701	0,436	0,640	0,294
Maximum velocity	V_{max}	m/s		0,783	0,587	0,790	0,535
Water flow	**Q**	**m^3/s**	**0,167**	**0,119**	**0,033**	**0,081**	**0,107**
Water surface	Q_o	m^3/s		0,141	0,039	0,096	0,137
Wetted perimeter	P	m		1,85	0,98	1,46	3,73
Hydraulic radius	R	m		0,109	0,092	0,102	0,125

Certain hydrometric measurements on the Biogradska River were performed in October and November 2021 in order to review samples and consequences of the reduction of the water area of Biogradsko Lake, and to link certain phenomena and processes in the basin. Characteristic values are presented in Table 3. An overview of water gauging stations (GoogleEarth) is shown on Figure 25.

Figure 25. Locations of water gauging stations

Measurements were performed by mini current meter (AOTT) and by using the "surface-velocity" method under ISO 748. These measurements provided a current insight into the intake regime of the Biogradsko Lake in the hydrological minimum.

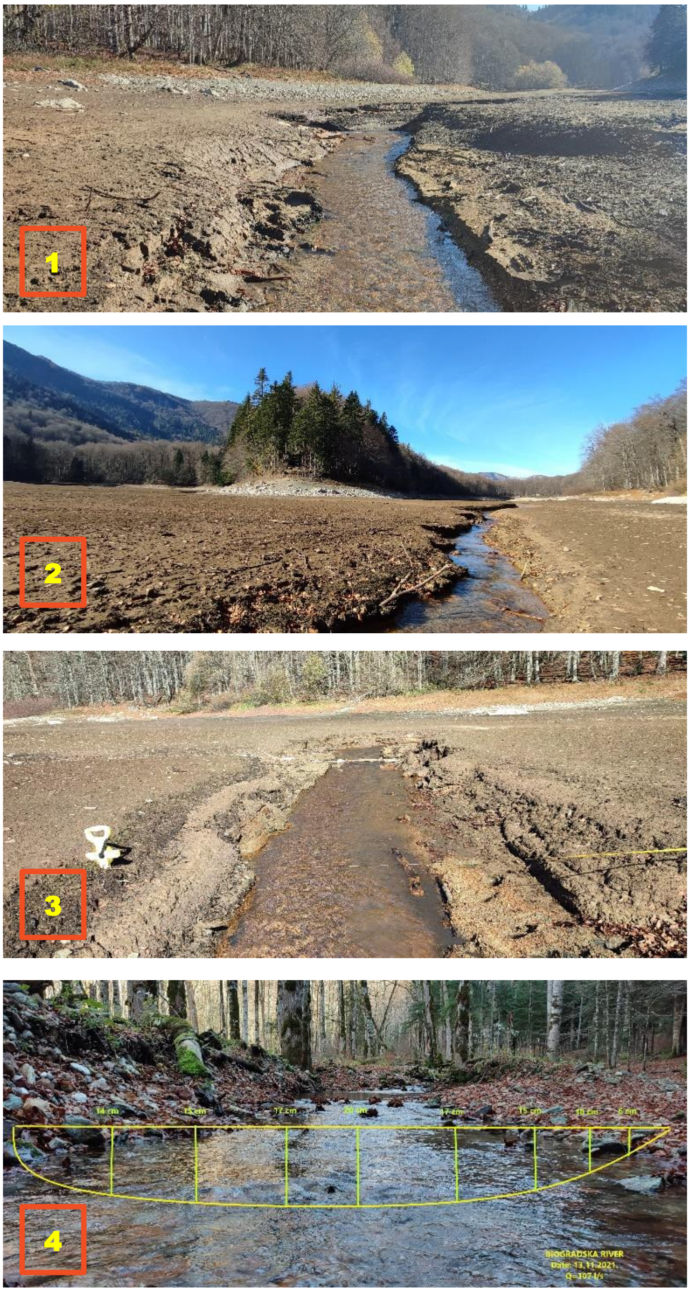


Figure 26. Hydrometric profiles on the Biogradska River
(Photo: Culafic G., 2021)

4.3. Lalev Stream

Lalev Stream or Bendovac (some authors call it so) is the second important tributary of Biogradsko Lake. It originates from the spring below Ravna Krnjača (1.853 m.a.s.l.) and Askova Glava (1.837 m.a.s.l.) and flows into the Lake on its northeast side. The length of this course is approximately 2.500 m, total inclination 606 m, and the average length is 242.2‰. Due to its rather pronounced inclination, it constitutes a true torrent water course, but due to a small surface of the basin which is covered by abundant vegetation in its most part, erosion processes are not developed. Estimated minimum water volumes are in the range of 5-10 l/s (the section visible to, by the eye, and running on the surface).

In addition to the water of the Biogradska River and Lalev Stream, Biogradsko Lake is fed by the water from several weak intermittent courses and springs. In addition, a considerable amount of water comes from precipitation (liquid and solid).

4.4. Jezerštica

Jezerštica is a distributary of Biogradsko Lake, runs out of the enlarged part of the Lake on the southwest side, and flows into Tara on its right side (at 832 m.a.s.l.). The surface of the Jezerštica basin (with Biogradsko Lake and Biogradska River) is 37.1 km^2, perimeter of the basin is 27.2 km and medium width of the basin is 3.10 km (Hrvavčević S, 2004). Immediately after running out of the Lake, Jezerštica intersects the frontal moraine wall and erodes it intensively thus deepening further its bed. Jezerštica used to flow out of the Lake freely and carried away a large volume of water. That led to fast and high fluctuations of the Lake water levels. To prevent this, a low stone dam was put up at the distributary outlet, and it was torn down again after some time.

A certain volume of water emerges in the middle part and downstream Jezerštica during summer and autumn months. It is the water that leaches from the Lake through moraine material. Unfortunately, hydrological data on Jezerštica are missing.

Periodic measurements on Jezerštica, as well as on the Biogradska River and Lalev Stream were conducted during 1988 and 1989 in order to identify the volume of water that is lost by infiltration from the Lake (Čađenović and associates, 2012). Having in mind that these are a few measurements, they cannot be used as the basis for drawing a reliable conclusion, but for presenting the current condition of the water course.

Table 4. Measured values of flow on the Biogradska River

Jezerštica	28.9.1988.		25.10.1988.		4.10.1989.		24.10.1989.	
Profile	H (cm)	Q (l/s)	H (cm)	Q (l/s)	H (cm)	Q (l/s)	H (cm)	Q (l/s)
Mouth to Tara	37	332	32.5	160	46	644	54	1150
Running out of the Lake	0	0	0	0	25	183	38	387

(Čađenović and associates, 2012)

The above hydrological measurements indicate that in the recession precipitation period, losses from the Lake dominantly occur by underground routes. This is supported by one of the measurements (28 September 1988) when there was no flow on the overflow from the Lake, and 332 l/s was measured near the mouth of Jezerštica into Tara.

5. PROBLEM OF LAKE SILTATION BY SEDIMENT

Biogradska River and Lalev Stream, as independent tributaries of Biogradsko Lake, bring abundant sediment to the Lake of the same name during a certain period of the year. The riverbed erosion processes, or fluvial erosion processes, are pronounced in downstream sections, just before the mouth into the Lake, i.e. around 9.000 m of length of the riverbed in the former case, and 130 m of length in the latter case. (Jevtić, 1976).

Strong river erosion processes mainly expressed as riverbed corrosion are observed in the length of around 900 m upstream from the mouth of the Biogradska River into the Lake. These are in fact the processes of intense undercutting and caving of dilapidated and unconsolidated banks composed of moraine material that take place at the height of 1.5 to 2.0 m above the bottom of the riverbed. As a result of the lasting destructive influence of the river water, and due to high transport power of upstream profile of the bed, downstream section of the river flow, as well as the river valley, are largely silted with sediment as a consequence of the sudden modification of the longitudinal inclination of the bed, i.e. the occurrence of the so-called spilling gradient. The erosion deposit sedimented over decades silted practically the entire river valley giving it a convex form due to which the water course splits into numerous arms or it is, however, in the phase of high meandering between two river banks.

The chapter of the Main Design (Jevtić, 1976) dealing with sediment hydrology includes a calculation of probable average annual volume of sediment affecting the Lake.

The average annual volume of bed load and suspended sediment reaching the Lake is W = 26 349 m^3/year.

Out of this sediment volume:

- suspended sediment WS = 19 590,41 m^3/year
- bed load Wv = 6 758,69 m^3/year

Based on the estimation made back then, it was considered that around 3.5-4 ha of active surface of the Lake was silted with river sediment. It is also established that continuous destruction of the bed disrupts the water course regime of the Biogradska River. The processes similar to the ones on the Biogradska River are found in the course of the Lalev Stream, as an independent tributary of the Lake, whereby in case of the Lalev Stream this process is limited to the length of around 100 m upstream from the Lake.

Peak flow from the basin and intensity of soil erosion were calculated based on the calculations of Spalević et al. (2004). As per the survey results, peak runoff from the basin equals 867.19 m^3/s.

The production of the erosion material in the basin amounts to 17.179,8 m^3/year, while realistic losses of soil from the basin equals 7.983,85 m^3/year, i.e. 282.3 m^3/km^2 a year.

Based on erosion processes, the Biogradska River is classified into category 4 of destructiveness (Z=0.252) and according to the classification of the erosion intensity, the studied drainage belongs to the area of weak mixed erosion.

According to the survey of Nikčević and Ristić (2005), the processes of sediment deposition reduced the Lake surface by 4-5 ha. The flow introduces the finest particles to the Lake thus forming 2-3 m thick sludge in individual depressions. The erosion coefficient equalling Z=0.3 is determined according to Gavrilović.

According to this study, the total annual production of erosion material of the Biogradska River basin amounts to Wyear=25671.35 m^3/year. Wp=21897.7 m^3 reaches the hydrographic network and expressed as a specific sediment yield (bed load and suspended), it amounts to Wpsp = 762.99 m^3/km^2/year.

It should be pointed out that all the mentioned surveys speak about the results based on models. The volume of deposited material and silting of the Lake could be best determined by measuring the change in sediment deposits after a certain period of time. Measurements of the Association of Young

Researchers of the Faculty of Forestry in Belgrade (Dožić and associates, 1989) could be taken as the baseline.

The goal of the survey conducted in the field in August 1986 was to perform a detailed survey of the Lake bottom and direct perimeter and thus obtain a 1:500 map with equidistance of 1 m.

Since the Lake comprises two sections which can be presented separately, a narrower and longer section extending from northwest towards southeast, and a wider and shorter section extending approximately in the east-west direction, measurements are based on two interconnected networks. Thirty-four profiles were set-up on the narrower section, and 23 profiles on the wider section of the Lake.

A traverse line of 22 points in total was set-up in the Lake surrounding, and they extend along the southern side of the Lake. Linking of the traverse line to the known mark was performed also by the invert and an open mark on trigonometer located on the watershed towards Jezerštica was used. The measurement method by probe with a ribbon was applied for measuring depth, whereby the reading accuracy was 1 cm.

After completion of field measurements and processing of data, a 1:500 scale map of morphology of the Biogradsko Lake was developed, as well as a map with the position of profiles. Each profile was also presented in the scale 1:500/1:100, which was used as the basis for calculating the volume of the Biogradsko Lake at the level of overflowing to Jezerštica.

These data are very interesting since they provide a realistic picture of the condition of the Lake's bottom at the time of the survey. These data allow multiple further surveys, and one of them that especially stands out is the possibility to calculate the volume of sediments of the Biogradska River deposited in the Lake in the previous period.

Account should be taken also of climate change and the fact that the number of days under snow in this area is dropping, and rainfall is increasing. Hence, the intensity of torrents is rising. Gradual draining during snow melting is reducing. A possibility of running-off from the basin in upper sections of the basin should also be examined (Spalević et al. 2021). Quick run-off of water generated by rainfall after increasingly intensive precipitation caused by obvious climate change can slow down the development of a dense grass cover as well. Wooden braids and partitions, smaller terraces created by natural materials and placed in upper sections of the basin would intercept emerging torrents right at the point of their formation. Running-off would slow down. Soil would adopt-absorb more water due to backwater of torrents. This water that is slowed down and absorbed in saturated soil in areas of the upper section of the basin would drain slowly towards the Lake during dry days.

Balanced plant communities, such as forests of Biogradska Gora, protect shallow formed soil from the torrent nature of erosion, particularly in geological-ecological conditions of steep mountain terrains (Pavićević 1990).

The canopy closure differentiation with respect to the analysed area in the National Park Biogradska Gora dominates significantly in the ranges between 0.9-1.0 (36.1%) and 0.7-0.8 (36.8%), which means that most stands in Biogradska Gora have partly complete canopy or closed canopy, which corresponds to rainforest nature and preserved structure of these forests.

Broken and sparse canopy occurs on the total of 14.6% of the area, which is certainly an indicator of a good condition of these forests. The broken canopy in these areas is a consequence of either orographic climate factors or damages caused by abiotic factors.

Disturbances of canopy are of lower magnitude with a small incidence of medium disturbances and mainly occur due to falling of old trees, only 18 gaps of crowns larger than 150 m^2 (Motta et al 2015).

The most recent results of the survey of an analysis of the composition of mud and the structure of pollen in mud layers from various periods also indicate the progressive dynamics of forest ecosystems in the last two hundred years (Cagliero et al 2021).

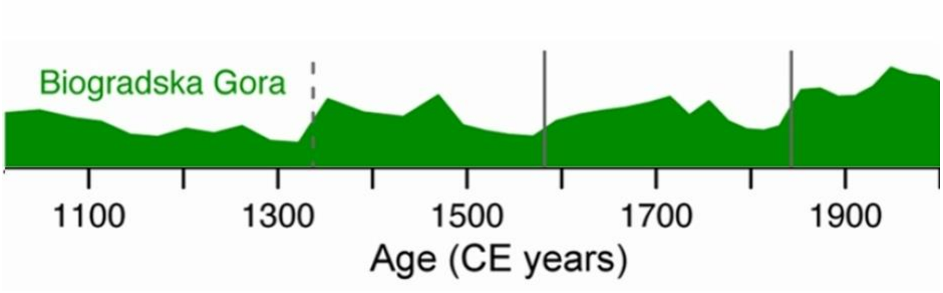


Figure 27. Woody and shrub vegetation in the region of Biogradska Gora in the last 1000 years (Cagliero et al. 2021)

The Biogradska River influenced and still influences the reduction of the Lake basin by depositing a large volume of bedload. Filling the Lake basin with bed load reduces space for water accumulation, and the Lake is becoming increasingly shallow and smaller in volume.

Siltation of the Lake in the past was more intense than today. Due to higher precipitation, the flow of the Biogradska River was higher and thus the erosion and transport power as well. Such situation is confirmed by the understanding of the transiency of the Lake as a hydrographic facility, all the more so given that the water loss is increasing, since a section of the Lake lie on limestone. "The geological composition of the terrain where the Lake is situated is rather simple. The terrain is built by older porphyry, then cavernous Triassic limestone and recent silty deposit. However, the tectonic structure of the terrain is somewhat more complex. The contact between igneous rocks and limestone is a tectonic one and slightly inclined towards northeast; but tectonic specificities are not resolved. One section of the Lake is situated on an igneous rock, and the other deeper section on limestone" (Milojević Ž. B., 1955).

6. PROBLEM OF WATER SINK IN THE LAKE

Based on the review of the existing documents (Chapter 2), it can be concluded that the problem of infiltration of water of Biogradsko Lake has been considered since the middle of the last century. In addition to registering of sinkhole, an attempt was even made in the '50s to rehabilitate the bottom of the Lake by means of a "concrete carpet" (Vlahović 1991).

Around 15 sinkholes (Figure 28 and Annex) in the dry section of the Lake basin during reconnaissance of terrain in November 2021 (when the water level of the Lake was very low). Although the observed sinkholes are "scattered" over a large surface of the bottom of Biogradsko Lake, we have classified all registered sinkholes into three infiltration zones so as to present them more clearly in this Study.

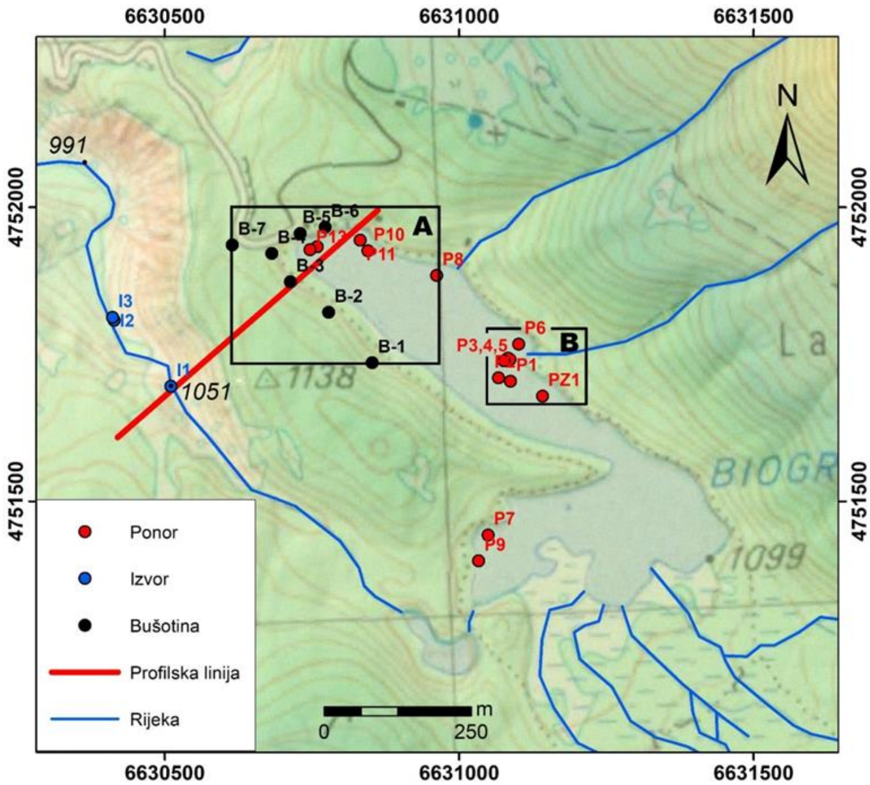


Figure 28. Map of position of registered sinkholes and springs[1]

[1] Note: Previously executed boreholes are also presented here (sinkholes and springs were located during field visit on 7 November 2021, when the water level of the Lake was very low). More detailed maps and photographs of sinkholes and springs are provided in the Annex.

As it can be seen in Annexes, dimensions of sinkhole openings vary. They range from several tens of centimetres to several meters. The size of sinkhole itself ultimately does not have to be directly linked with its water infiltration capacity, but a large number of them along the bottom of Biogradsko Lake anyway indicates high water routing through the glacial sediment.

The water level in the Lake dropped by around 10 cm between two visits to the Lake (31 October and 7 November 2021), although the inflow through the Biogradska River amounted to 167 l/s (measured on 7 November 2021). Even if evaporation from the water surface during this time span of 7 days is considered, a conclusion is drawn that the infiltration capacity at the water level at the time exceeded 170 l/s. It should be kept in mind that most of sinkholes during those days were situated in dry areas, so it is realistic to expect that the rise of the water level will increase substantially the losses of water from the Lake.

Almost all authors who addressed this matter agree that infiltration water of Biogradsko Lake emerges on springs in the Jezerštica River valley (Figure 28 (map), Figure 29 (profile) and Annex). In the period of high waters, when the hydrostatic pressure that the Lake water puts on its bottom reaches its maximum, and considering the estimated volumes of water in Jezerštica amounting to around 28 m^3/s (Nikčević et al. 2005), we assume that the Lake water infiltrating through sinkholes contribute minimum 10% to the above volume, which represents some 2-3 m^3/s.

Regarding the infiltration model itself, there has been no agreement between researchers. Based on the previous documents, the following two hypotheses could be singled out:

1. infiltration takes place via glacial sediments of intergranular porosity (and possibly via cracked volcanic rocks in the underlaying stratum) (Jevtić, 1976; Vlahović, 1991) (Figure 29);
2. infiltration takes place mostly through kartsified limestone (${}_3T_2^1$) which are assumed to be distributed in the underlying

stratum of glacial sediments (Mihajlović and Radulović V, 1991) (Figure 29).

Some facts supporting the **first hypothesis** are listed below:

- limestone in the underlying stratum of glacial sediments were not drilled in any of the 7 executed boreholes (Geology Survey, 1995),
- the results of two conducted tracing tests (Geology Survey, 1995) indicate a very slow circulation of ground waters, characteristic of intergranular environment,
- two smaller springs emerging from the slope were observed on the right bank of Jezerštica (around 200 m downstream from the main spring) during field visit.

The facts supporting the **second hypothesis**:

- the observed concentrated infiltration of water which generally occurs when the terrain floor is built of karstified limestone,
- red limestones ($_3T_2^1$) are observed in the Jezerštica bed, and they are shown on geological maps in some of the previous studies (Geology Survey, 1995),
- the main efflux of ground waters in the Jezerštica valley is concentrated and occurs in the zone of possible contact between limestone and vulcanite,
- the largest number of sinkholes is registered along the north-eastern bank of the Lake which is further away from the spring (exploratory boreholes were not executed along this bank; blocks of red limestone ($_3T_2^1$) are observed, although the presence of this mapped unit is not expected on the surface of the terrain of the catchment area).

In addition to the above hypotheses, account should be taken of the third possible option according to which the Lake water is lost through the moraine material, flow over volcanic rocks of the underlying stratum, and emerge in the Jezerštica Riverbed through deluvial sediment through the unconsolidated source area. In our view, the moraine material of heterogenous granulometric composition in frontal and lateral moraines, diverse lithostratigraphic and petrographic origin, provided for the existence of privileged directions of draining of the Lake water.

Chronologically, the number of sinkholes and losing of water from the Lake progressed noticeably over time. This trend is noticeable nowadays as well. Increasing of water routing through glacial sediments leads to increasing washing of smaller fraction from thus increasing permeability of moraine sediments. The increase in circulation through the material inevitably leads to increasing loss of water from the Lake.

From the hydrological aspect, moraine sediments should be singled out as hydrogeological complexes, i.e. the rock masses characterized by a two-fold hydrogeological function. Moraine sediments are impermeable in most of their part. Biogradsko Lake was formed due to this characteristic. Equally, this is the explanation for the unsuccessful dyeing test conducted by the Geology Survey in 1989. Dyeing agent remained in isolated impermeable parts of moraine, which had no communication with the privileged water routes.

On the other hand, due to heterogenous composition, special permeability zones and routes singled out, where water breakthrough occurred causing the formation of sinkhole forms and permanent loss of water from the Lake.

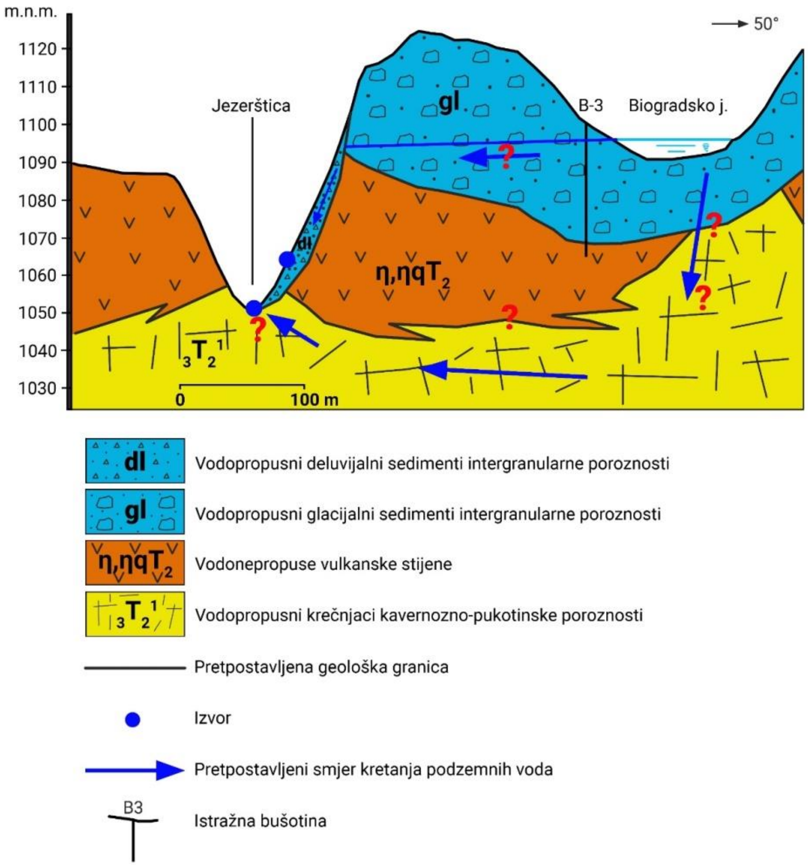


Figure 29. Hypothetical hydrogeological profile of Biogradsko Lake – Jezerštica

Future hydrogeological surveys should be aimed at clarifying the considered infiltration model. Such surveys should define in more detail the geological structure of the underlying stratum of glacial sediments along the north-eastern and the southwestern Lake shore, i.e. establish weather limestone or volcanic rocks are found below the sediment (in the zone of the sinkhole). Also, registering of the direction and velocity of running of ground waters (by performing a tracing test) would significantly contribute to defining of the hydrological system of Biogradsko Lake – Jezerštica.

Addressing the above described hydrogeological issues is a necessary step that should precede the development of the plan to rehabilitate sinking of waters of Biogradsko Lake. Rehabilitating the infiltration zones will in any case be an uncertain and a highly complex task.

7. PROBLEM OF ERODED SLOPE IN THE JEZERŠTICA CANYON

With its kinetic energy, the Jezerštica River cuts into volcanic rocks thus eroding and undermining its right bank, whereby it formed a steep slope, i.e. an erosion shell-like scar, more than 120 m high and around 650 m wide. Contemporary washing out and gullying processes are present in this area. Erosion of material along this slope takes place primarily in volcanic rocks represented by quartzkeratophires and keratophires.

The formation of this erosion scar is the consequence of intense geomorphological processes (fluvial, deluvial, proluvial and colluvial erosion). The fluvial process caused by the energy of Jezerštica water was definitely the initial process that disrupted the natural conditions and stability of the slope.

This multi-annual processes along the said slope reduces the size of the basin of Biogradsko Lake.

The problem of erosion of this slope was addressed in the earlier period and some of the conclusions will be presented below.

✓ Institute for Water Management of Erosion Areas – Faculty of Forestry (1976). Main Design for regulation of eroded slopes in the Jezerštica Canyon, Belgrade. Investor: Republic Institute for Nature Protection of the Federal Republic of Montenegro.

The reasons behind the development of the Main Design are defined by the Terms of Reference "*Main Design for regulation of eroded slopes in the Jezerštica canyon to prevent the process of undercutting of the basis of high river banks by periodically strong river water, as well as the requirements for further protection of these erosion river banks".*

It is also stated that *"Jezerštica is thus formed based on lateral overflowing of water from the Lake, but also based on emerging of water from loose material".*

"In terms of relief, the entire catchment area of the Biogradska River is characterized by highly pronounced, steep terrains, with average inclination of lateral sides of up to 50% and a relative inclination of the bed in terms of flow of J_t = 6.94 %.

It belongs to the category of terrains which are characterized by high energy potential of basins and a potential destructive flow, which may manifest itself in the case of sudden and frequent precipitation".

The aim of the conceptual rehabilitation design refers to creating a stable slope with a natural inclination where conditions would be created for binding with vegetation or some other available measure. Developing an artificial "support" in the form of a gabion at the foot of the slope side is proposed in order to stop erosion and washing-off of denudation material (Figure 30).

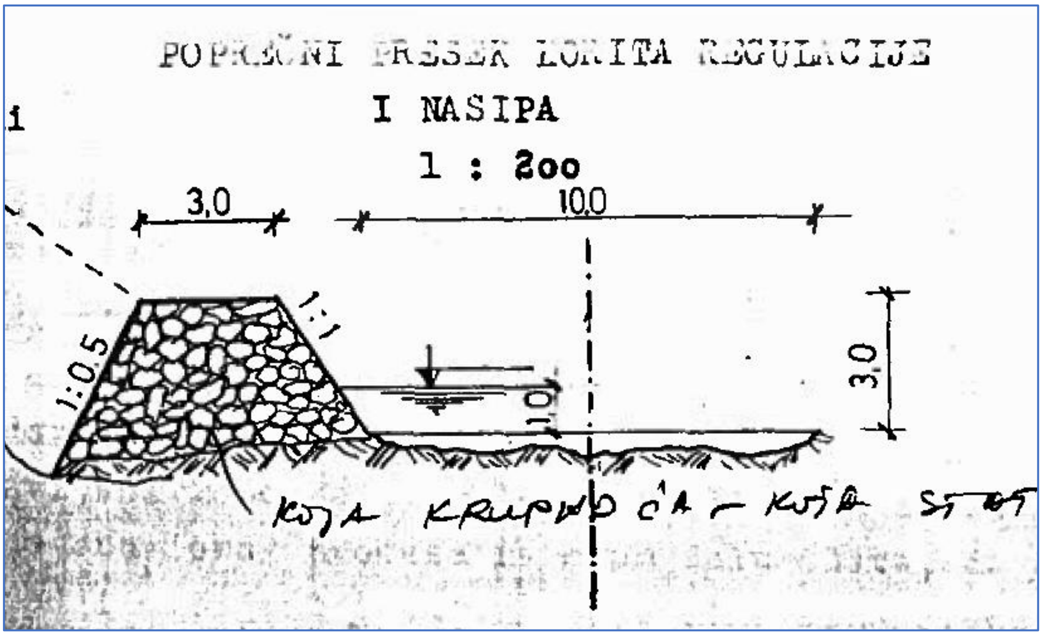


Figure 30. Cross-section of regulation of the Jezerštica bed with a protective embankment

The most urgent measure proposed here is to firstly secure the slope from the bottom side, which should prevent further removal of sediment from the slope sides. The proposed intervention refers to creating an artificial "support" which would stop removal of decomposition products. They note that development "should not use the material from colluvium debris, but from the left river bank of Jezerštica".

- ✓ Greens of Montenegro (2005). Biogradsko Lake – Conceptual Design for Anti-Erosion Protection, Podgorica. Investor: Parliament of Montenegro – Programme for supporting economic development projects.

The intention of the author of this document is to prepare the preliminary design for rehabilitation of the slope in the Jezerštica riverbed which is exposed to progressive erosion that may lead to disappearance of the Biogradsko Lake. In the author's words, the project would resolve erosion of threatened frontal moraine which makes a natural dam of Biogradsko Lake on its north-western side. The solution that is presented is a technical-biological one.

The following was prepared within the Study:

- → an analysis of erosion processes (magnitude, type and intensity),
- → an analysis of the use of land in the basin,
- → pedological conditions in the basin,
- → meteorological-climate conditions in the basin,
- → calculation of sediment yield,
- → the concept of protection of Biogradsko Lake.

An analysis is conducted here with respect to high water relevant for dimensioning the Jezerstica riverbed (on the section of eroded slope), which is estimated on the basis of the data from the existing project documents (Institute for Water Management of Erosion Areas – Faculty of Faculty (1976), Main Design for Regulating Eroded Slopes in the Jezerštica canyon, Belgrade) and equals Q_{max}= 23.8 m^3/s, while the value of maximum water of Q_{max} =40 m^3/s was taken for calculating the slope stability.

The authors state here that *"the main problem in the protection of Biogradsko Lake is to urgently secure the right river bank of Jezerstica (downstream) in the zone of eroded moraine wall. When high water occurs, Jezerštica undermines the slope basis thus causing a violent caving of large amounts of material into the riverbed. Movement of the material down the slope destroys also the sporadic occurrence of autochthonous vegetation"*.

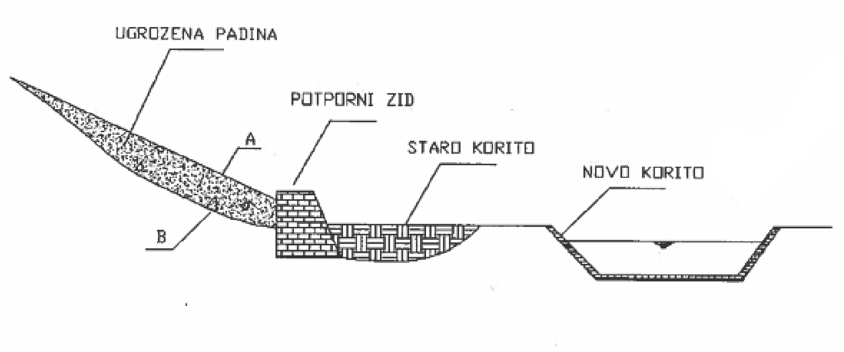
It is stated here that the optimum protection of the Lake comprises three components:

- protection of the right river bank of Jezerštica from undermining,
- rehabilitation of colluvium debris and ravines on moraine wall, and
- protection of the Lake from siltation with erosion material.

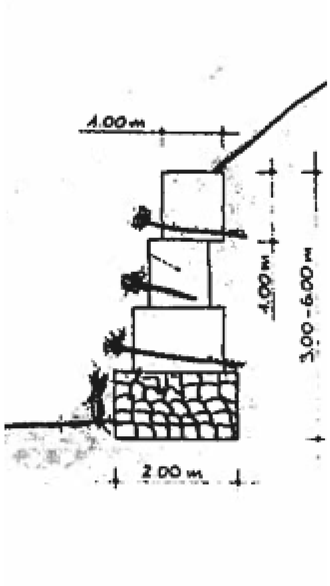
Intense erosion of the right river bank of Jezerštica, i.e. the frontal moraine poses the main problem of protection of Biogradsko Lake.

Three options for securing the slope basis are proposed:

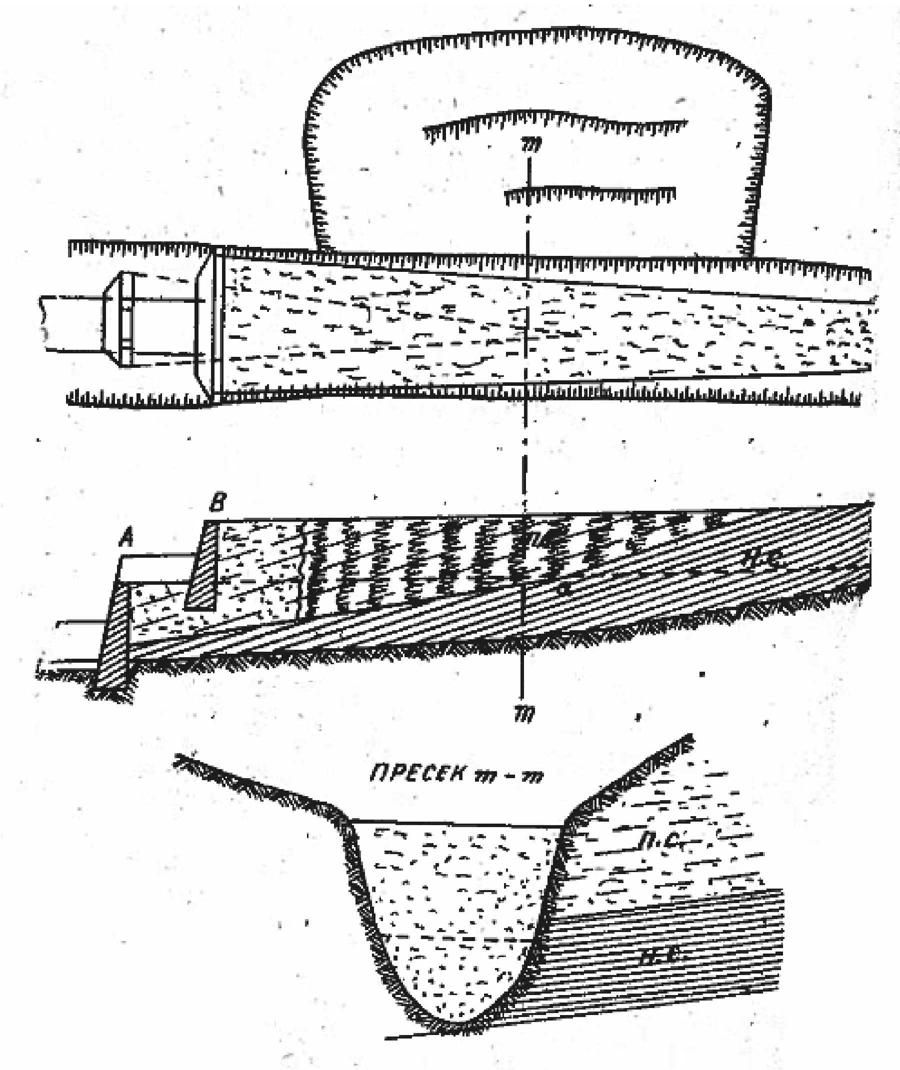
I. option: implies a retaining wall built of large pieces of stone with realignment of Jezerštica riverbed to 50-100 m from the slope;



II. option: implies a retaining wall (embankment) built of stone blocks without realignment of Jezerštica riverbed (this solution is envisaged by the project of the Faculty of Forestry from 1976);

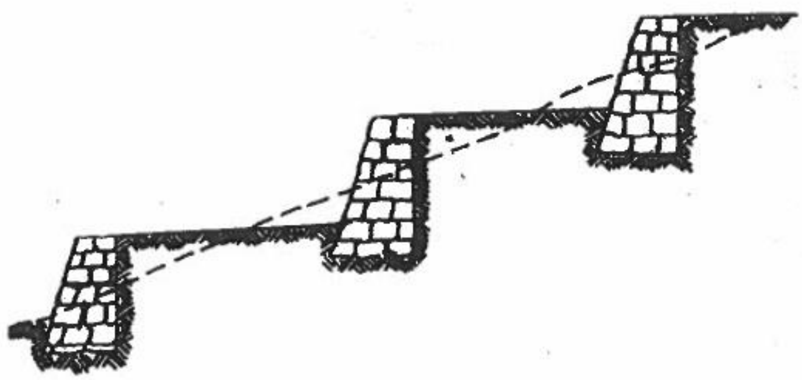


III. option: implies building of a transverse facility (partition) at 20-30 m from the lowest point of the threatened river bank. The idea is to use the aggradation of transversal facility as the stabilizer of



the slope.

Also, rehabilitation of colluvium debris and ravines on moraine wall is envisaged. Extremely steep upper sections of the slope include sources of erosion material forming colluvium debris. The material is a product of decomposition of rocks, and the effect of gravity supported by surface water causes it to slide very quickly down the slope to the water course. On the slope, particularly in higher parts where vertical sections occur intermittently, with deep ravines, colluvium debris and landslides, it is possible to intervene sporadically with facilities such as: wooden braids, small wall to prevent washing-off, small contour walls etc. The useful height of these facilities is very small in order to avoid burdening of already destabilized slope. If an artificial support of the slope having a stabilizing effect on the entire slope would be formed, movement of larger volumes of material would not be possible. Inclination would then be formed in lower parts of the slope enabling the occurrence of autochthonous vegetation, and later the formation of soil which would be a lasting solution to the problem of stability in this section. That would have a stabilizing effect on higher sections of the slope since movement of larger volumes of material with continuous deepening of ravines would not be possible.



Longitudinal profile and cross-section are also presented here, as well as the Priced Bill of Quantities and Bill of Quantities for the required works.

It should be noted here that Quaternary glacial sediments are found in the upper horizons of the slope, and that they build almost vertical sections reaching in some places the thickness of several tens of meters. Due to continuous running-off and removal of material along this area, further progressive breaking in glacial sediments can be expected in the future, whereby the ruptured mass can be extremely large in volume. Such developments would cause immense consequences for the survival of the Lake basin itself, and this peripheral space constitutes the area with high level of hazard.

Also, account should be taken of the fact that this terrain is highly inaccessible and located in the protection zone, which also complicates potential rehabilitation solutions.

8. PROPOSAL OF FURTHER SURVEYS

There are three differentiated problems within the zone of Biogradsko Lake that need to be addressed:

- the problem of siltation of the Lake with eroded material transported by the Biogradska River and Lalev Stream;
- the problem of sinking Lake water through a series of ponors (sinkholes) at the bottom of the Lake; and
- the problem of progressive erosion in the Jezerštica canyon.

In the future, each of these may lead to a complete devastation of this jewel of nature and its permanent loss. The solution to these problems should be comprehensive since addressing one of them alone not sufficient to preserve the Lake. The rehabilitation of Biogradsko Lake should follow the principle **"nothing is over until it's over"** and that is why this task is very complex and addressing it requires a committed and pragmatic approach.

As highlighted in some chapters of this Study, Biogradsko Lake was subject to various surveys on several occasions. In addition to the survey conducted mid '80s by the Geology Survey and although it was not finalized, it can be considered thoroughly planned and systematically conducted, and all other surveys can be considered "ad hock", conducted in an arbitrary manner, over a very short period and mostly came down to individual observations, without serious measurements and lasting observations.

Proposing rehabilitation solutions lightly can be highlighted as a particular problem. Some reports, the contents of which we had an opportunity to see, offer a concept of rehabilitation solutions only on the basis of a single field visit. Without going into the merits of the proposed solutions, and refraining from commenting them, what comes as a conclusion based on the analysis of everything done so far on Biogradsko Lake is that there are no quality maps (geodetic, hydrological, geological and hydrogeological) which would allow giving a credible and quality proposal of the manner of solving some of the existing problems. Most of the proposed rehabilitation solutions are based on approximations, analogy and estimates which is not enough and does not offer certainty in terms of further financing and designing. Finally, none of the proposed solutions underwent the assessment test, both professional and non-professional public.

That is why the concept of future surveys is primarily defined in a way to conduct audit and control of the existing maps, amend them where possible, and prepare the maps that are missing. Preparing new maps, amending the existing ones and drawing up of the Terms of References for developing the Preliminary Design for addressing the existing problems on Biogradsko Lake should constitute phase II of this Project implementation.

Considering the complexity of the overall problem, the idea is to apply creative engineering rehabilitation solutions which are in uncompromising harmony with the natural surroundings of Biogradska Gora.

Once the required relevant geodetic, bathymetry, geological, hydrogeological and hydrological maps are completed, a tender should be launched to develop the Preliminary Design for integrated solution to all of the observed problems affecting the future existence of Biogradsko Lake. Having this in mind, maps must be developed at the level that is satisfactory for this type of works so as to avoid, as much as possible, the use of analogy, approximation and estimations in designing final solutions.

The required maps are grouped as follows:

1. geodetic map 1:5000;
2. geological map 1:5000;
3. hydrogeological map 1:5000;
4. hydrologic maps; and
5. bathymetry map with a calculation of thickness of deposited eroded sediments.

8.1. Hydrological measurements and observations

Water is a unique and indispensable natural resource of limited quantities and uneven spatial and temporal distribution. The fact that all forms of life and all human activities are more or less linked with water clearly underlines the importance of how it is treated. Thus, water can become a limiting factor for development, and a threat to human health and sustainability of natural ecosystems, which is also the case with Biogradsko Lake.

Therefore, it is especially important for any society to design the policy and strategy for regulation, use and protection of water resources. Recently, increasingly serious water problems arise, and they become even more complicated due to the consequences of global climate change, which are increasingly expressed through the precipitation and flow regime. One of the most serious consequences of the global climate change is worsening of extreme non-stationary phenomena, which is very pronounced in the basin of Biogradsko Lake.

Due to the observed change of precipitation regime, i.e. shortening of the precipitation (liquid and solid) season, as well as extending of long and very dry periods, especially during autumn, the water area of the Lake's basin reduced drastically, which puts a question mark over the survival of the Lake and its water ecosystems.

Gaining an insight into the current situation will be attempted by putting in place monitoring of hydrology and climate elements, as well as future projections (trend of analyses within monthly variations), which will be the basis for further steps aimed at adopting plans and measures for revitalization and conservation of the basin of Biogradsko Lake and Jezerštica.

The work programme comprises field (divided into two phases) and office work.

The first phase of the field work relates to:

- ❖ putting in place hydrological monitoring of surface water (for automatic and continuous reading of water level (diver)) and a control instrument (staff gauges) on the Biogradska River - 1 profile, Jezerštica - 3 profiles and Biogradsko Lake - 1 profile) and ground waters (installing equipment in piezometers);

- ❖ geodetic measurement of hydrometric profiles (cross-section and setting the “0” level of the water gauge), and piezometer profile.

The second phase comprises:

- ❖ Performing simultaneous hydrometric measurements on the Biogradska River, Jezerštica and Lalev Stream (minimum 8-10 series) to cover all amplitudes of fluctuations of the water level (H_{min} and H_{max}). The measurement will use current meters and the ultrasound instrument ADCP (Acoustic Doppler Current Profiler), and the following normative references will be applied: the method of determining flow by measuring velocity and surface (the “surface-velocity” method) under ISO 748 and the method of measuring flow by the ultrasound (acoustic) method under ISO 6416:1992.

- ❖ Overlaying, reading and storing of data from the installed measuring equipment (diver) with a view to defining the regime of oscillation of the level of ground and surface waters.

Locations of measurement sites are presented on Figure 31[2].

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[2] Note: *In order to establish the yield of springs I_1 and I_2 situated on the right river bank of Jezerštica and which emerge below the sections (covered by sediment and where, as assumed, the water that infiltrates in the Lake emerges), where it is not possible to perform measurements and observations, the plan is to set-up 2 profiles, one in the Jezerštica source area, and the other downstream from the spring I_2, where observation of the water level and*

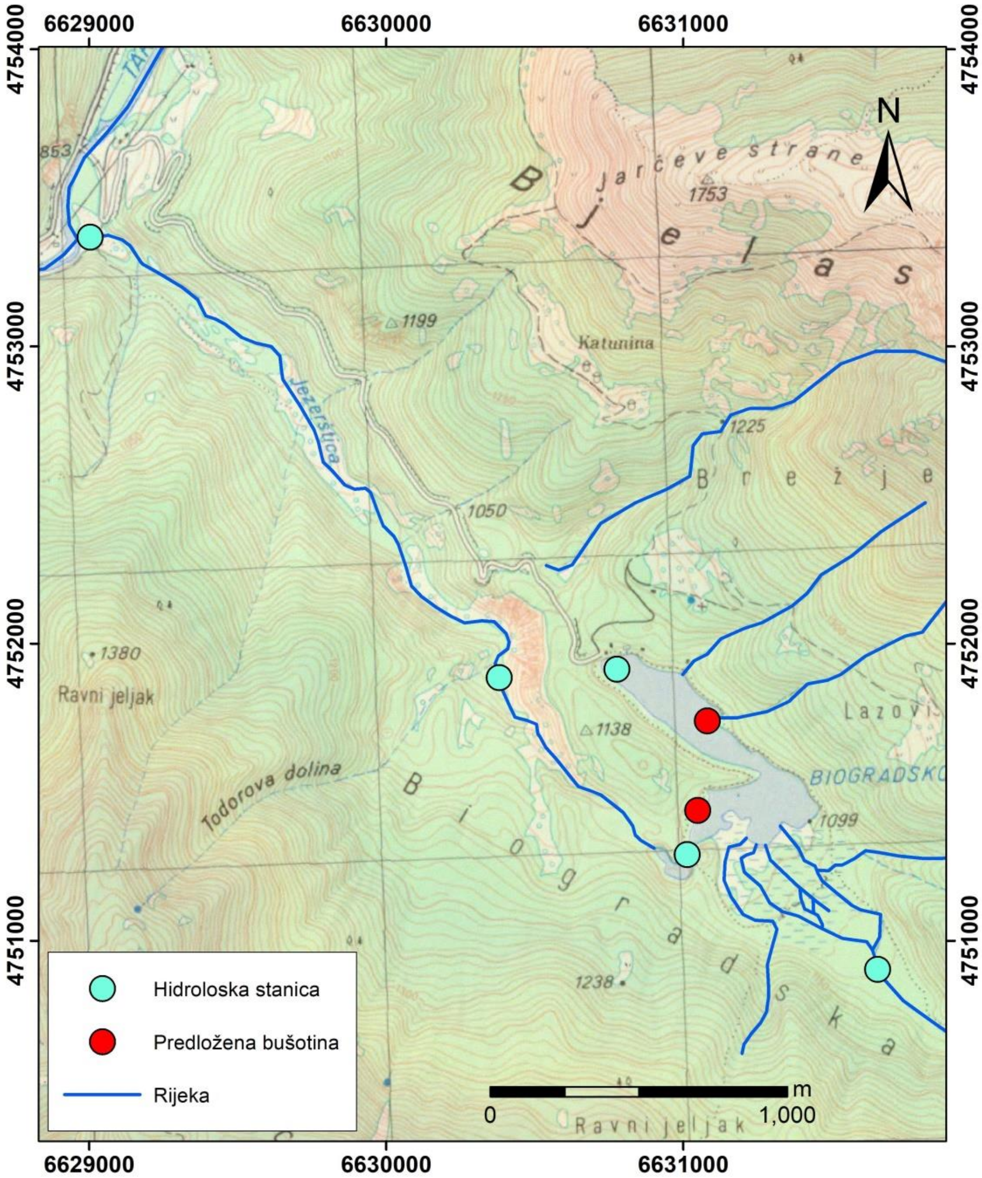

Figure 31. Positions of hydrometric profiles and proposed boreholes

The study and office work will relate to:

- ✓ compiling and validating hydrological and climate data through adequate software programmes;
- ✓ the analysis of the hydrological regime of the basin of Biogradsko Lake and Jezerštica (average, low and high

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measurement of water flow and thus determine quantities of water being lost by underground route (through moraines and limestone canals).

water), hydrological balance (in average, low-water and water-abundant years), considering boundary conditions etc.

8.2. Hydrogeological surveys

Hydrological mapping of the survey area needs to observe and follow the main principles and methodologies of hydrogeological surveys. Speaking about principles, it primarily refers to the level of details and progressiveness of the survey. In order to perform mapping completely, it is necessary to choose the routes along which terrain will be visited. The routes should be chosen on the existing hydrogeological map 1:5000, and after revision of the existing geological map 1:5000 is completed.

The hydrogeological map 1:5000 should include directions of circulation of ground water. This especially relates to the water infiltrating through sinkholes along the bottom of Biogradsko Lake and probably emerging on Jezerštica springs in the canyon of the same name. It is necessary to perform dyeing experiment by means of a tracer in order to identify routes of circulation of ground waters.

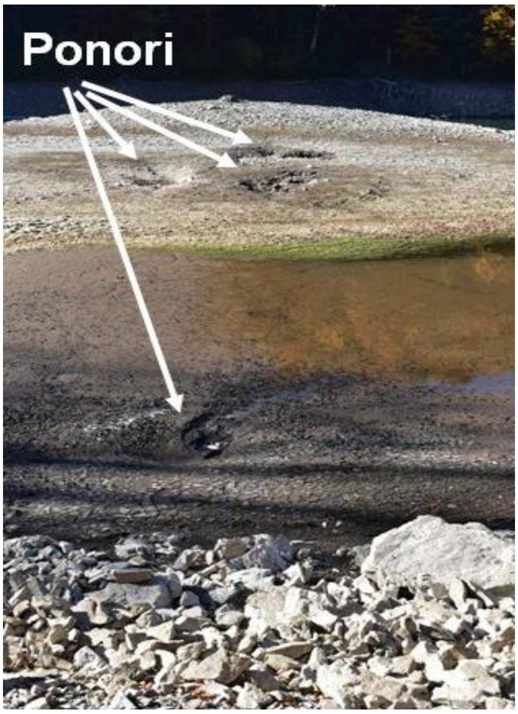

Figure 32. Sinkholes which would allow pouring of tracer
(Photo: Dubljević V., 31.10.2021)

Experiment of tracing of infiltrating water. Dissolved tracer should be poured into one of the infiltrating watercourses which occur at low water level of Biogradsko Lake (Figure 32).

Sodium-fluorescein in the amount of 2-3 kg should be used as a tracer.

This implies the following activities:

- Preparation of the experiment implies the procurement and use of means of protection (gloves, glasses), as well as the obligation for the persons engaged in pouring the tracer not to be also members of the observation team in order to avoid any possibility of transfer of tracer particles into the observation zone;
- Tracer can be previously dissolved in 40 l of water and 5 l of alcohol. Mixing of dye should continue until it is fully dissolved, after which the prepared solution would be poured directly into the infiltrating watercourse;
- Once dye is poured, sinkshould be monitored carefully until tracer is fully infiltrated into the underground area;
- The observation subjects of the primary network are the two springs in the Jezerštica valley (Figure 33). After dyeing, observations are performed every 3 hours, and 10-minute sampling frequency from the moment of registering of dye. When visiting the spring for the first time, it is necessary to place meshy (water-permeable) bags with activated charcoal able to absorb tracer (using adequate reagent in the laboratory would allow verifying whether tracer was in contact with activated charcoal). The secondary network facilities are the downstream section of Jezerštica and the Tara River (in the bridge zone) where observations and sampling are performed twice a day (if tracer emerges in those zones, but does not emerge in upstream springs, sampling is also required at 10-minute frequency). Once emerging of tracer in visible concentrations stops, four more samples are taken (every 6 hours). (Note: the Lake shore should be visited several hours after pouring tracer, immediately below

pouring points, so as to determine whether tracer is emerging along the bottom of the Lake);

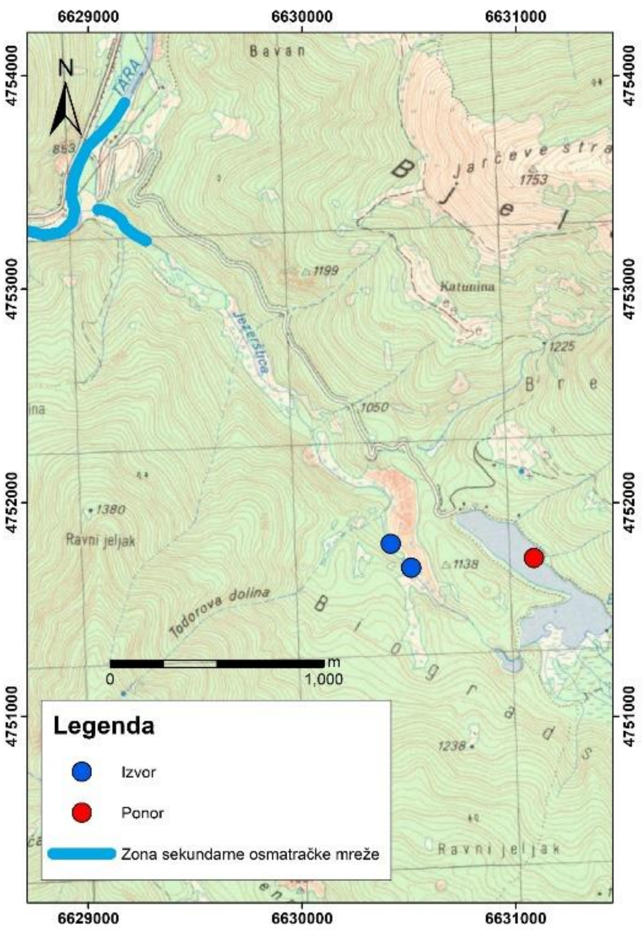

Figure 33. Position of sinkholes and the observation network facilities[3]

- Observation of the tracer presence should be performed in three ways:

  -]visually and by calibration,
  - by fluoroscopic lamp and calibration, and
  - spectrophotometrically in the laboratory.

The first two procedures are conducted directly in the field. Observers should have corresponding calibration samples previously prepared in the laboratory (8 in total for 10^{-1} to 10^{-8} g/l). In addition, all bottles for samples must be sterile and not used previously.

[3] Springs in Jezerštica valley, downstream Jezerštica and a part of Tara flow.

- Processing of results is performed by the procedure of quantitative analysis. A curve of the intensity of emergence should be constructed and the volume of emerged tracer should be calculated based on the collected data.

The future hydrogeological surveys for the purpose of developing of the hydrogeological map 1:5000 should be aimed at the clarification of the considered infiltration mechanism. Those activities should define more completely the geological structure of the underlying stratum of glacial sediments along north-eastern and southwestern Lake shore, i.e. establish whether limestone or volcanic rocks are found below the sediment (in the sinkhole zone). Also, registering directions and velocity of ground waters (by performing a tracing experiment) would contribute considerably to the definition of the hydrogeological system Biogradsko Lake – Jezerštica.

Addressing the above described hydrogeological matters is the necessary step that should precede the development of the Preliminary Design for integrated rehabilitation of Biogradsko Lake. Rehabilitation of infiltration zones will in any case be an uncertain and highly complex task.

The work as per this position will result in the revision of the existing hydrogeology map of the wider study area in the 1:5000 scale.

8.3. Detailed geological, hydrogeological and engineering-geological mapping

Geological mapping of terrain that should be performed under this Project primarily relates to the control and verification of the existing geology map 1:5000, i.e. defining and control of lithology composition and age of mapped units, as well as defining the tectonic composition of the study area in the part and to the extent it can affect specific hydrogeology characteristics of the area, which are subject of the survey.

The existing topographic map 1:5000 should be revised from the geological aspect, including development of one longer geological profile to be done perpendicularly to the direction of the Lake, with a cross-section over frontal moraine and the large erosion scar in the Jezerštica canyon. The objective of developing profiles is primarily the spatial definition of all geological formations and their structural composition. For the purpose of quality mapping, it would be necessary, and technically very demanding, to execute several profiles along the large erosion scar in the Jezerštica bed and thus define their lithological and stratigraphic components.

Especially important for this Project are the geological relations existing within Triassic formations, more specifically, spatial relations should be defined between crystal limestones T_2^2, rocks of volcanic-sediment formation T_2^2 and Triassic magmatic rocks. The relation between these lithological components is especially important in a section of the Biogradsko Lake where frontal moraine descends towards the Jezerštica canyon where a large erosion scar is formed.

8.4. Exploratory drilling

In case it seems necessary, a possibility of executing two exploratory boreholes needs to be foreseen. Potential locations of the boreholes are shown on Figure 31.

Geological exploratory boreholes will be executed with a view to establishing lithological, granulometric composition, spatial position and thickness of dipping of glacial sediments, with a special emphasis on the ration of crystal limestones, volcanogenic-sediment series and magmatic rocks. In addition, drilling will determine depths down to the ground water level, filtering characteristics of water-bearing surrounding.

Exploratory drilling, in case it takes place, will be performed mechanically, by rotation method with continuous coring, initial diameter of Φ146 mm and end diameter of Φ131 mm. The designed depth of boreholes is 35-40 m. The real depth will depend on specific geological conditions of the terrain and will be set by the project supervision while drilling.

The following needs to be monitored during exploratory drilling: the speed of advancing of drilling tools, drawn down of drilling tools, difficult rotation of drilling tools, emergence of water etc. The core percentage should be 90%. The extracted core should be stacked in one-meter-wide intervals and marked properly. Stacking should observe the sequence of the extracted core, and an empty space with clearly written lengths will be left in intervals where core was not extracted. At the completion of drilling, core should be photographed.

Solid and perforated PEHD pipes Φ125 mm will be installed in the borehole. The length of the perforated section will depend on specific hydrogeology conditions of terrain, thickness and filtering characteristics of the water-bearing environment and will be set by the project supervision after drilling is finalized, if it takes place.

8.5. Geophysical survey

In order to determine the thickness of sediments in the section of the Lake that was backfilled for years by the finest sediments brought by the Biogradska River and Lalev Stream, it would be ideal to conduct seismic refraction surveys given the obvious difference in physical-mechanical characteristics of deposited sediments and volcanic rocks found in the underlying stratum. It would be good for this type of survey to conduct shallow refraction seismic surveys. These surveys can be conducted only in early autumn (end September and October), when the Lake reaches its hydrological minimum. Since arrays of geophones need to be placed over the dried section of the Lake, the consistency of deposited sediments and their compressive strength is the limiting factor for the implementation of this method. The strength of sediments must be such to have the bearing capacity for the operator who would install the required equipment, in order to avoid his uncontrolled draw down.

In order to conduct refraction-seismic surveys, the following needs to be done, i.e. surveys will have to comprise:

- ❖ determining depth and velocity of distribution of elastic longitudinal ($\mathbf{V_p}$) and transversal waves ($\mathbf{V_s}$) in individual lithology environments, i.e. fine deposited sediments and volcanic rocks in the underlying stratum;
- ❖ determining thickness (**D**) of surface complex of deposited sediments; and
- ❖ determining spatial distribution and depth dipping of individual lithology constituents.

Interpretation of results of refraction-seismic surveys will be based on setting the value of velocity of distribution of elastic longitudinal and transversal waves in various lithology surroundings. It is possible to calculate depth of deposited sediments based on the difference in the velocity of distribution of elastic longitudinal and transversal waves. The results of refraction-seismic surveys are presented in the form of the hodochrones of the velocity of distribution of refraction-seismic waves which provide the time of distribution required for the elastic waves to reach the ignition point, then the receiver-geophone set-up along the profile.

All these parameters: velocity of distribution of elastic longitudinal and transversal waves, volume weight and thickness of lithology environments contribute to putting together the geodynamic model of terrain down to 50 meters of survey depth.

The refraction-seismic surveys will be conducted along several seismic profiles of the overall length of around 2000 m, and receivers (geophones) will be located along the profiles spaced at 12 meters. Elastic waves will be caused by mechanical impact by a 10 kg hammer at 5 measuring points.

Seismic refraction surveys should be conducted in the period of hydrogeological minimum. That would allow performing a quality correlation of results of the refraction profile with the profile from the executed boreholes, and the prepared geology map 1:5000. The result of surveys planned and conducted in such a way would create a clearer picture of the sediment thickness and thus allow calculation of volumes of sediment that can be removed from the Lake basin and result in the increase of water volume in the Lake basin.

On the other hand, having in mind the **Study of the Morphology of the Bottom of Biogradsko Lake**, prepared by the Association of Young Researchers of the Faculty of Forestry in Belgrade in 1989, it is possible to calculate the volume of the material backfilling the Lake in the previous period, from 1989 to date, and then estimate the mean annual sediment yield in the Lake. These data are necessary to acquire as quality and reliable rehabilitation solutions as possible in the Preliminary Design for integrated solution to the observed problems on Biogradsko Lake.

In case that application of shallow reflective seismic is not possible due to previously mentioned consistency and compressive strength of deposited sediments, consideration should be given to the possibility to use *sub bottom profiler*, or a similar device, designed to operate as a marine device, i.e. a device which allows acquisition of data about the Lake bottom, from the sea surface or, in this case, Lake surface. The device is portable, small power, but able to record layers and segregate them even when they are 6 cm thick. This is in fact echo sounder emitting 10 kHz acoustic signal, and the signals with such features are characterized by such penetration capacity that a signal can penetrate even up to 40 m into the ground, which substantially exceeds our needs in terms of surveying the depth of sediments in Biogradsko Lake. Shallow water can certainly reduce the usability of such an instrument in the conditions of Biogradsko Lake. In cases when depth to the bottom is less than 1m, the use of such type of device is very limited.

It is necessary to perform the final processing of data in one of professional software for processing of hydrographic measurements, by using also the paper records, which sometimes offer a better picture of the position of the bottom when measurements are performed in the Lake basin.

Any further modelling of data and their visualization can be performed in some of professional GIS tools which offer the option for calculating the terrain model, differential model and offer a possibility of further cartographic processing.

8.6. Geodetic and bathymetry survey

The available geological, hydrogeological and engineering-geological maps are prepared on the topographic map 1:5000. It is still not known to us whether this geodetic map can be found in Montenegro. A possibility is actively sought to acquire the map regardless of whether it is in analogue or digital format. In case it is possible to acquire the geodetic map 1:5000, future measurements and observations should be adjusted to that situation.

Namely, if analogue versions of the geodetic map exist, then they only need to be digitalized and upgraded with the changes that took place in the meantime. In case there is neither analogue not digital versions of the map 1:5000, then the geodetic survey should be repeated.

However, due to specific terrain configuration reflected in extremely high overgrowth in the riparian part and a relatively low water level, the surveys that would be conducted on the Lake require the use of exclusively conventional methods of geodetic survey for the purpose of achieving satisfactory accuracy, both for stabilization of the network and the implementation of geodetic measurements.

The most favourable period for implementing the survey would be autumn (end of September and beginning of October), since the water level is low in that period, leaves have already fallen off, and it is possible to stabilize the grid of points which would be within the range of visibility.

The surveys within the grid must be performed by the method of measuring angles and lengths. One existing point of the national trigonometric grid and at least one point determined by the GPS method should be used as the basis, if the open sky allow GPS measurement.

Levelling of 1D and 2D grid would be performed by subsequent calculation and a stable and reliable grid of some 25 points would be ensured. These points would then be used for subsequent geodetic measurements of the shore by the total station.

Definition of the GPS grid that represents a simpler and quicker form of defining of geodetic map is not possible since there is no open sky in the entire section of the Lake, but high overgrowth makes a “mask” and gives unsatisfactory accuracy of the measurement.

Bathymetric measurements should be implemented by a standard configuration of the single-wave dual-frequency eco sounder, with additional paper records, GPS receiver and tables for the velocity of ultrasound distribution in fresh water.

A part of data which could not be collected by bathymetric method due to poor signal, they would have to be additionally recorded geodetically, and this refers to depths of the Lake below 70 cm.

The new geodetic grid could be potentially used also for georeferencing of the existing cartographic material which would serve for calculating the siltation that occurred in the period from 1986 until the day of the new survey.

8. BILL OF QUANTITIES AND PRICED BILL OF QUANTITIES

	Description	M.U.	Quant.	Unit price without VAT	Total without VAT
	Hydrological research				
1	Monitoring of surface waters (automatic equipment and infrastructure)	pcs	5	3850,00	19.250,00
2	Staff gages	pcs	15	160,00	2.400,00
3	Hydrometric measurements and overlaying data from instruments	pcs	10	600,00	6.000,00
4	Hydrological analysis of phenomena and processes in the basin of the Biogradsko Lake and Jezerštica	pcs	1	2000,00	2.000,00
	Hydrogeological research				
1	Hydrogeological mapping of terrain	day	10	300,00	3.000,00
2	Performing a test of dyeing of water	day	7	1,00	3.500,00
3	Data processing and revision of the hydrogeological map 1:5 000	day	10	200,00	2.000,00
	Geological research	day			
1	Geological mapping of terrain	day	10	300,00	3.000,00
2	Exploratory drilling (optional)	m	80	100,00	8.000,00
3	Data processing and revision of the geological map 1:5 000	day	10	200,00	2.000,00
	Geophysical research				-
1	Field refraction seismic surveys	m	2000	5,00	10.000,00
2	Processing of data of refraction seismic surveys	day	10	500,00	5.000,00
	Geodetic and bathymetry surveys and measuring				-
1	Stabilization of the operational polygon	day	11	300,00	3.300,00
2	Levelling of height and 2D grid	day	25	300,00	7.500,00
3	Terrestrial survey of the coast to 1100 m.a.s.l.	day	60	300,00	18.000,00
4	Georeferencing and digitalization of historical data	lump sum	1	2.000,00	2.000,00
5	Processing of recorded topographic measurements	day	5	300,00	1.500,00

6	Calculation of the differential model zero/new condition	lump sum	1	1.000,00	1.000,00
7	Bathymetric measurement of the Lake	day	25	300,00	7.500,00
8	Processing of bathymetric measurements	day	15	300,00	4.500,00
9	Drawing of transversal profiles of the Lake	day	5	300,00	1.500,00
10	GIS development	lump sum	1	1.000,00	1.000,00
	Total without VAT				**113.950,00**
	Contingencies			**10%**	
	VAT 21%				**23.929,50**
	TOTAL WITH VAT				**137.879,50**

10. CONCLUSION AND FINAL REMARKS

The Project "Rehabilitation of Biogradsko Lake" has been one of the priorities in the environmental protection sector of the Ministry of Ecology, Spatial Planning and Urbanism for years, and as such was also one of the priorities on the Single List of Infrastructure Projects.

The problem of erosion in the Jezerštica canyon, infiltration and loss of water from the Lake, as well as siltation of the Lake with river load was recognized more than half a century ago and has always been linked to the possibility of permanent disappearance of Biogradsko Lake.

To this end, the Ministry of Ecology, Spatial Planning and Urbanism decided to complete the first phase, i.e. an analysis of the current situation of Biogradsko Lake through the current IPA Project "Support to Project Preparation for Environment and Climate Change Sector" (IPA 2016). It is planned to collect all the existing documents about Biogradsko Lake within this phase, to analyse them and define the problems that need to be addressed. Also, a proposal and a plan of further activities which should lead to lasting remediation of Biogradsko Lake should be prepared in the first phase.

While working on the first phase, three problems that need to be solved were clearly differentiated within the zone of Biogradsko Lake:

- the problem of siltation of the Lake with eroded material transported by the Biogradska River and Lalev Stream;
- the problem of infiltration of the Lake water through a series of ponors (sinkholes) at the bottom of the Lake; and
- the problem of progressive erosion in the Jezerštica canyon.

In the future, each of these may lead to a complete devastation of this jewel of nature and its permanent loss.

The solution to these problems should be comprehensive since addressing one of them alone not sufficient to preserve the Lake. The rehabilitation of Biogradsko Lake should follow the principle **"nothing is over until it's over"** and that is why this task is very complex and addressing it requires a committed and pragmatic approach.

The concept of future surveys is primarily defined in a way to conduct audit and control of the existing maps, to amend and digitalize them where possible, and to prepare the maps which are missing but deemed necessary.

As defined by the Terms of References for the first phase of this project, it is necessary to plan works and activities of the second phase. The following is planned for the second phase of the Project:

1. control and amending of the existing plans, and their digitalization where possible;
2. preparing of new missing maps which are deemed necessary;
3. drafting of the Terms of Reference for developing of the Preliminary Design for integrated rehabilitation of the existing problems on Biogradsko Lake.

Once the required and relevant geodetic, bathymetry, geological, hydrogeological and hydrological maps are completed, a tender should be launched and implemented within the third phase to select the best Preliminary Design for integrated solution to the existing problems affecting the future existence of Biogradsko Lake. Having this in mind, maps must be developed at the level that is satisfactory for this type of works so as to avoid, to the highest extent possible, the use of analogy, approximation and estimations while drafting of the Preliminary Design.

Given the complexity of the overall problem, the idea is to implement the rehabilitation of Biogradsko Lake in several phases. If consideration is given to the fact that completion of this Study is the completion of **phase I** of the Rehabilitation Project, the following phases are planned until the final completion:

Phase II – *Amendment to existing maps and development of new missing ones, definition of the Project (Problem analysis) and writing of Terms of References for developing the Preliminary Design for Integrated Rehabilitation of Biogradsko Lake*;

Phase III – *Launching of international prize competition for selecting the best Preliminary Design for Integrated Rehabilitation of Biogradsko Lake, and choosing the best solution;*

Phase IV – *Preparing Environmental Impact Assessment for the Preliminary Design for Integrated Rehabilitation of Biogradsko Lake;*

Phase V – *Developing the Main Design for the rehabilitation project on the basis of the Preliminary Design for Integrated Rehabilitation of Biogradsko Lake;*

Phase VI – *Launching a tender for selecting a contractor for implementing works as per the Main Design for Rehabilitation of Biogradsko Lake;*

Phase VII – *Implementation of works as per the Main Design for Rehabilitation of Biogradsko Lake and its permanent rehabilitation.*

Since these are activities and works that should take place in the ecologically most sensitive and most vulnerable area, ultimately creative and pragmatic engineering solutions which are in uncompromising harmony with the natural environment of Biogradska Gora, which will not in any way threaten the existing harmony, must be applied when developing the *Main Design* for Rehabilitation and in executing works thereunder.

ANNEX I - PRELIMINARY PROJECT OF SAND EMBANKMENTS

ANNEX II – TABLE FOR COLLECTION AND ORGANIZATION ON AVAILABLE DATA

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