Project: “Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation” Interreg CBC Italy-Croatia 2014.-2020.

Priority Axis: Safety and resilience

Specific objective: Improve the climate change monitoring and planning of adaptation measures tackling specific effects, in the cooperation area

(D_3.1.4) Report on the initial hydrogeological and agricultural conditions of the Croatian site

Work Package 3: Studying

Activity 1: Sites characterization

Partner in charge: PP4 (UNIST-FGAG)

Partners involved: PP4 (UNIST-FGAG), PP5 (CROATIAN WATERS), PP6 (DUNEA)

Final version

Public report

September, 2022

1 Contents

2 Introduction

Present version of the report represents a final version of the hydrogeological conditions as found within the river Neretva valley done as a part of a project “Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation” Interreg CBC Italy-Croatia 2014.-2020.

3 Review of available documentation

The available documentation has been reviewed and the key data, as well as the examples of results from chronologically arranged studies and projects in the Table 2.1 are given below. It is noted that some of the old documents have missing certain information and files that should be contained within it.

Table 3.1 Chronological review of available documentation

YEAR	PROJECT TITLE	AUTHOR
1962.	*Geophysical investigations /geoelectrical and seismic/ Opuzen - mouth of Neretva*	GEOFIZIKA, Zagreb
	Grain-size distribution curves Opuzen - mouth of Neretva	ELEKTROSOND, Zagreb
1963.	*Hydrological - geological boreholes Opuzen - mouth of Neretva*	ELEKTROSOND, Zagreb
	Hydrogeological investigation works Opuzen - mouth of Neretva	ELEKTROSOND, Zagreb
	Geological investigations Opuzen - mouth of Neretva	ELEKTROSOND, Zagreb
	Project: Melioration downstream of the Neretva River 1st part /The general part/	FAO experts - engineers of USSR, Opuzen
	Project: Melioration downstream of the Neretva River 2nd part /Flood defence/	FAO experts - engineers of USSR, Opuzen
	Project: Melioration downstream of the Neretva River 3rd part /Drainage/	FAO experts - engineers of USSR, Opuzen
	Project: Melioration downstream of the Neretva River 5th part /Water supply for irrigation/	FAO experts - engineers of USSR, Opuzen
	Project: Melioration downstream of the Neretva River 7th part /Pumping stations and electricity supply/	FAO experts - engineers of USSR, Opuzen
	Project: Melioration downstream of the Neretva River 10th part /Hydrogeological and engineering-geological conditions/	FAO experts - engineers of USSR, Opuzen
	Excerpt from the conceptual design from 1959. of additional melioration works on "Luke - irrigation with water from the lake Modro oko"	PROJEKT, Zagreb

1964.	*Study /Luke - piezometers/*	ELEKTROSOND, Zagreb
	Study /Vrbovci - piezometers/	ELEKTROSOND, Zagreb
1965.	*Geotechnical report*	ELEKTROSOND, Zagreb
1966.	*Investigation works* *Opuzen - Diga*	GEOFIZIKA, Zagreb
	Water investigation works *Opuzen - Modrič*	GEOFIZIKA, Zagreb
1966.	*Geotechnical report* *Embankment at the mouth of Mala Neretva*	Geotechnical institute, Zagreb
	Water investigation works *Opuzen - Šetka*	GEOFIZIKA, Zagreb
	Water investigation works *Opuzen - Vidrice*	GEOFIZIKA, Zagreb
1973.	*Conceptual design of the meliorated area Kuti /hydrogeology/*	PIK NERETVA, Opuzen
1996.	*Water management solution and arrangement of the Lower Neretva basin*	Faculty of civil engineering, Split
2005.	*Drilling report of two pairs of piezometers downstream of the Neretva River*	GEOKON - ZAGREB d.d.
2008.	*Geotechnical investigation works for irrigation system conceptual design downstream of the Neretva River*	GEOKON - ZAGREB d.d.
	Geotechnical investigation works for the construction of sidewalks (promenades) along the left riverside of the Crna River in Rogotin from km 0 + 162,96 to km 0 + 386,57	GEOKON - ZAGREB d.d.
	Preliminary geotechnical investigation works for the Neretva Bridge near Opuzen	GEOKON - ZAGREB d.d.
2011.	*Geotechnical investigation works for the development of a design solution for the reconstruction and renovation of concrete structures and hydromechanical equipment of the embankment at the mouth of Mala Neretva*	GEOKON - ZAGREB d.d.
2012.	*/Study 095-12-01/*	GEOKON - ZAGREB d.d.
	Geotechnical investigation works for renovation of the separation embankment Subsystem Mislina - Kuti	GEOKON - ZAGREB d.d.

2013.	*Geotechnical investigation works for renovation of the Neretva River bank slopes at six critical locations from the mouth to the town of Metković*	GEOKON - ZAGREB d.d.
	Geotechnical investigation works for project of Mala Neretva banks arrangement	GEOKON - ZAGREB d.d.
	Geotechnical investigation works for siphon below Mala Neretva at the pumping station Prag (Vidrice)	GEOKON - ZAGREB d.d.
2013.	*Geotechnical study for irrigation system Subsystem Opuzen (Phases A and J)*	Institute IGH d.d., Zagreb
2014.	*Geotechnical investigation works for renovation of the right river bank of the Neretva River in Komin*	GEOKON - ZAGREB d.d.
	Piezometers drilling for groundwater monitoring in the area of Mala Neretva	GEOID - BEROŠ d.o.o., Varaždin
2017.	*Geotechnical investigation works for pipelines of Glog irrigation system*	GEOKON - ZAGREB d.d.

3.1 Geophysical investigations /geoelectrical and seismic/ (Opuzen - mouth of Neretva) (1962.)

Geophysical investigations were performed at three informative profiles located at the Neretva Delta, west of Opuzen. The main assignment was to determine the depth of bedrock using both geoelectrical and refraction method, with a purpose of simultaneous validation of the results obtained.

Profiles of geoelectrical probes were laid in the NW – SE direction, transversely to the Valley. A total of 150 geoelectrical probes were measured up to a maximum sounding depth of 200m. Several mechanical boreholes were taken for determination of the geoelectrical parameters. Using seismic refraction method, 25 seismic probes on a total of three profiles were investigated.

Results show that the depth of the quaternary sediments base vary within 20m – 30m, except the south-eastern part of the Profile II, where the depth of bedrock reaches 40m. Surface part of the sediment is separated into zones along the profiles, where lower values of the specific resistivity indicate a higher degree of salinity and higher values indicate lower degree of salinity. The following figures show situation and its scheme, as the examples of the previously mentioned results.

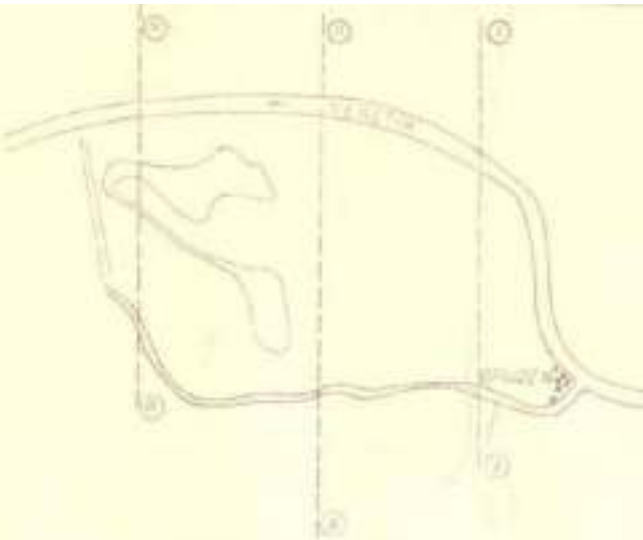


Figure 3.1 A scheme of the situation with profiles

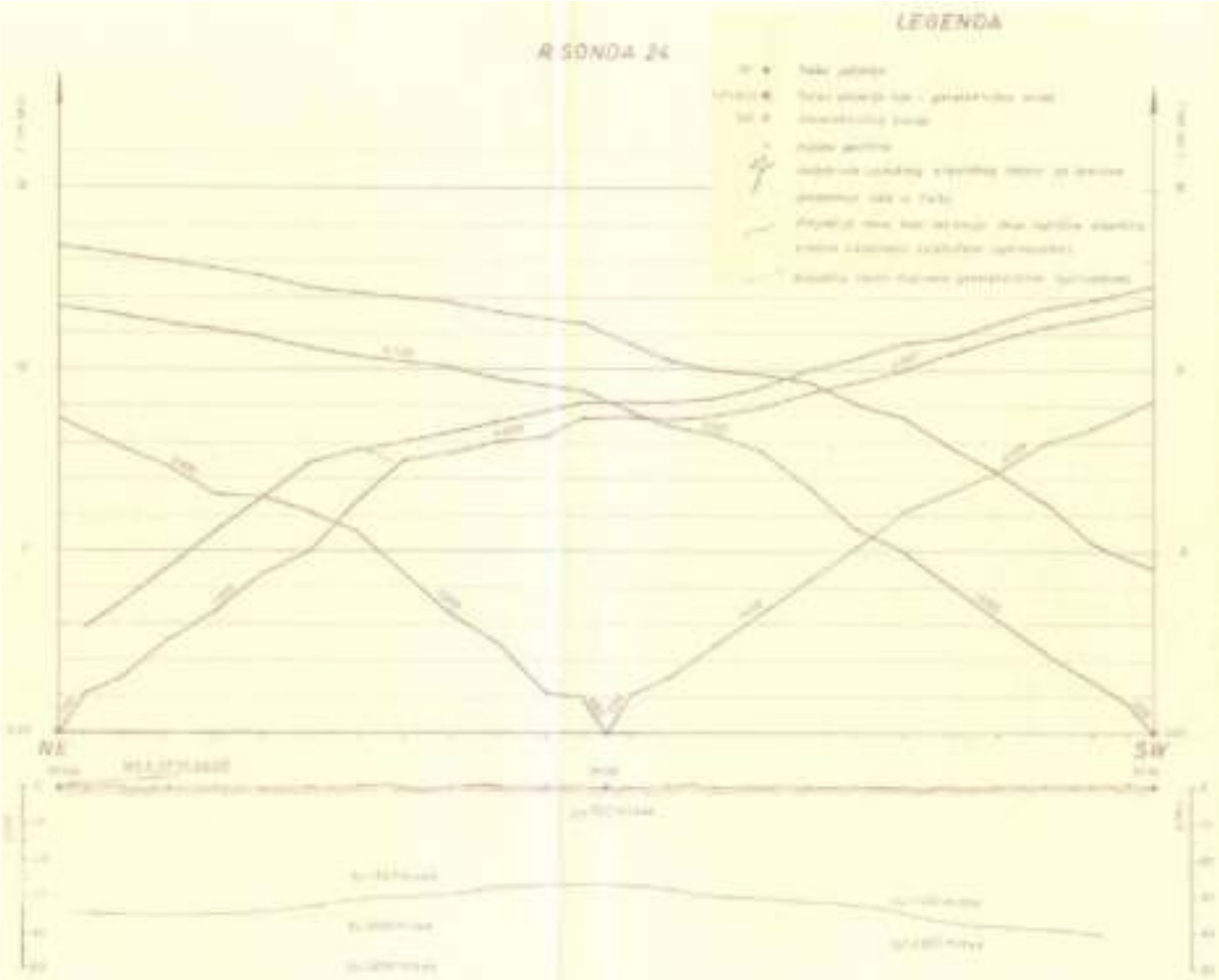


Figure 3.2 An example of the result of seismic refraction

Figure 3.3 An example of the result of geoelectrical sounding

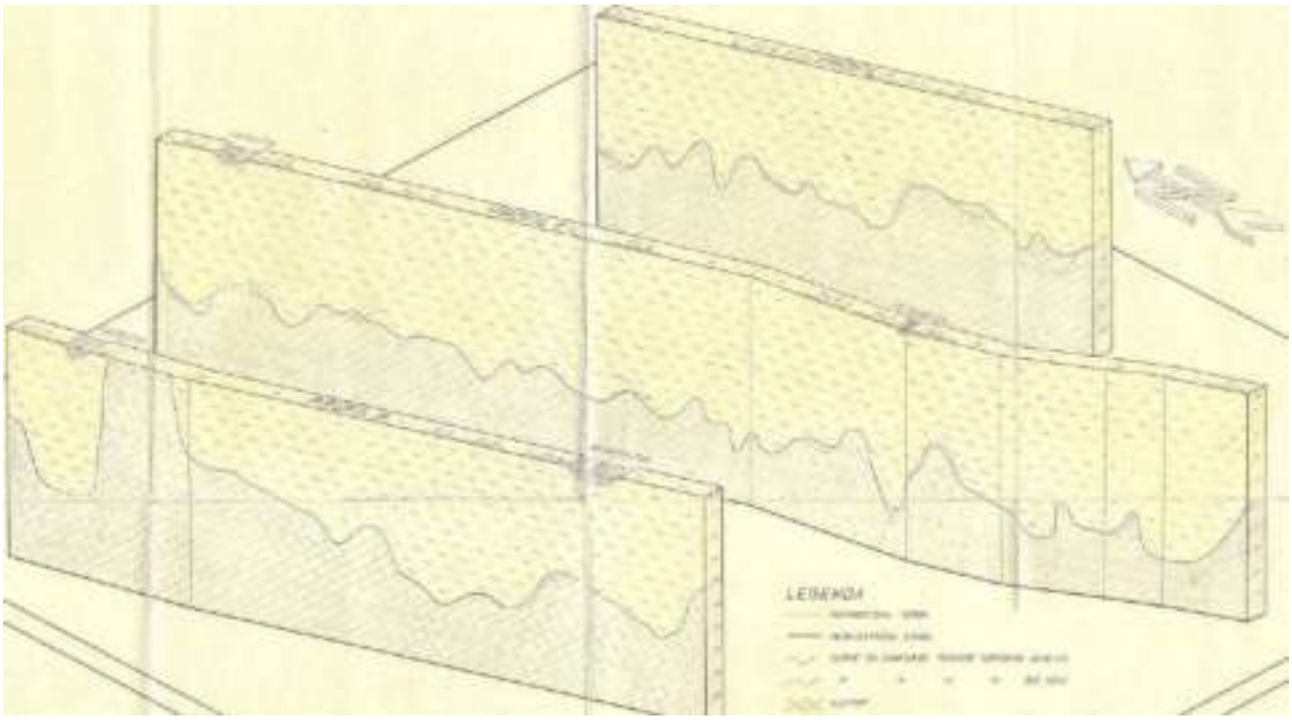


Figure 3.4 Results of geophysical investigations

3.2 Grain-size distribution curves (Opuzen - mouth of Neretva) (1962.)

Grain-size distribution curves are given for boreholes positioned at following locations: embankment Diga, Rivers Crepina, Velika Neretva and Mala Neretva as the area between, hydrogeological boreholes, pumping station at the mouth of Mala Neretva River (left river bank), the ditch Velika Neretva River – Prunjak stream, supply channel Metković – Opuzen, pumping station Metković (left river bank 8m upstream of the bridge) and borrow pit Gabela.

Results are shown as grain-size diagrams with distribution curves, information of the hydraulic conductivity and inequality coefficient for every layer, as the depth of layers.

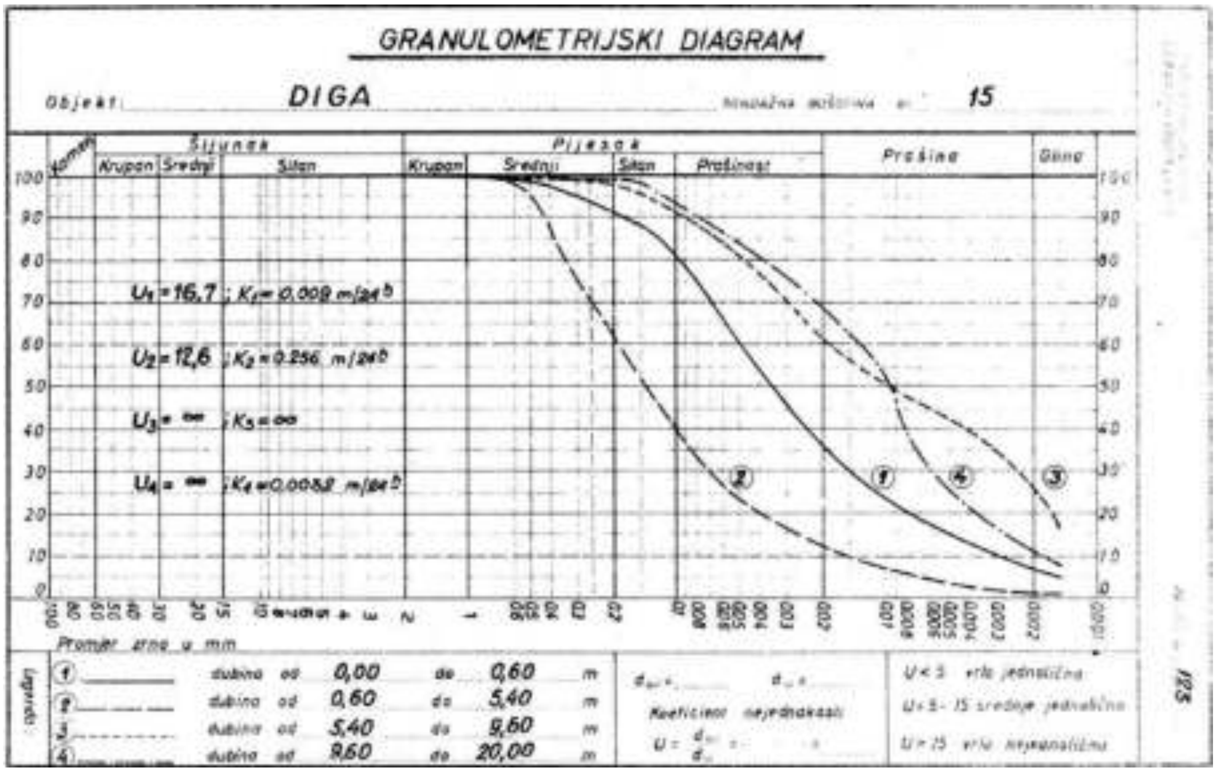


Figure 3.5 An example of grain-size diagram

3.3 Hydrogeological investigation works (Opuzen - mouth of Neretva) (1963.)

Hydrogeological investigation works were taken at the Neretva Valley, bounded with Opuzen on its right and sea on its left side. North boundary was considered Neretva River, while the Rilići hill its south and south-west border. The objective of investigation was to determine filtration soil properties and geological profiles, as the salinity of groundwater.

Results determine soil grain-size composition, as the consistency and porosity of coherent soils. Samples of water were taken from different depths for chemical analysis and salinity determination. Slug and pumping in situ tests gave measurement of change in water level as the amount of water.

Drilling was performed on 33 locations, while several boreholes reached the bedrock which approved the previous geoelectrical and seismic measurements. Measured hydraulic conductivity is within limits 10^{-4}m/s and 10^{-8}m/s, which is approved by determination of hydraulic conductivity using grain-size curves, and is referring to poorly permeable materials.

Soil analysis show the main components of it: fine to coarse grained sand, silt, silty sand, clay, loam, peat and the top layer humus. It is concluded that sands cause salinization because they enable saltwater intrusion and its mixing with fresh water, and increase of salinity with depth.

The following figures show an example of borehole with geological profile, data for slug and pumping tests with values of hydraulic conductivity and the Neretva River water levels with precipitation and groundwater level fluctuations.

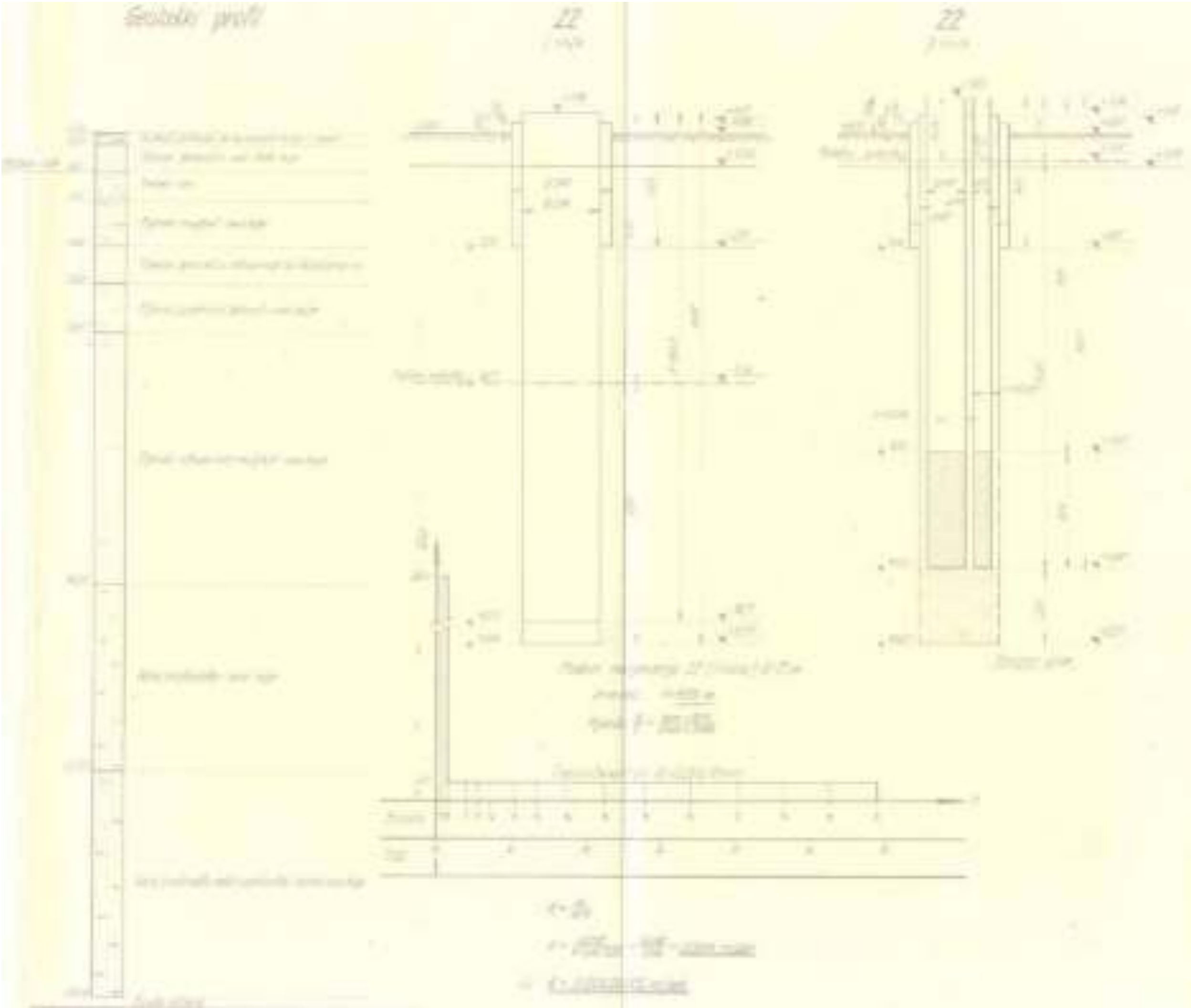


Figure 3.6 Geological profile and results of slug test

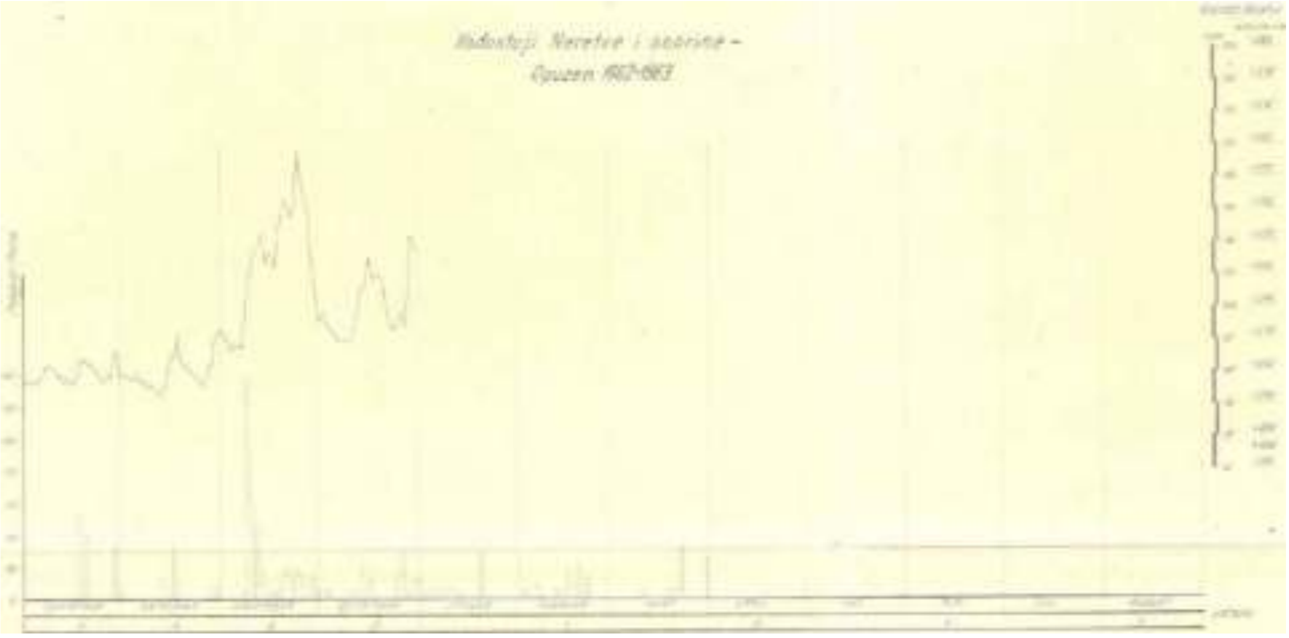


Figure 3.7 The Neretva River water levels with precipitation

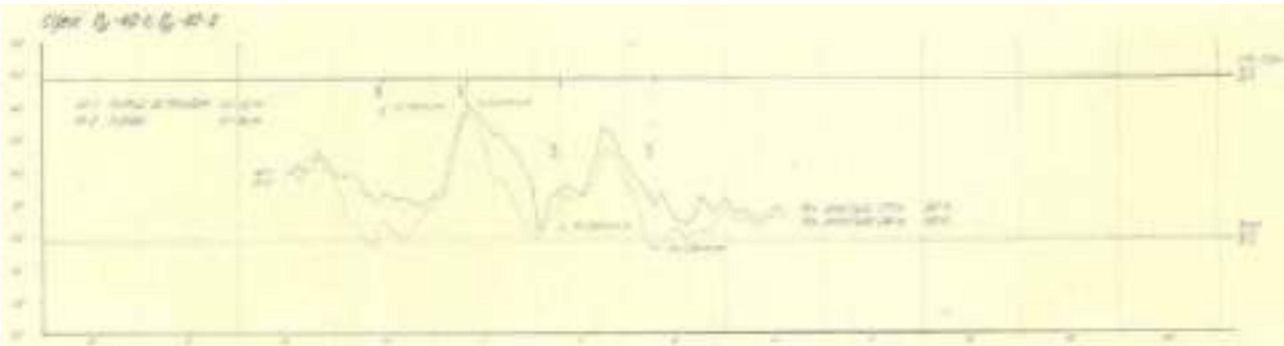


Figure 3.8 An example of groundwater level fluctuations

3.4 Hydrological - geological boreholes (Opuzen - mouth of Neretva) (1963.)

The documentation is incomplete and provides an insight into information about several geological profiles at pumping station at the mouth of Neretva River and Metković pumping station. The classification of water for use in irrigation is described, but the results are missing.

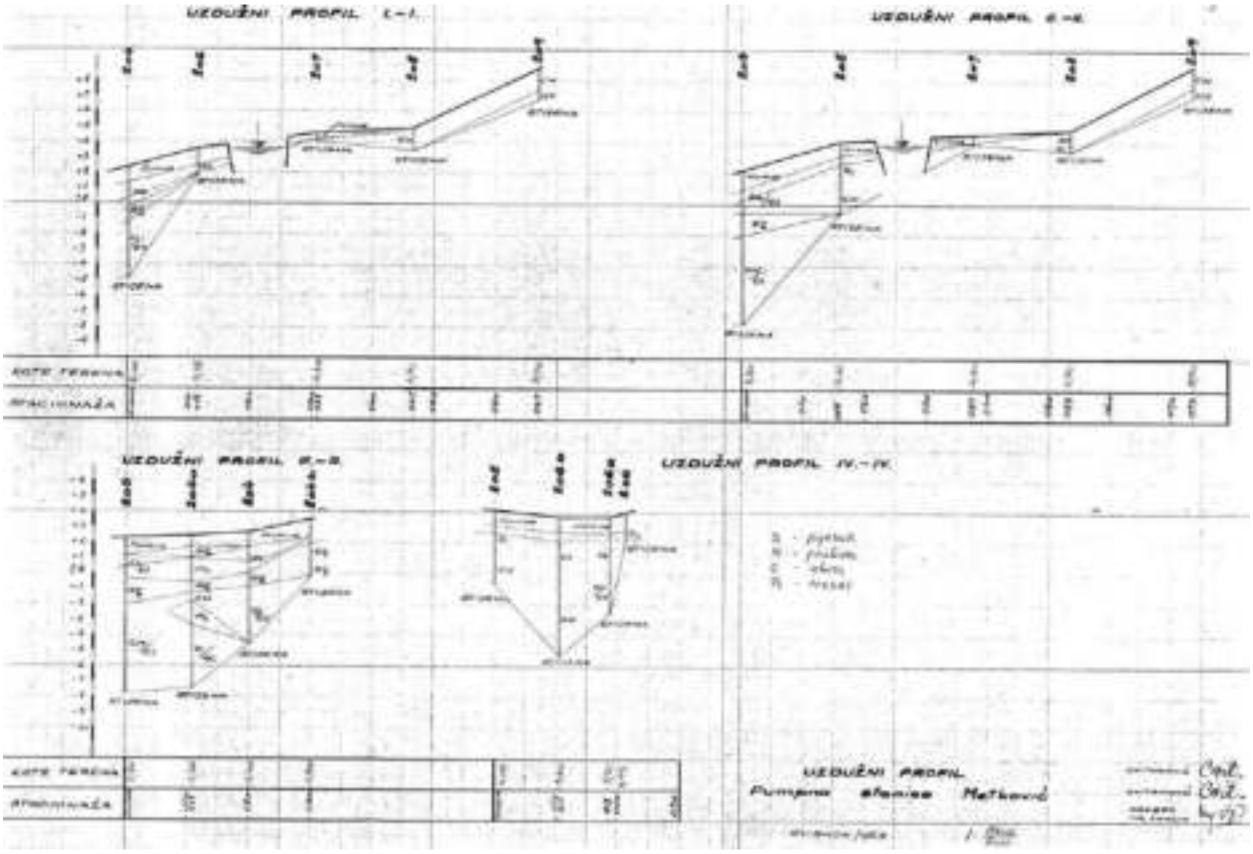


Figure 3.9 Geological profiles at Metković pumping station

3.5 Geological investigations (Opuzen - mouth of Neretva) (1963.)

The study deals with the results of geological surveys using the known geomechanical laboratory research. Geological terrain mapping of the Neretva Valley west of Opuzen was done within investigations, including the area of 40km^2. Insight is given into geological structure of the terrain, hydrographical and hydrogeological conditions, as well as the brief description of the origin and development of the Neretva Valley.

The Neretva Valley is surrounded by hillsides composed of limestones containing all karst forms as a result of a long-term erosion. The hills descend steeply toward the Valley and disappear under alluvial deposits. Limestone mounds are rising from the plain and are connected to the surrounding karst terrain.

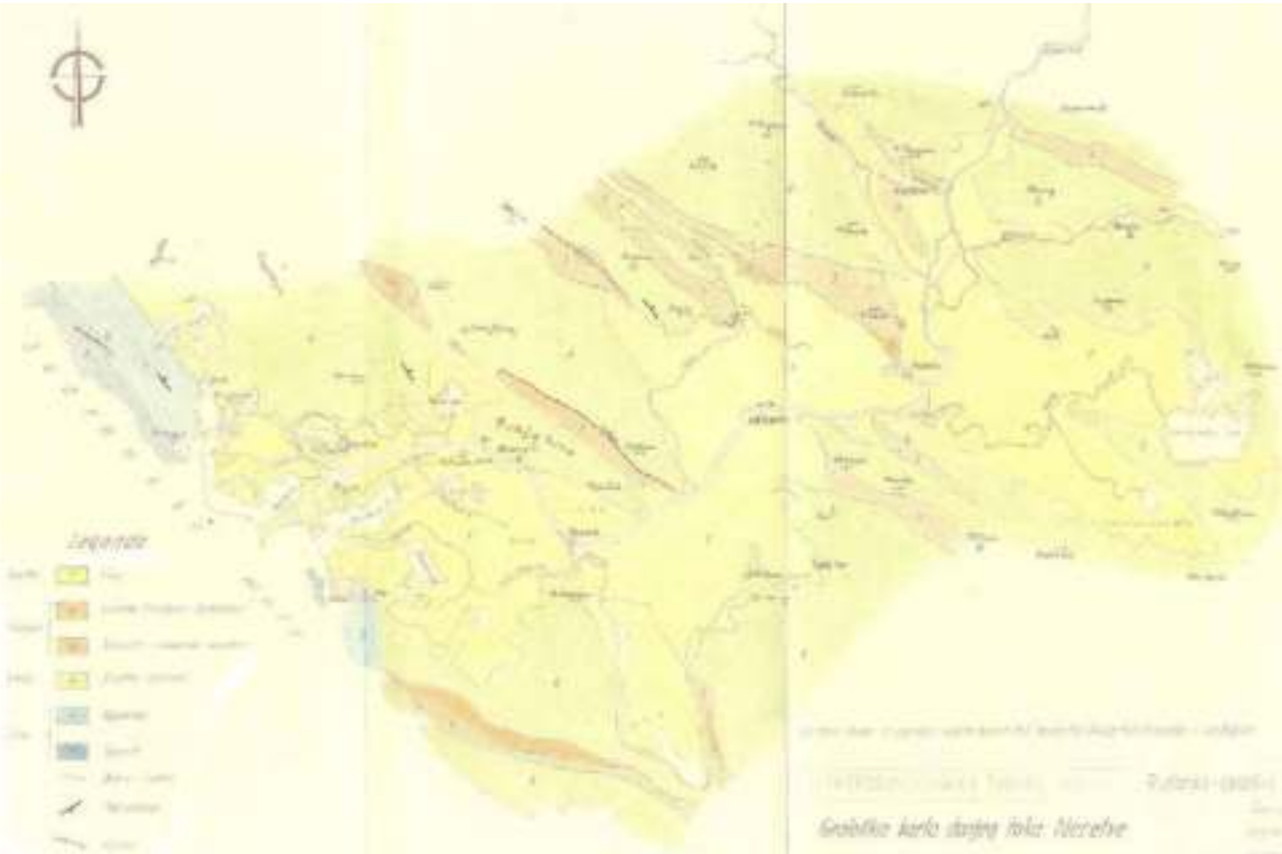


Figure 3.10 Geological map downstream of Neretva River

The whole area abounds in waters, whether the freshwater watercourses or springs and precipitation, and the main impact on it has seawater which during the high tides intrudes into the land and performs salinization of groundwater and terrain. Therefore, it is concluded that meliorations are necessary with a purpose of removing excess waters and soil desalinization to the depth required by agriculture.

Figure 3.11 Springs and watercourses downstream of Neretva River

3.6 Project: Melioration downstream of the Neretva River 1st part /The general part/ (1963.)

The general part of this project gives an insight into the area from Opuzen to mouth of the Neretva River with historical issues and climatic factors. Available project data from 1956 to 1961 was analysed and given conclusions indicate lack of information (hydrogeological, hydrological, agronomic, topographic and soil information), incomplete assessment of severe soil salinization and underestimated costs of required measures. It is noted that area of the inundation must be taken into account to reduce the total volume of ground works during the melioration process.

The aim of the project is to develop, test and present successful production, land melioration methods and agricultural measures using appropriate physical and economic conditions. Rational production management under conditions of efficient water management measures is emphasized as an important part of the program. Further measures and required investigation works are defined.

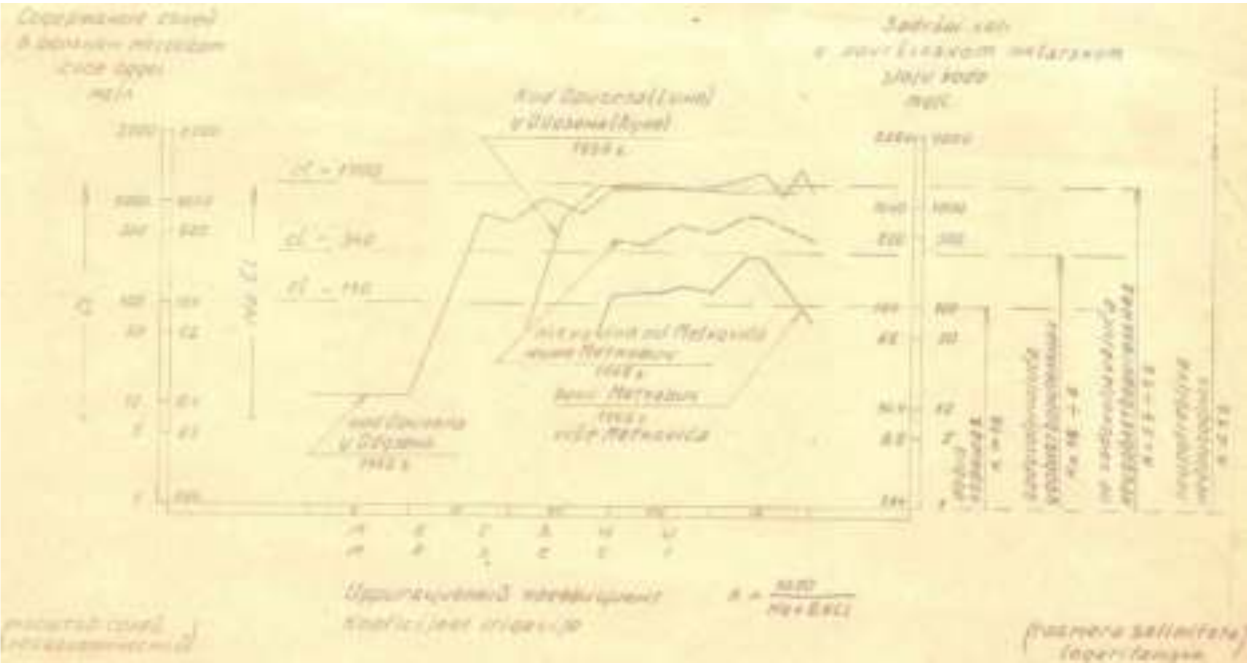


Figure 3.12 Chart of the Neretva River water salinity

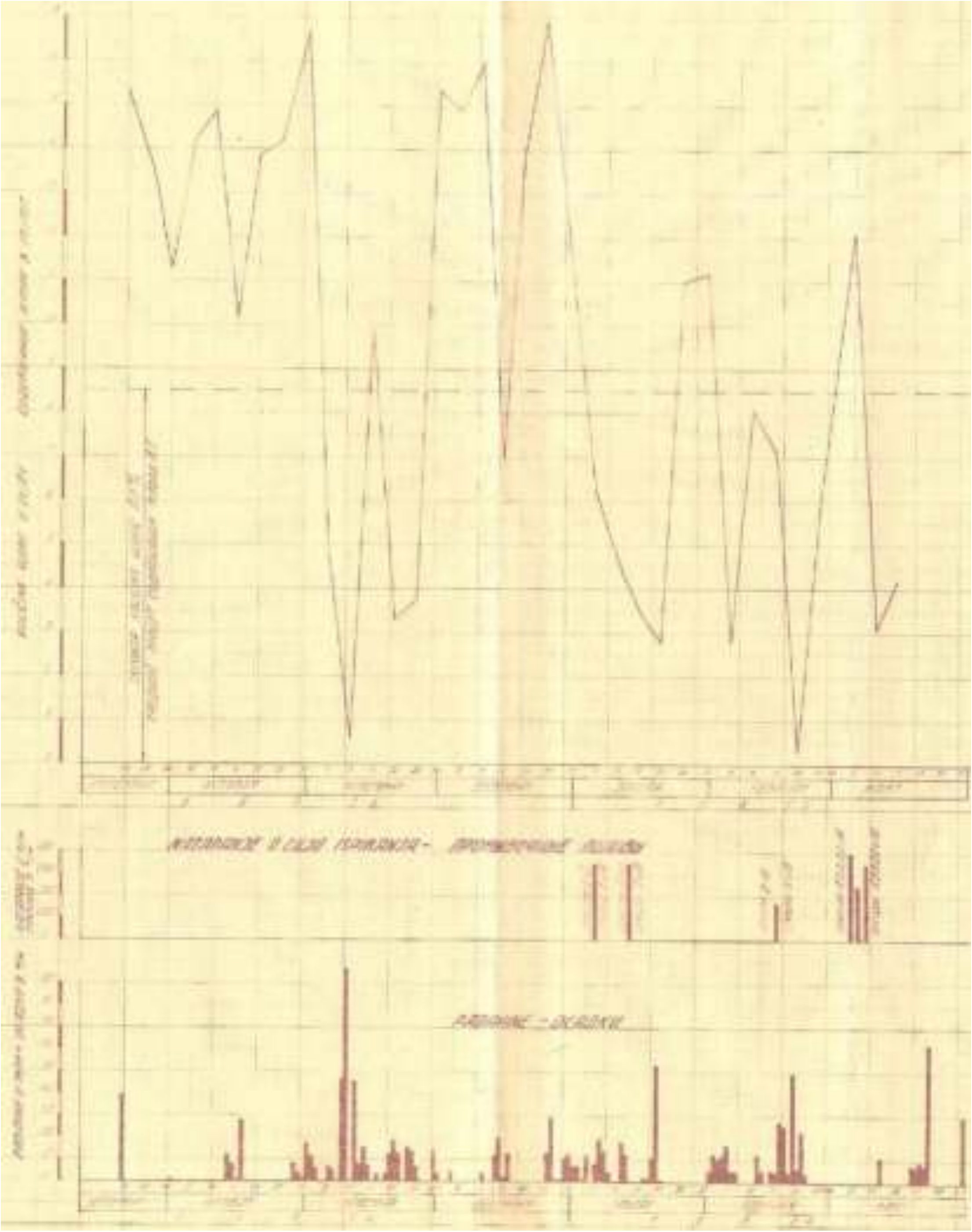


Figure 3.13 Diagram of the amounts of chlorine from the pumped water

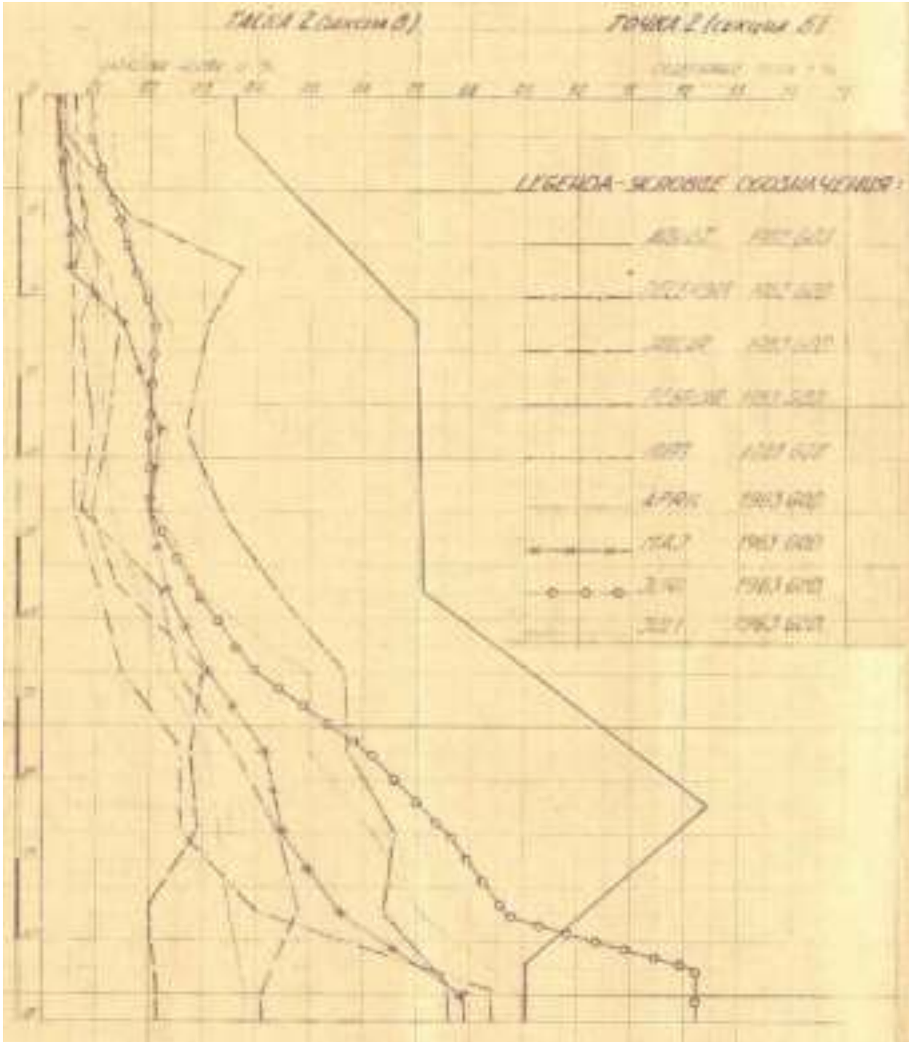


Figure 3.14 Diagram of the soil salinization dynamics

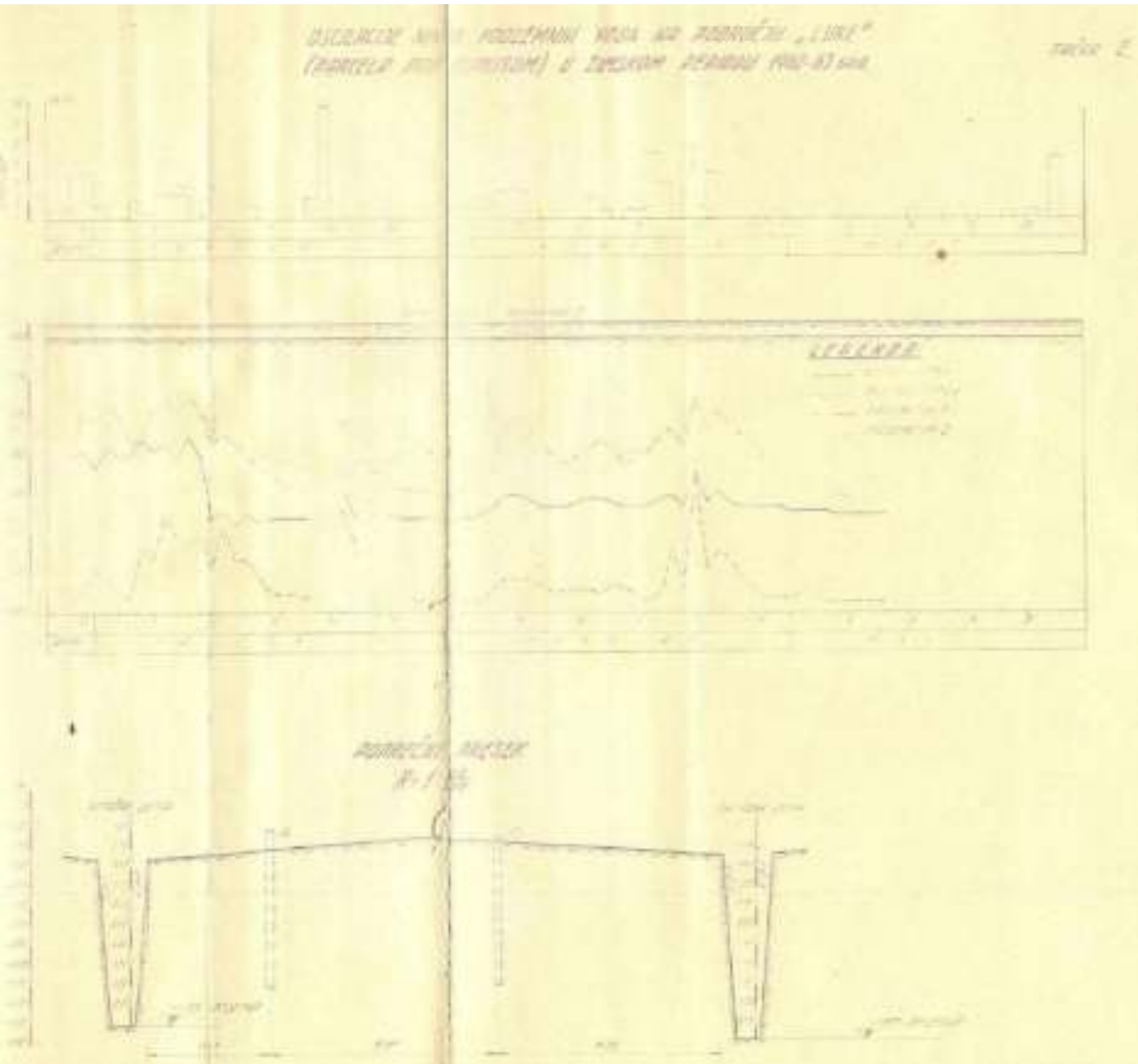


Figure 3.15 Groundwater level fluctuations in the Luke area

3.7 Project: Melioration downstream of the Neretva River 2nd part /Flood defence/ (1963.)

Melioration was planned in the area from Opuzen to the mouth of Neretva to create tangerine, vineyard and vegetable plantations. This part of the project provides a summary of the existing situation and problems with flooding, where it is emphasized that in the winter and spring around 80% of the area is flooded and during the periods of significant high water levels around 90%. Emphasis is also given on the seawater intrusion and groundwater salinization during the summer and autumn periods due to reduced flow of the rivers and sea tides. According to the analysis (1962), salt concentration in groundwater reaches a value between 40g and 50g of salt per 1l of water.

The previous construction works required for melioration process are listed: embankment construction located by the sea, closing the openings on the left embankment of the Neretva River, construction of embankment and channel for drainage of water flowing from the hills to the Vidrice area and to resolve the issue of the Mala Neretva.

Technical and economic analysis of earlier projects related to Mala Neretva has been made and two river regulation variants were elaborated: the first one with dams at the source and the mouth of Mala Neretva, both with sluice, and the second one with embankment dam at the source and dam with sluice at the mouth of Mala Neretva. It is concluded that the second variant of the river regulation is better in terms of volume of works and costs.

Several variant solutions were given for the embankment located by the sea that follows the route of the existing embankment Diga and solutions generally differ in the southern section route. The embankment with sluice at the island of Osinj was selected as more economically acceptable solution that increases the usable land area by 15ha. The cost of works is given for each variant.

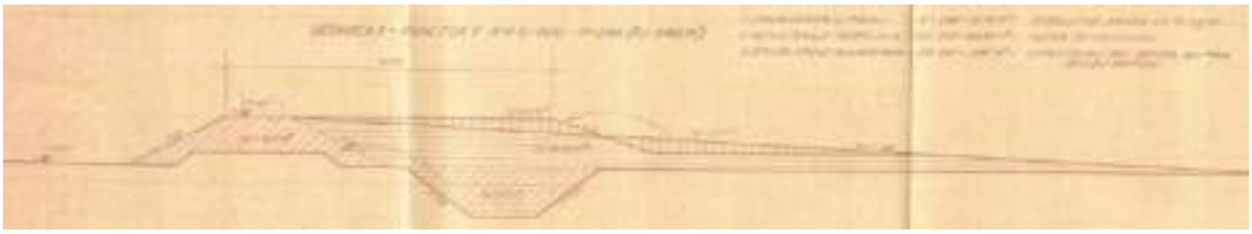


Figure 3.16 An example of cross section of an embankment by the sea

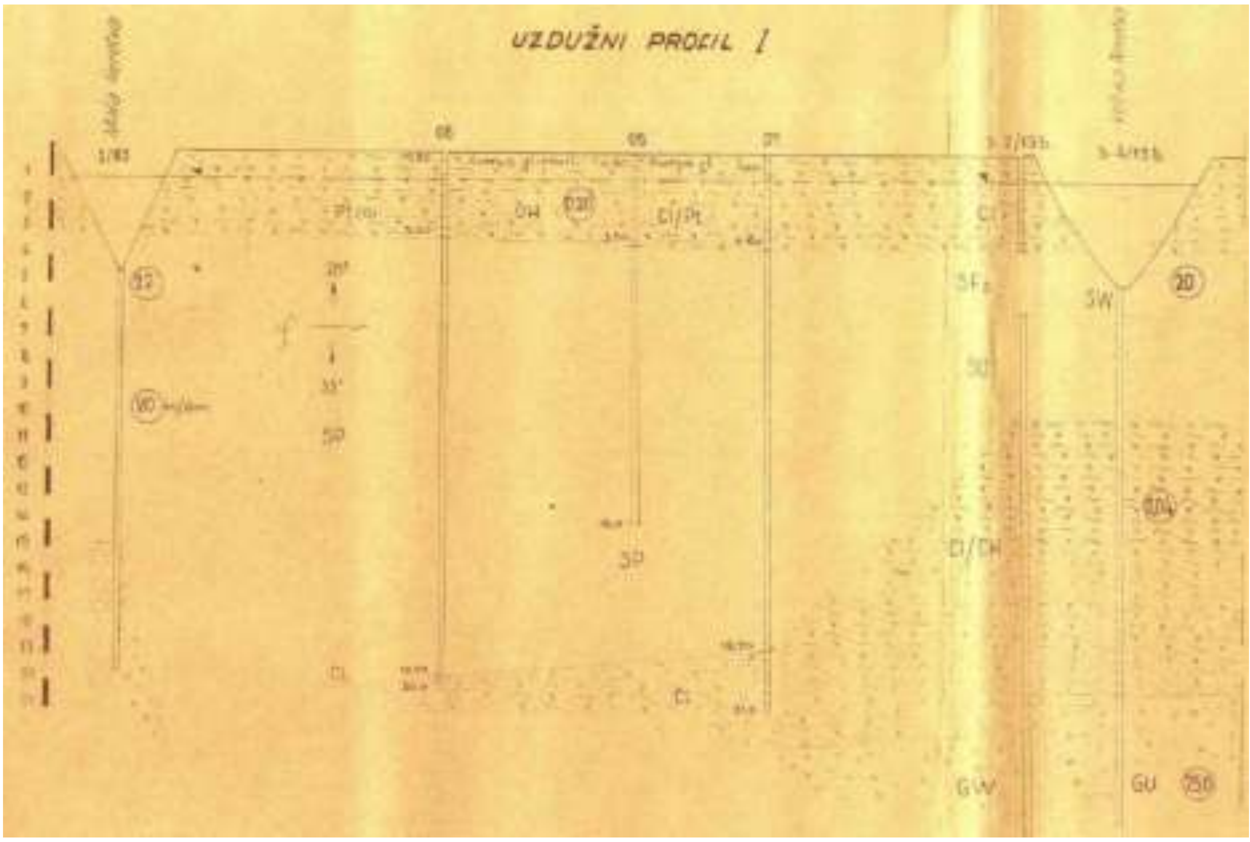


Figure 3.17 An example of longitudinal profile

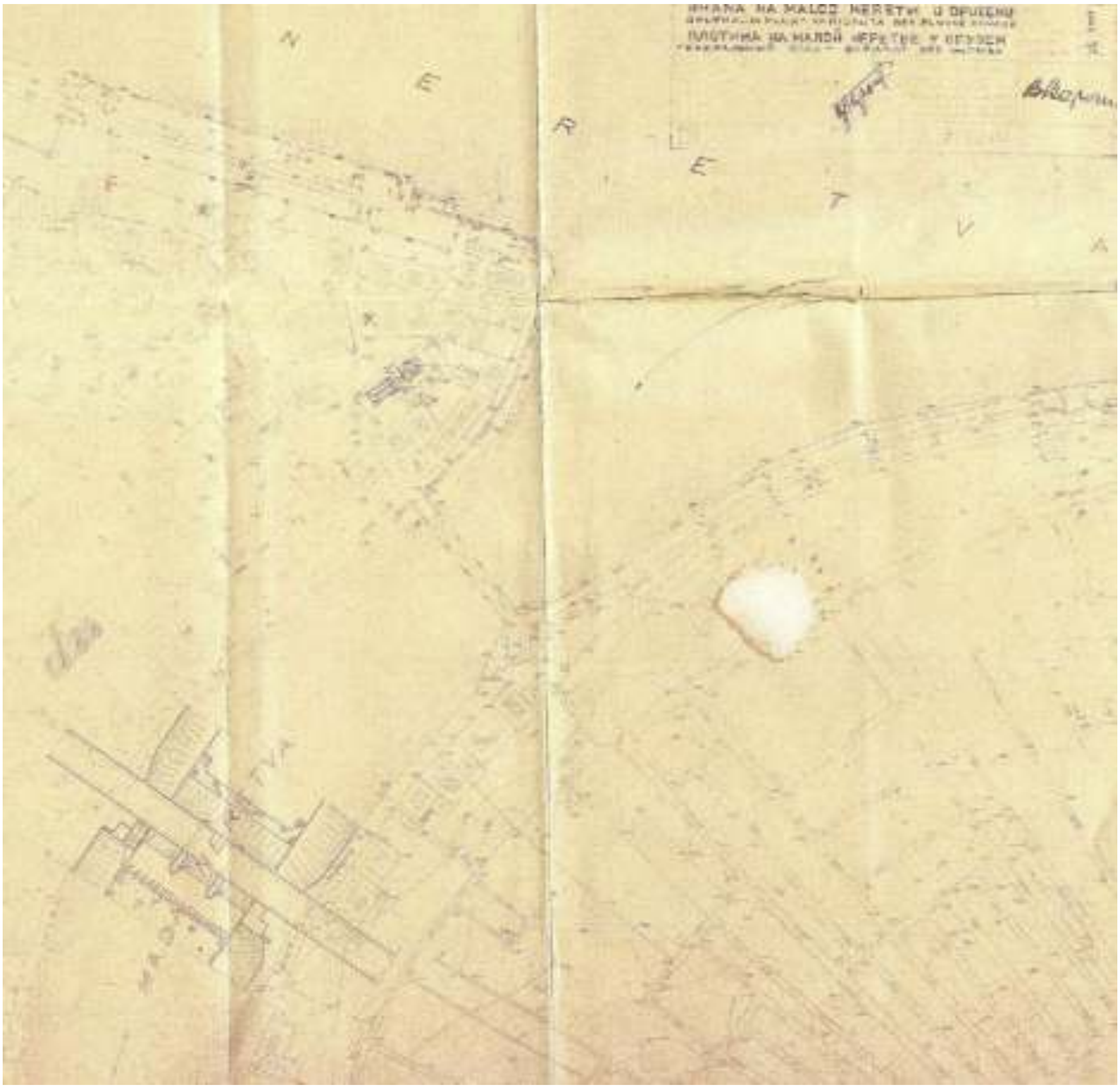


Figure 3.18 Situation of dam at the Mala Neretva River in Opuzen

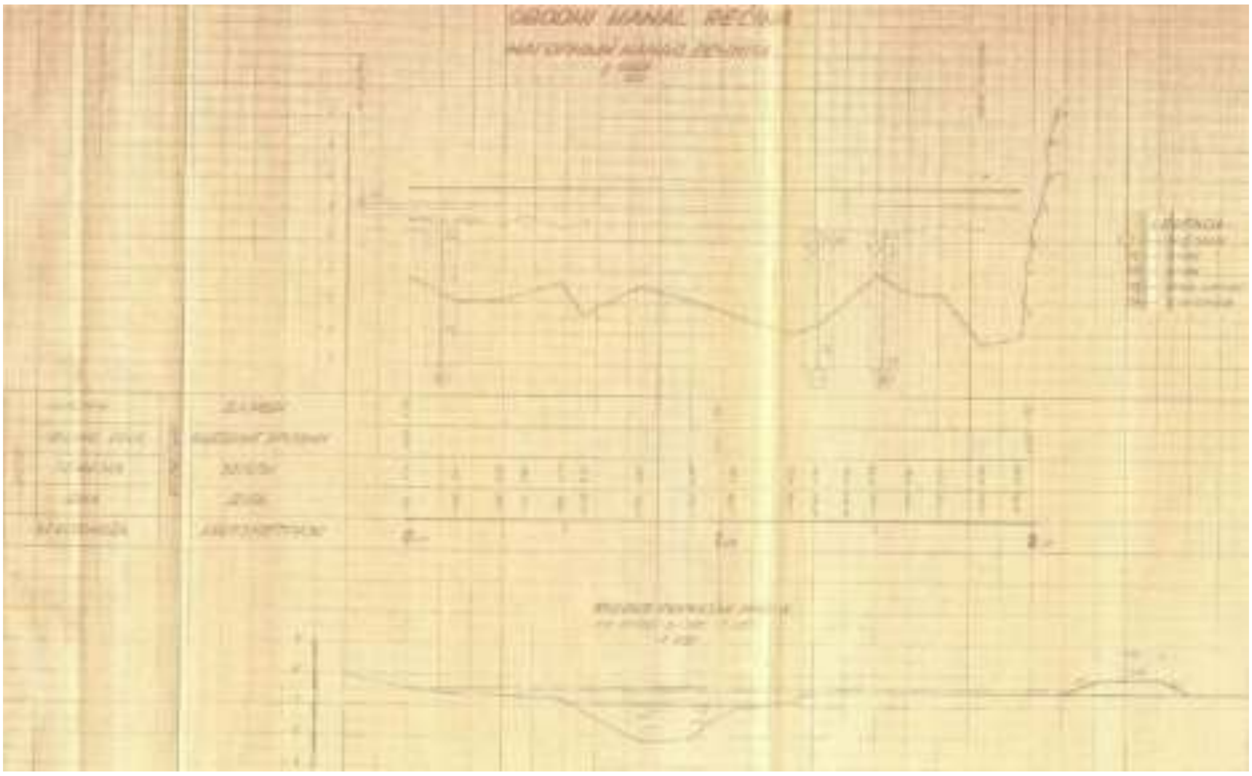


Figure 3.19 Longitudinal profile and cross section of the channel Rečina

3.8 Project: Melioration downstream of the Neretva River 3rd part /Drainage/ (1963.)

This part of the project aims to cover the basic drainage, laid in the sandy layer below the clay soil at depths that provide groundwater levels below the critical depths and its evaporation in summer, in purpose of intensive soil and groundwater desalinization as well as preventing further salinization of it. The task is also regulation and drainage of the surface runoff into the open channels. Drainage system is provided for lowering the groundwater level to the planned depth, out of which drainage is being done by a network of collectors made of concrete pipes, 30cm to 35cm in diameter. Collectors are pouring into open channel water recipient (first variant) or covered gravitational pipeline (second variant).

The project thus considers two variants: covered drainage system connected with open, deep channels both for drainage and surface water as a first variant, and covered drainage system (drainage water) connected with open, shallow channels for surface water drainage as a second variant. In the regulation of the surface runoff section, precipitation values were determined, maximum surface runoff module was calculated for the first variant and calculation of maximum inflow for the second one. Maximum and minimum flows at the mouth of the main channels as well as the flows of open channels and pipelines were determined, and selection of pumps and pumping stations for drainage was made.

Analysing and comparing given variant solutions and costs, advantages of the first variant with covered drainage system connected with open, deep channels are given as a conclusion:
- less investment and annual expenses,
- lower water level in open channels with a maximum elevation of -1m in terms of high water, which reduces the amplitude of water level fluctuations in open channels,
- ease of performing a transit drainage network,
- greater safety of exploitation of one pumping station instead of three according to the second variant,
- the construction of open, deep channels ensures the preliminary extension of the meliorated area, which is favourably reflected on the further construction of the collector and drainage network.

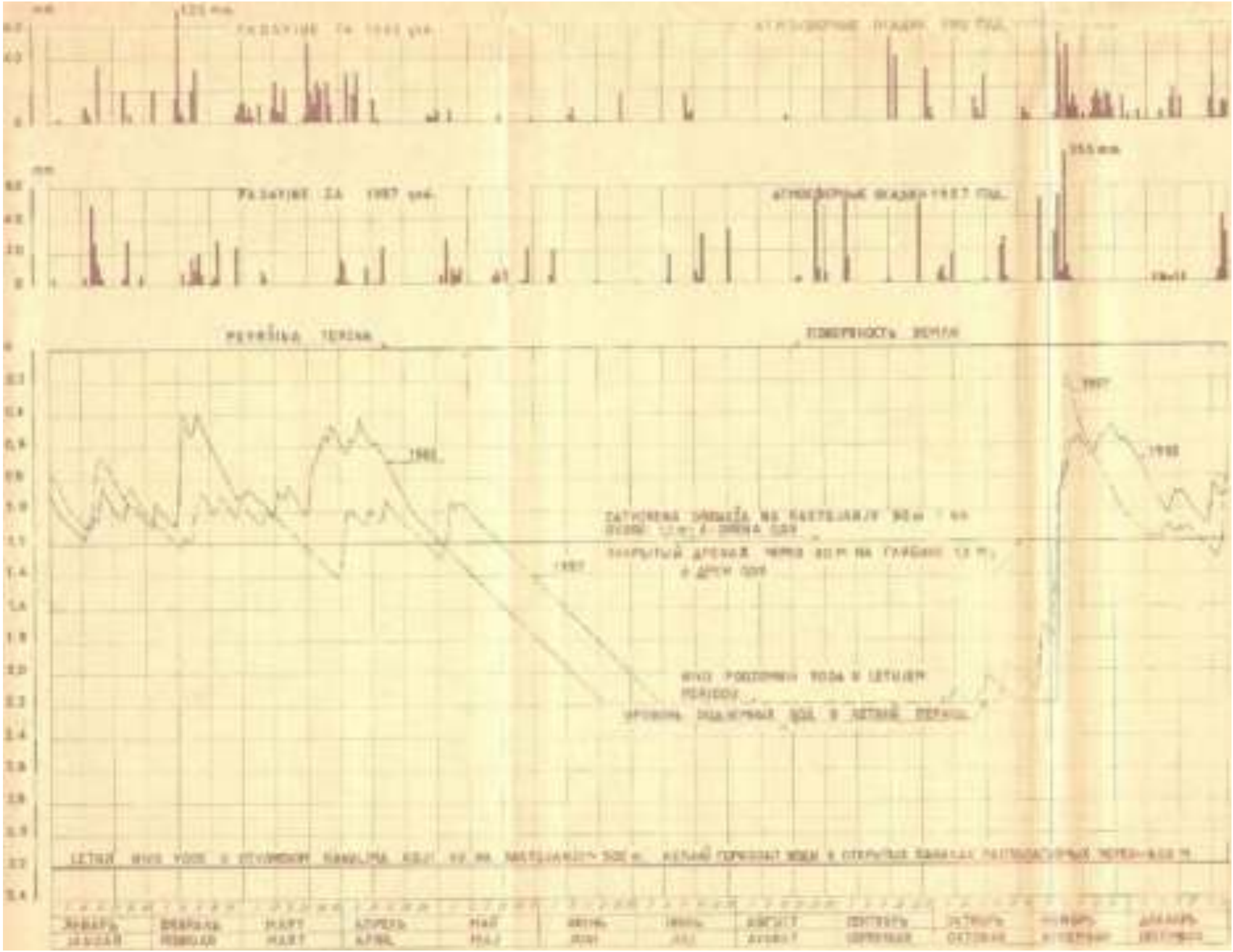


Figure 3.20 Groundwater level during drainage works on the Vidrice section

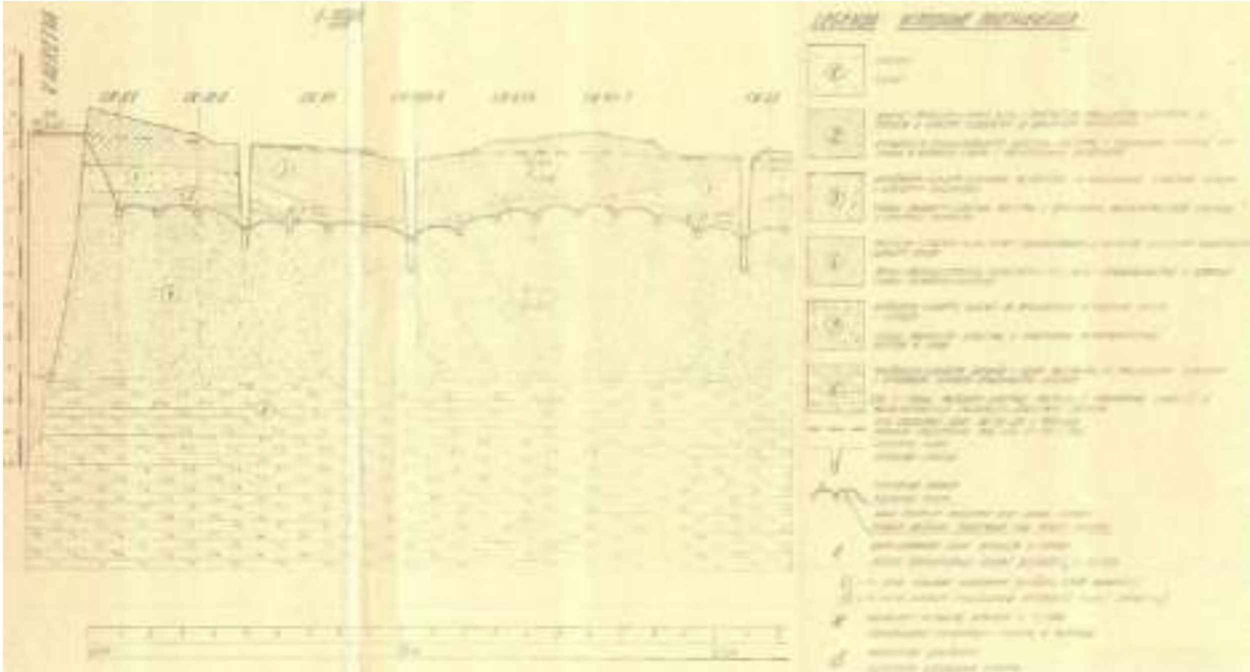


Figure 3.21 An example of calculated hydrogeological profile on the Volarske Soline section

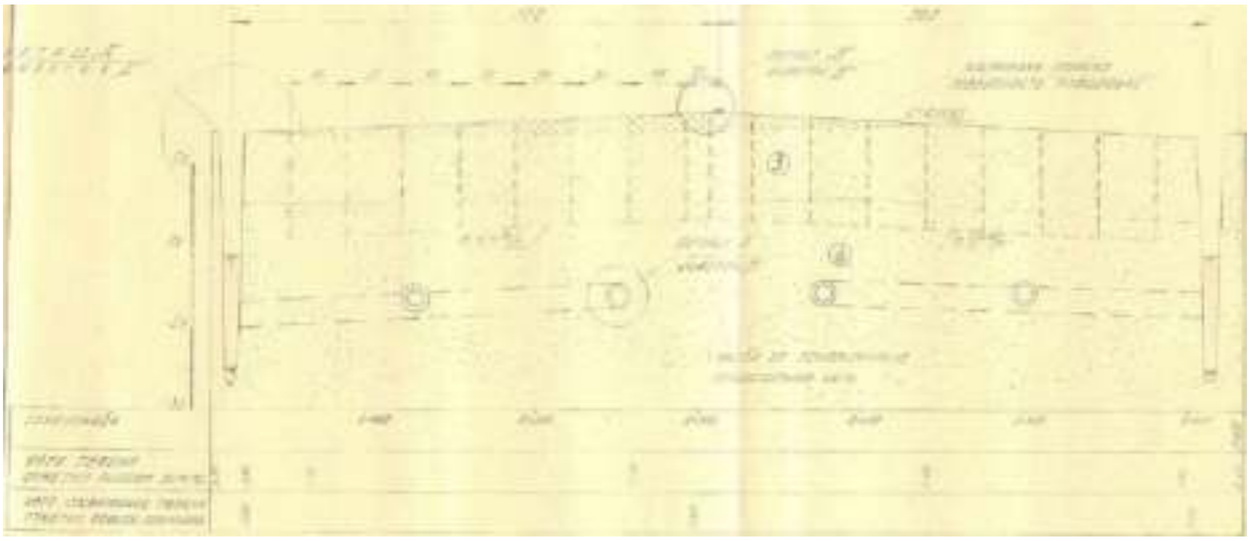


Figure 3.22 An example of cross section

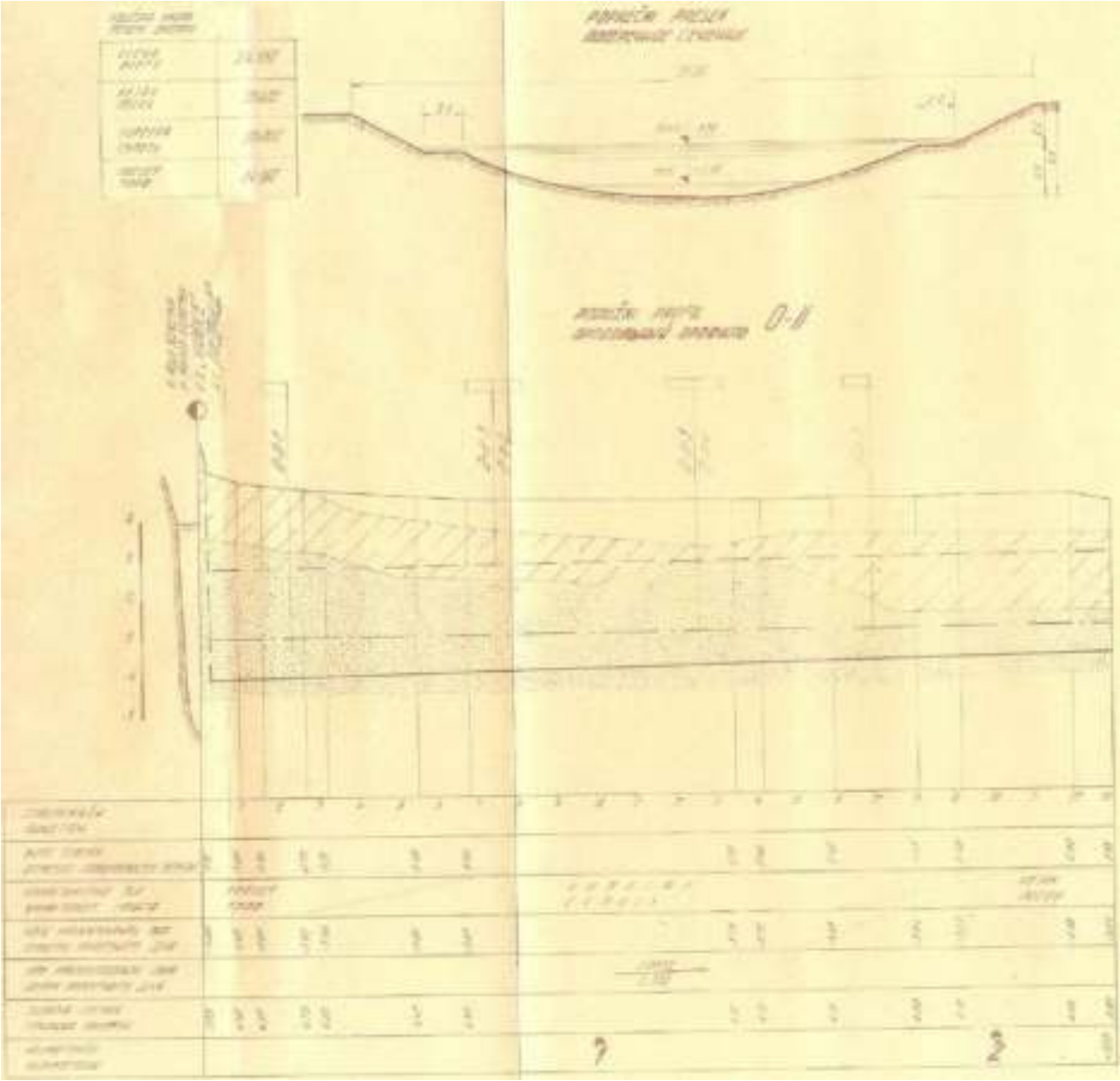


Figure 3.23 An example of longitudinal profile and cross section of channel on the Vidrice section

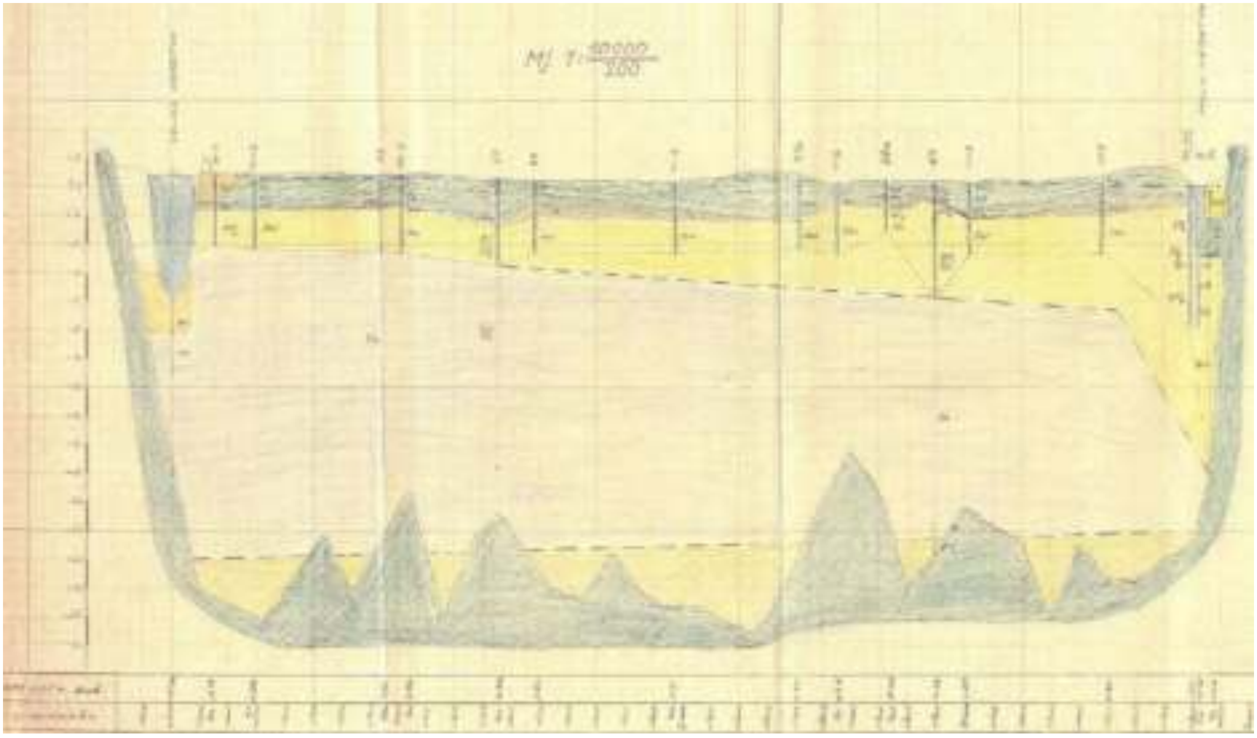


Figure 3.24 Hydrogeological profile I-I

3.9 Project: Melioration downstream of the Neretva River 5th part /Water supply for irrigation/ (1963.)

This part of the project contains the choice of the water intake position and the technical solution of it, as well as the hydraulic calculation and the cost of works. It is stated that the amount of water required for irrigation of the area between Opuzen and the mouth of the Neretva River is 3,20m^3/s and by including losses and requirement of the areas Luke (0,25m^3/s) and Kuti (3,00m^3/s), the total flow of the main channel must be 7,00m^3/s.

As it was concluded that this amount of water could only provide water intake in the Neretva River, chemical analysis were performed, according to which the location for water intake is determined, positioned 1,2km above the bridge in Metković. It includes construction of supply tunnel and pumping station with three pumps which provide water in period from 15th of June to 15th of October. Water for irrigation and land rinsing for the rest of the year is provided out of Neretva in the area of Opuzen, through the sluice on the Mala Neretva River.

After exiting the tunnel, water is separated into two channels: one for irrigation of the area Kuti in which the elevation of +2,00m needs to be provided, and the other channel passing towards Opuzen – mouth of the Neretva River area, with elevation of +1,56m at its beginning. Regulation of flow and elevation of water is done through manhole at the end of the tunnel.

Channel through the area between Opuzen and mouth of the Neretva River passes through the streambed and under the bridge between Opuzen and Metković, partly using existing channels, and after 7,2km downstream passes through the Stara Neretva riverbed with elevation between 1,00m and 1,10m. At the end channel is goes into the watercourse Lukavac and thereafter through streams Širina, Mislina and Prunjak is poured into the river Mala Neretva.

Dam with sluice is predicted at the channel entrance to the stream Lukavac for regulation of water level in the Stara Neretva River and volume of accumulation, as well as flood defence by the Neretva River. Renovation of existing embankment dam at the beginning of the Stara Neretva River is predicted with sandy-gravelly soil.

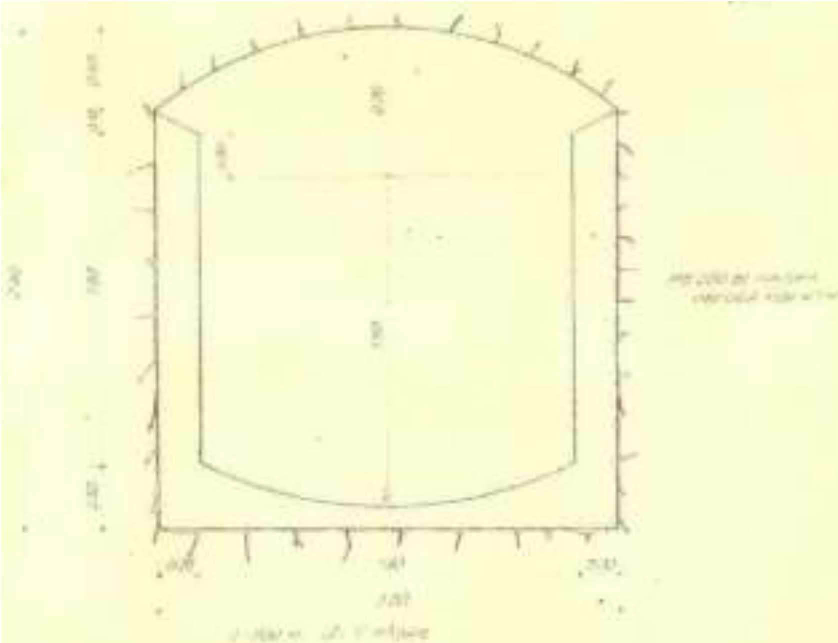


Figure 3.25 Cross section of the supply tunnel

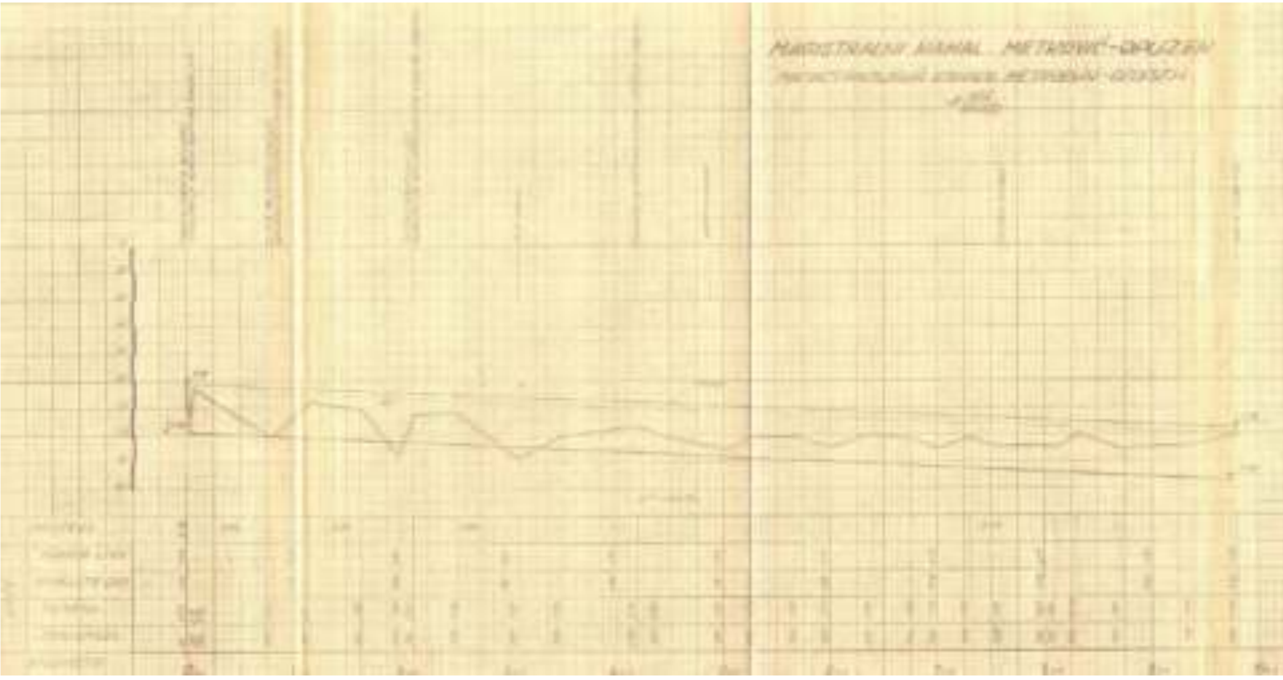


Figure Longitudinal profile of the main channel (Metković – Opuzen)

Figure 3.26 Cross section of an embankment dam at the beginning of the Stara Neretva River

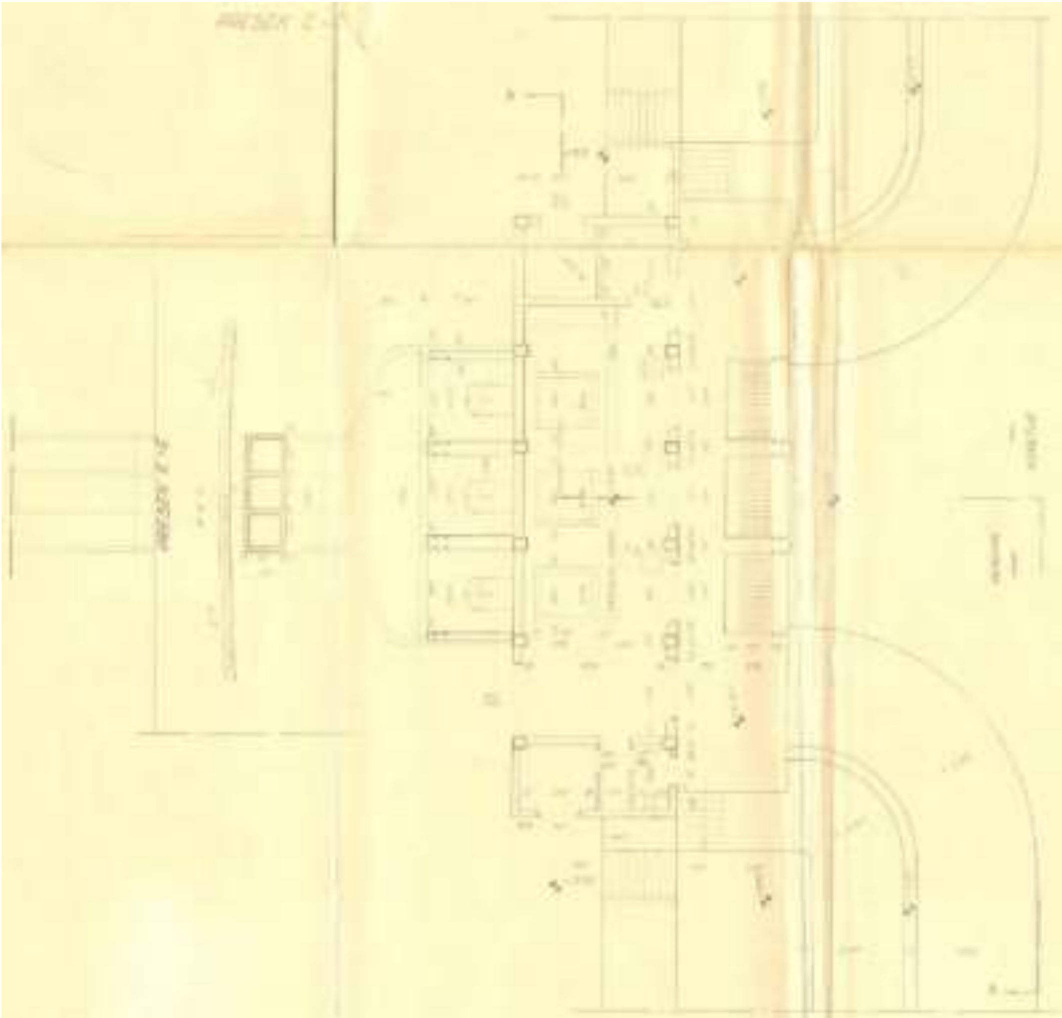


Figure 3.27 Metković pumping station

3.10 Project: Melioration downstream of the Neretva River 7th part /Pumping stations and electricity supply/ (1963.)

Based on the previous investigation and technical and economic compere of variant solutions, decision was made to drainage an area between Opuzen and mouth of the Neretva River with two pumping stations: pumping station Modrič for the area surrounded by Mala Neretva and the Neretva River and pumping station Prag between the Mala Neretva river and embankment along the foothills (Vidrice area), protecting the terrain from flooding.

This part of the project contains detailed description of pumping stations Modrič and Prag each containing two different variant solutions, capacities, selection of the pumping units, technical solutions, construction and electrical part of pumping stations and cost calculations.

According to the irrigation project, the tangerine plantations (2000ha) and the area with vegetables (500ha) have sprinkler irrigation system with a total of eight pumping stations, while area under vineyards have surface irrigation system. Electricity supply, dispatch management and consumer connectivity to the electricity system in the area between Opuzen and the mouth of the river Neretva are determined.

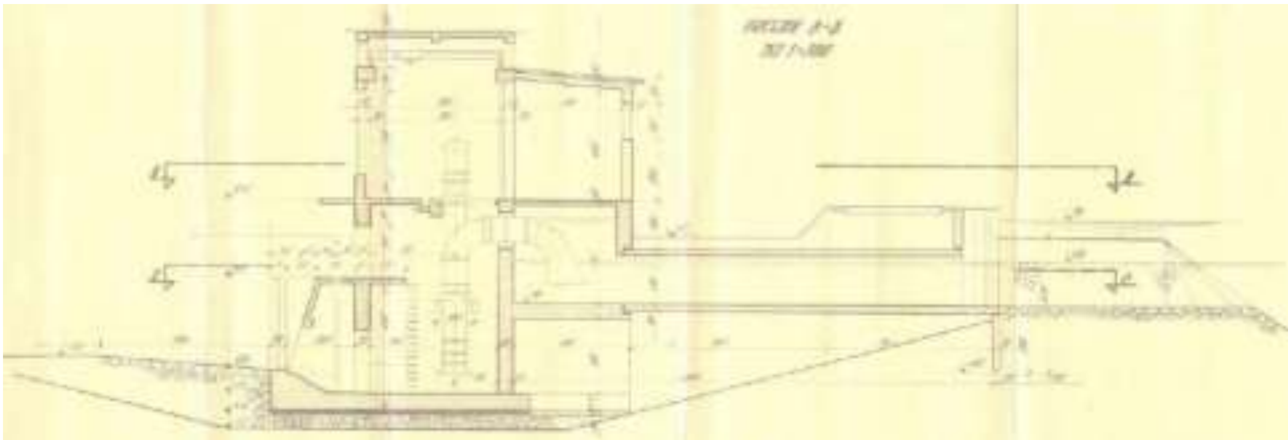


Figure 3.28 Prag pumping station

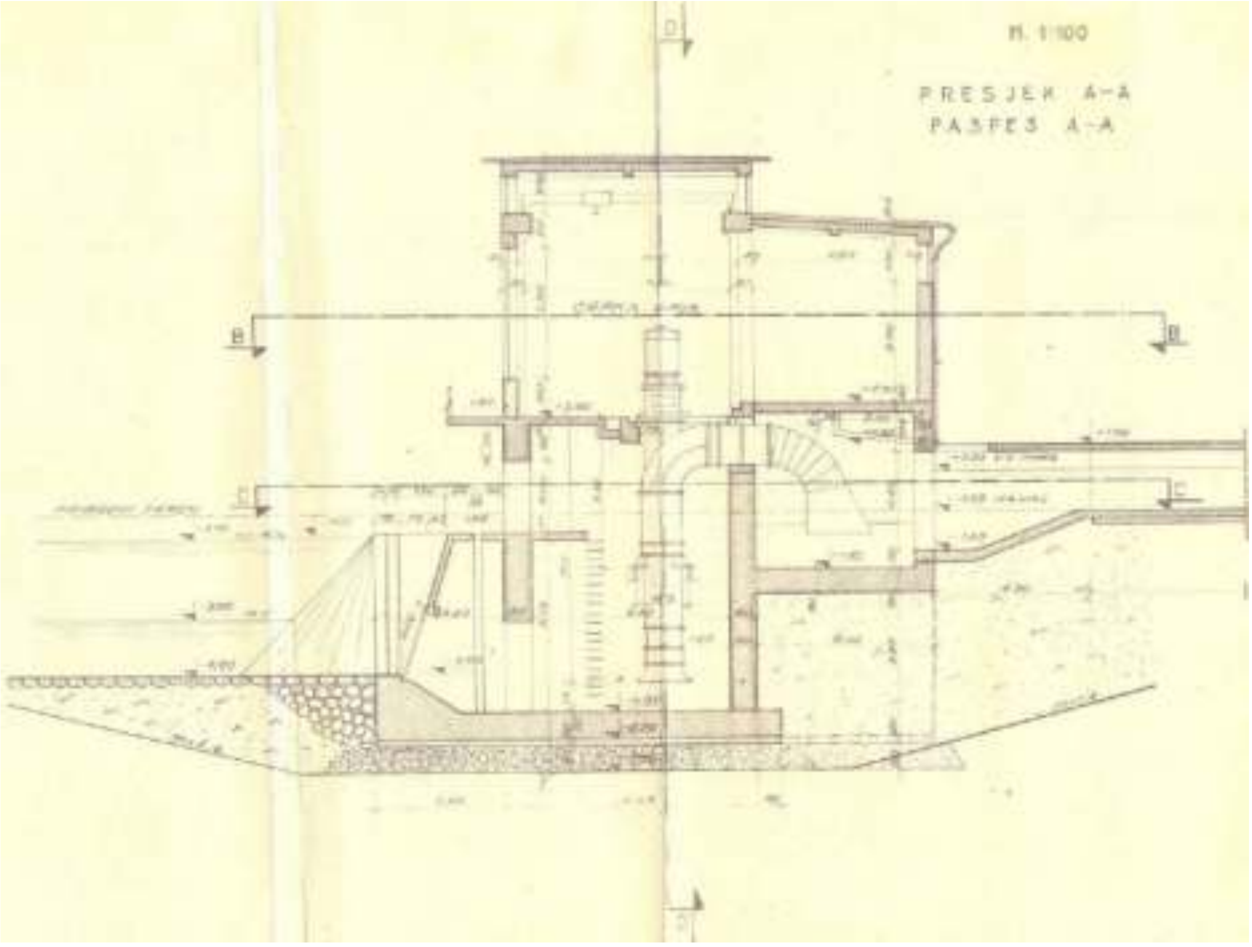


Figure 3.29 Modrič pumping station

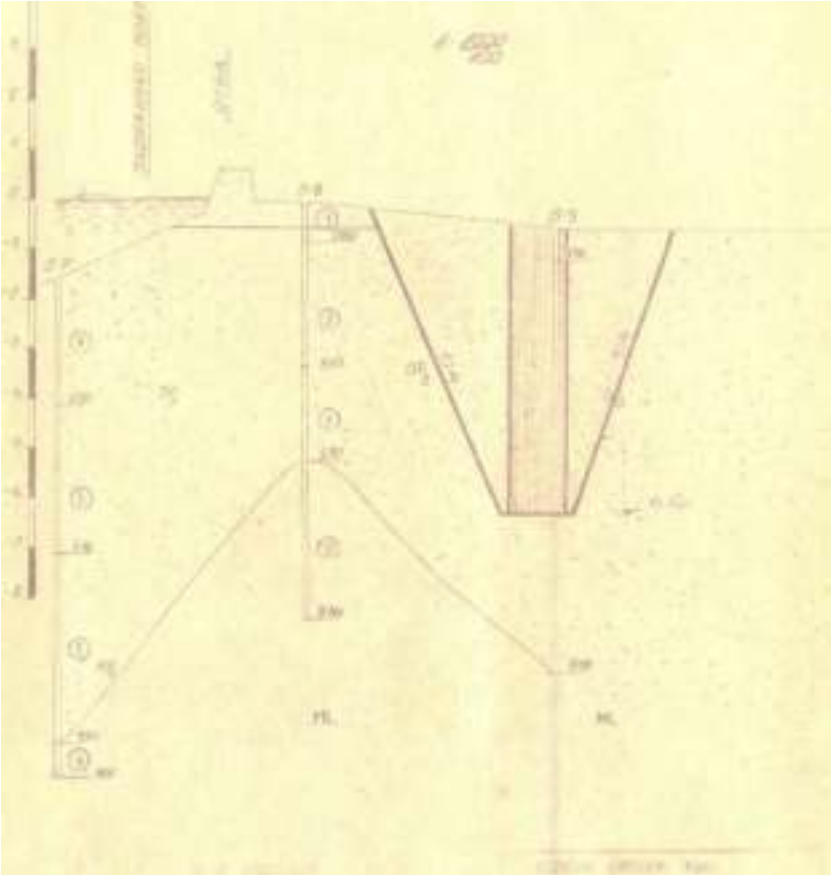


Figure 3.30 Geological profile on Modrič pumping station

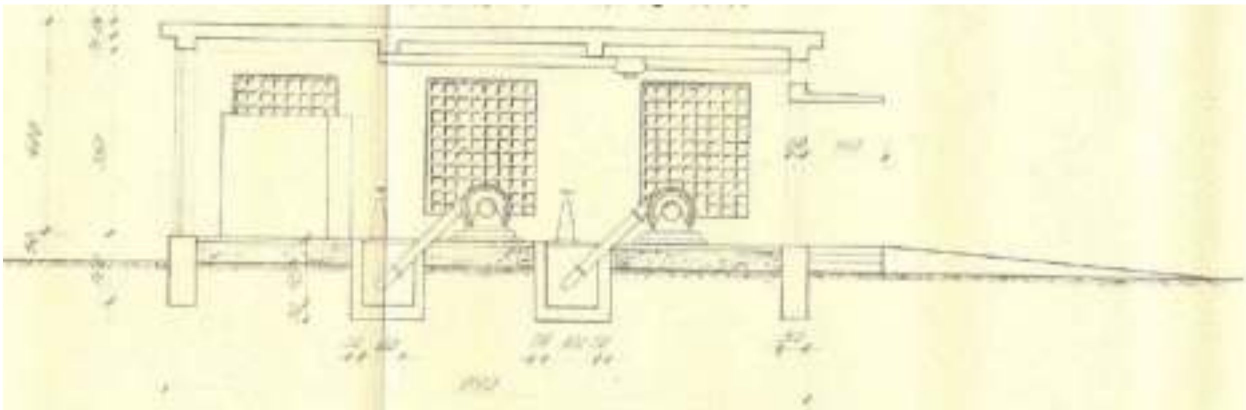


Figure 3.31 An example of cross section of pumping station for irrigation

3.11 Project: Melioration downstream of the Neretva River 10th part /Hydrogeological and engineering-geological conditions/ (1963.)

This part of the project contains description of lithological composition, hydrogeological conditions and geomorphology of the area. Valley is located on the Adriatic coast and is continuously exposed to tides and denivelation of the sea levels due to wind, as well as flooding. The observed territory is intertwined with a series of river backwaters – Mala Neretva, Crepina, Rečina and shallow lakes, the largest of which is Modrič Lake, and is representing the typical river delta.

Jurassic and Cretaceous rocks are part of the geological structure of the observed area, with chalk deposits of significant thickness with expressed phenomena of surface wear and tectonic disturbances, causing the rupture of rocks and water permeability. Thus, karst formations were formed at significant depth – cavern, karst channels, chasm, etc., resulting with large number of water sources.

The upper layer (reaches up to approx. -2m) of the Neretva River Valley is composed of sandy clay deposits of lake-marine and alluvial origin, listed sequentially from the surface to the bottom: heavy loam, silty and sandy clay, sandy loam, silty-mud formations, muddy and in the upper layers poorly decomposed peat, predominantly muddy and highly decomposed peat with depth increase.

Under the upper layer lays unconfined aquifer with fine sand of 3m to 8m thickness, depending on location, and fine to coarse grained sand and gravel of 3m-5m thickness. Below this layer lays 15m to 24m thick layer of sandy silt and sandy to silty clay, mostly plastic and low plasticity consistency. Layers thickness decreases in certain parts of the area of the Mala Neretva River. Above mentioned layer lays either on bedrock or on sandy to sandy-gravelly layer of fluvioglacial deposits (3m to 10m of thickness), representing confined aquifer inside of which water is held under pressure.

Hydraulic conductivity is determined for every specified type of deposit. By analysing the characteristics of engineering-geological conditions, the facilities that are provided are Metković, Modrič and Vidrice pumping stations, dams at the source and at the mouth of the Mala Neretva River as well as embankment at the sea side.

3.12 Excerpt from the conceptual design from 1959 of additional melioration works on "Luke - irrigation with water from the lake Modro oko" (1963.)

The Neretva River near area of Luke abounds with salty water and is not suitable for irrigation. Therefore, the supply of water from the right water system was predicted by direct water intake at the dam on the Trebižat and, when there is lack of water, by artificial lifting from the Neretva River by a pumping station upstream of Gabela into the water supply system.

A hydraulic calculation for pressure pipelines was made to supply the water to the Luke area with an estimated flow rate of 240 l/s. Construction part of the pumping station Modo Oko as well as mechanical and electrical equipment is specifically described and the total price of all construction works and equipment was made and given in a conclusion. The power line Luke II – Modro Oko and specification of the distribution network of pipelines for irrigation were also elaborated.

It was concluded that the Modro Oko Lake is the well downstream of the Neretva River most abundant with water with its minimum flow of 600 l/s. Water is suitable for drinking and irrigation purposes in terms of salinity and temperature.

3.13 Study /Luke - piezometers/ (1964.)

Terrain sounding was performed at the area of Luke, located at the right bank of the Neretva River, between Krvavac and Komin. The purpose of study was determination of sounding profile of the area by using three profiles, installation of several piezometers for observation of groundwater levels and generating basic geomechanical characteristics of soil.

A total of 18 piezometers were installed for groundwater level observation, half of them to the depth of 10m and the rest of them between 1,50m and 4,50m. Visual AC classification of soil were taken and undisturbed soil samples were used for laboratory measurement of geomechanical soil characteristics. Longitudinal profiles were specified using borehole profiles. Hydraulic conductivity determined by laboratory experiments on undisturbed soil samples reaches values between $2,56*10^{-7}$m/s and $1,30*10^{-8}$m/s. Chemical analysis of water was also taken and shown in Figure 32.

Oznaka sonde	L2	L3	L4	L6	L9
Dubina uzorka(m)	5,0	6,0	5,0	3,6	5,0
Isparni ostatak	9366	10560	3642	27592	14540
pH	7,2	7,2	7,2	7,0	7,5
HCO_3	991	1250	811	293	1961
Cl'	4338	4426	1500	12410	6710
SO_4''	395	979	80	1911	152
Mg^{++}	458	486	146	238	609
Ca^{++}	52	162	100	1435	98
NaCl	6230	6952	2240	18634	11040
Na^+	2440	2734	896	7318	4310

Figure 3.32 Results of chemical analysis measured in mg/l

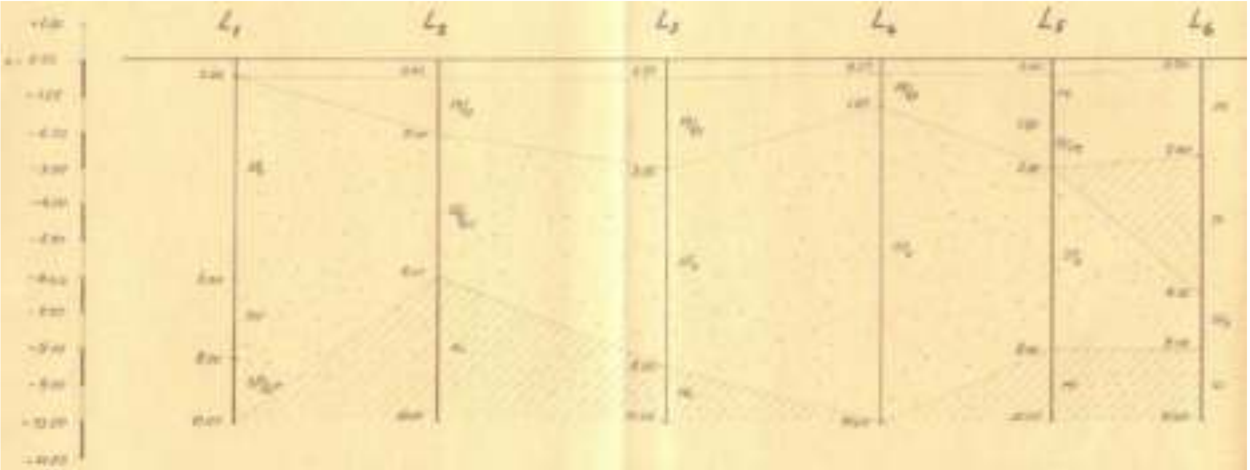


Figure 3.33 An example of longitudinal profile

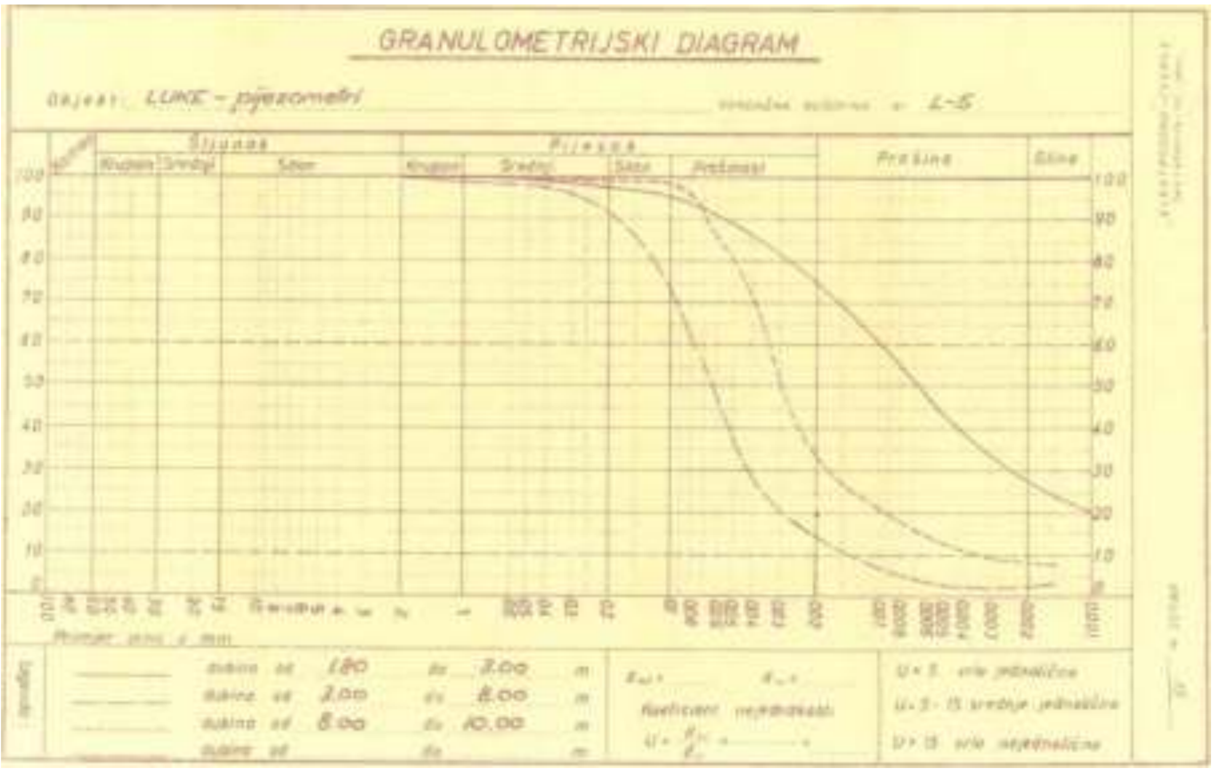
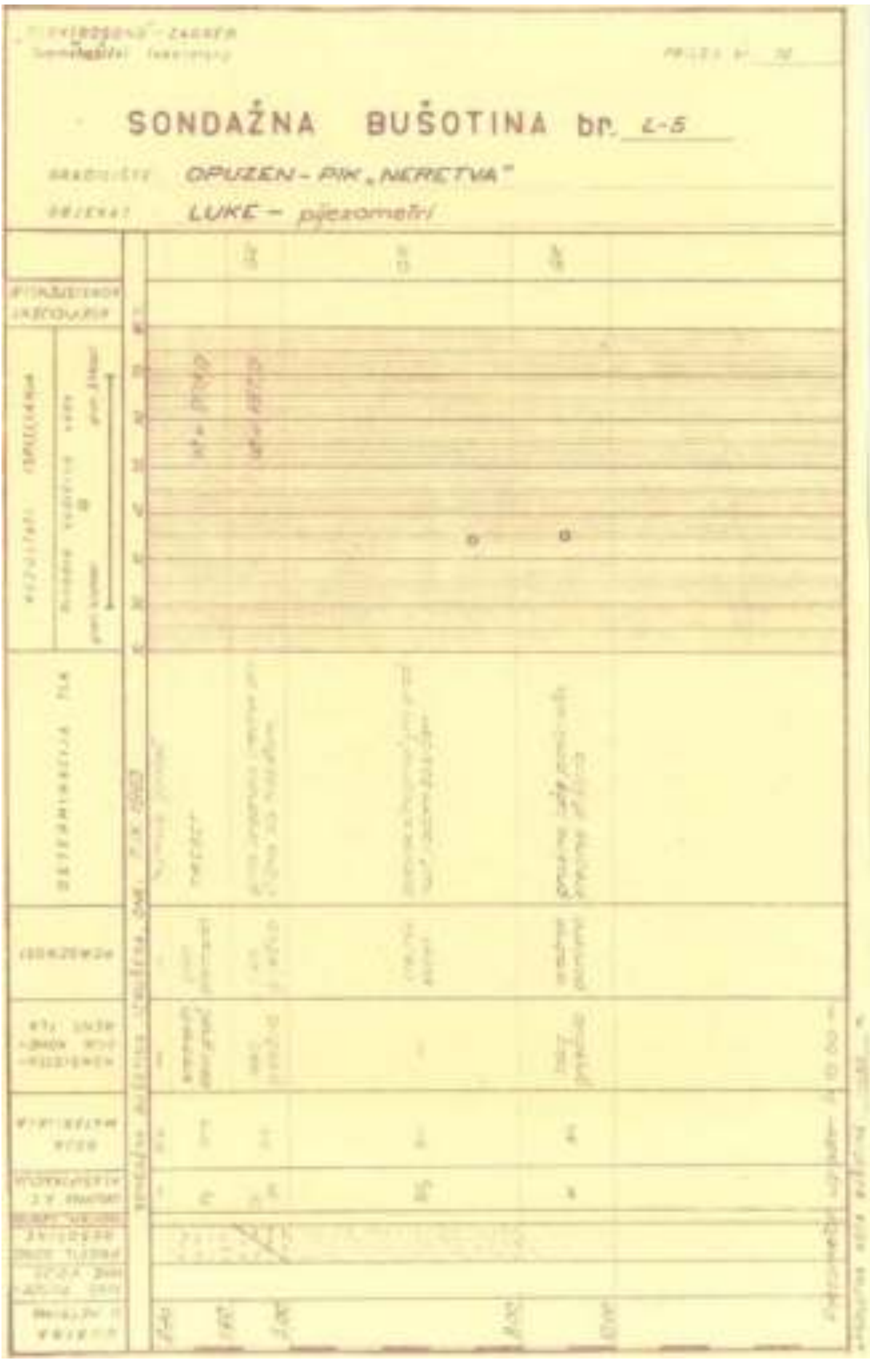


Figure 3.34 An example of grain-size diagram


SONDAŽNA BUŠOTINA br. L-5

OPUZEN - PIK „NERETVA"

LUKE — pijezometri

Figure 3.35 An example of borehole probe profile

3.14 Study /Vrbovci - piezometers/ (1964.)

Terrain sounding was performed at the area of Vrbovci, located at the left bank of the Neretva River, between Metković and Opuzen. The purpose of study was determination of sounding profile of the area by using two profiles, determination of bedrock depth, installation of several piezometers for observation of groundwater levels and generating basic geomechanical characteristics of soil.

Shallow boreholes were made next to the deep ones and afterwards used for shallow piezometers. Piezometers were installed in every borehole for groundwater level observation. Visual AC classification of soil were taken and undisturbed soil samples were used for laboratory measurement of geomechanical soil characteristics. Longitudinal profiles were specified using borehole profiles. Hydraulic conductivity determined by laboratory experiments on undisturbed soil samples reaches values between $6,77*10^{-8}$ m/s and $2,33*10^{-9}$ m/s. Chemical analysis of water was also taken and shown in Figure 37.

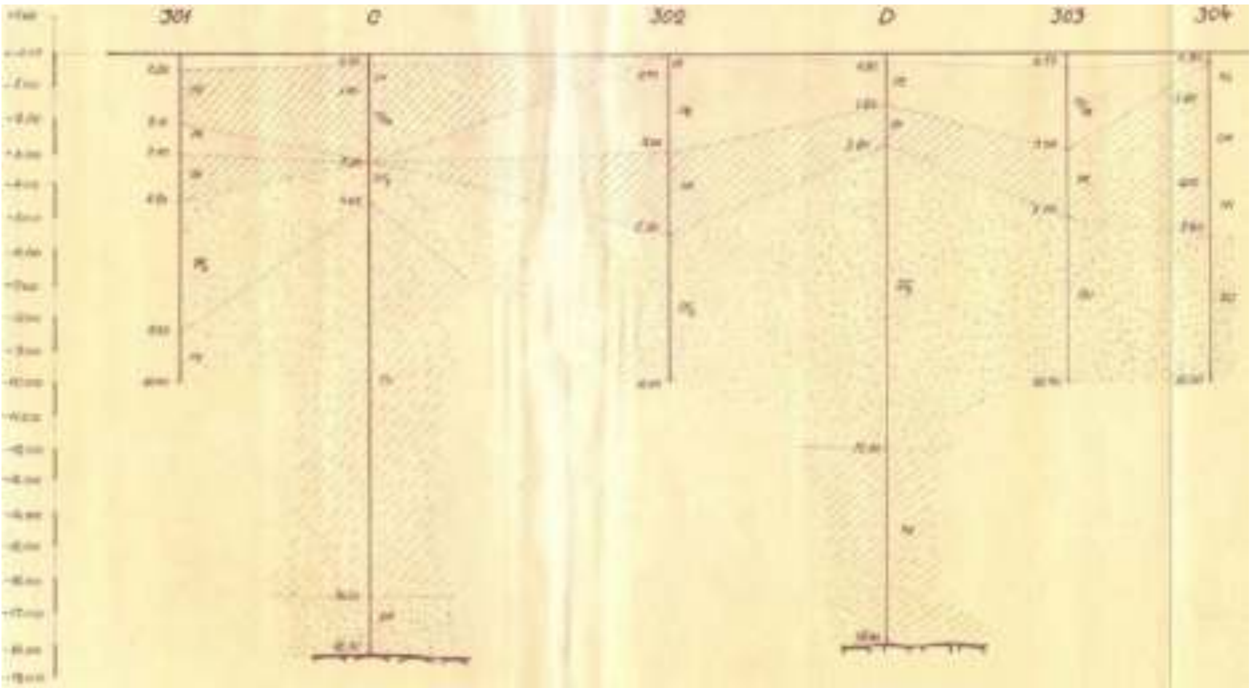


Figure 3.36 An example of longitudinal profile

Oznaka sonde	Dubina uzorka u m	Isparni ostatak	pH	HCO_3	Cl'	SO_4''	Mg^{++}	Ca^{++}	NaCL	Na^+
301	5,0	1874	7,2	628	641	39	77	84	950	373
301	5,0	1896	7,2	586	649	101	67	102	946	372
302	3,0	3104	7,2	1074	1046	105	187	152	1202	472
302	4,5	2944	7,2	982	1018	62	184	102	1220	480
303	5,0	1692	7,0	647	298	220	120	104	448	176
304	3,0	568	6,7	287	74	43	27	44	114	44
401	3,0	1312	7,0	645	222	29	103	102	295	116
401	5,0	1284	7,0	613	206	84	85	86	256	101
402	5,0	2444	7,0	665	904	115	77	184	1232	484
402	5,0	2482	7,0	396	990	212	108	100	1440	565

Figure 3.37 Results of chemical analysis measured in mg/l

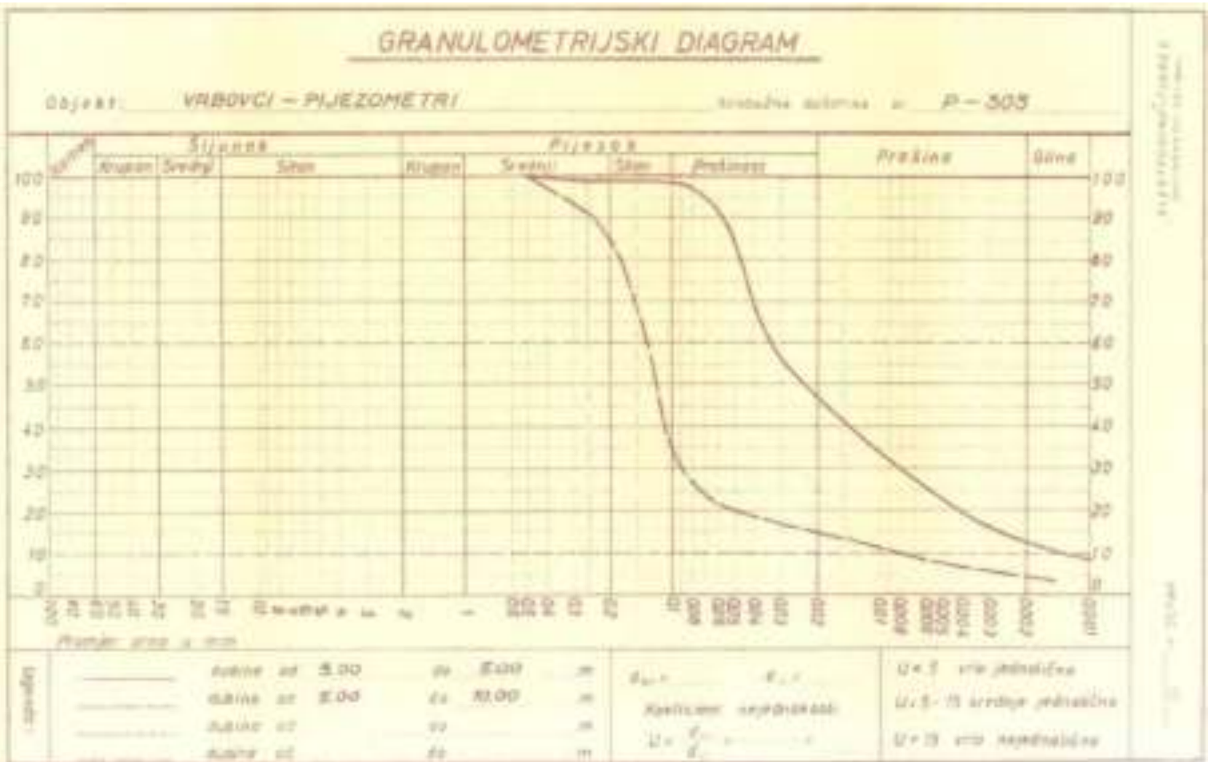


Figure 3.38 An example of grain-size diagram

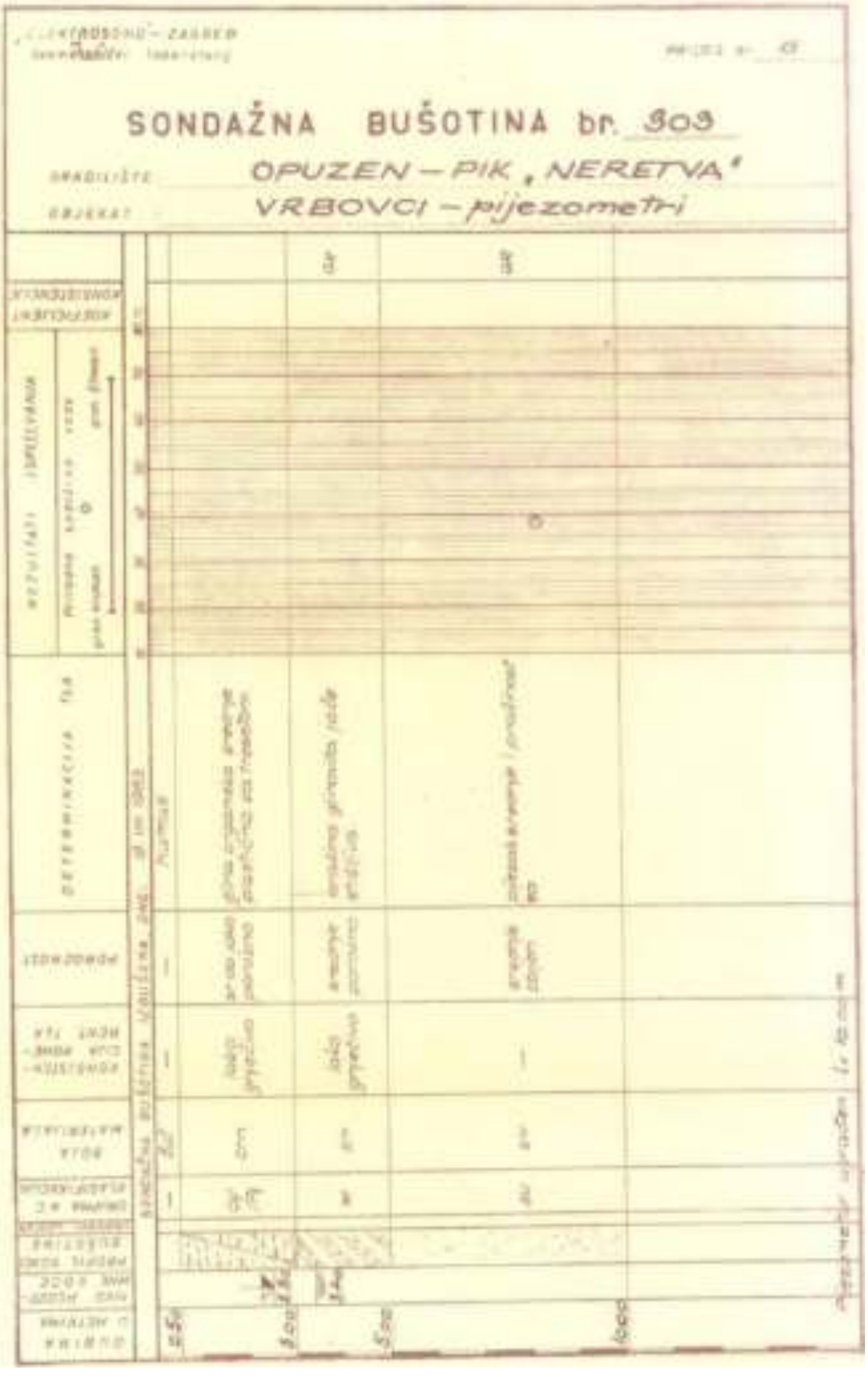


Figure 3.39 An example of borehole probe profile

3.15 Geotechnical report (1965.)

Terrain sounding was performed at the area of the Metković, Kula Norinska and Hum II pumping stations, bridge over the drainage channel in Vrbovci, at the area Vid-Kuti (geological boreholes) and Vrbovci (piezometers). The purpose of study was determination of sounding and respectively geological profile of the listed area, determination of soil quality and observation of groundwater levels. Certain number of boreholes were drilled at each facility to gain insight into the composition of the soil. Visual AC classification of soil were taken and soil samples from every change of layer were used for laboratory measurement of geomechanical soil characteristics, based on which longitudinal profiles were specified.

It was concluded that at Metković pumping station almost the entire profile consists of well granulated layer of gravel, therefore the foundation could be done at designed depth. For pumping stations Kula Norinska and Hum II, reinforced concrete slab was required below the foundation. Given the very high groundwater level, the bridge in Vrbovci needed to be based on wooden piles. At the area Vid-Kuti were analysed soil composition and geomechanical characteristics. Piezometers were installed in boreholes for groundwater level observation.

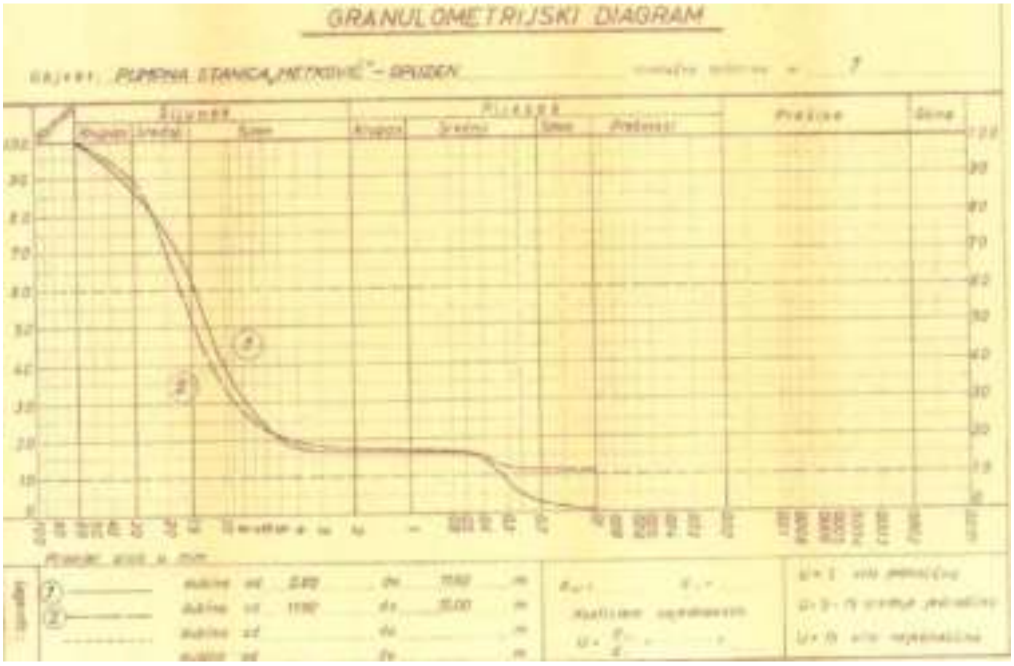


Figure 3.40 An example of grain-size diagram

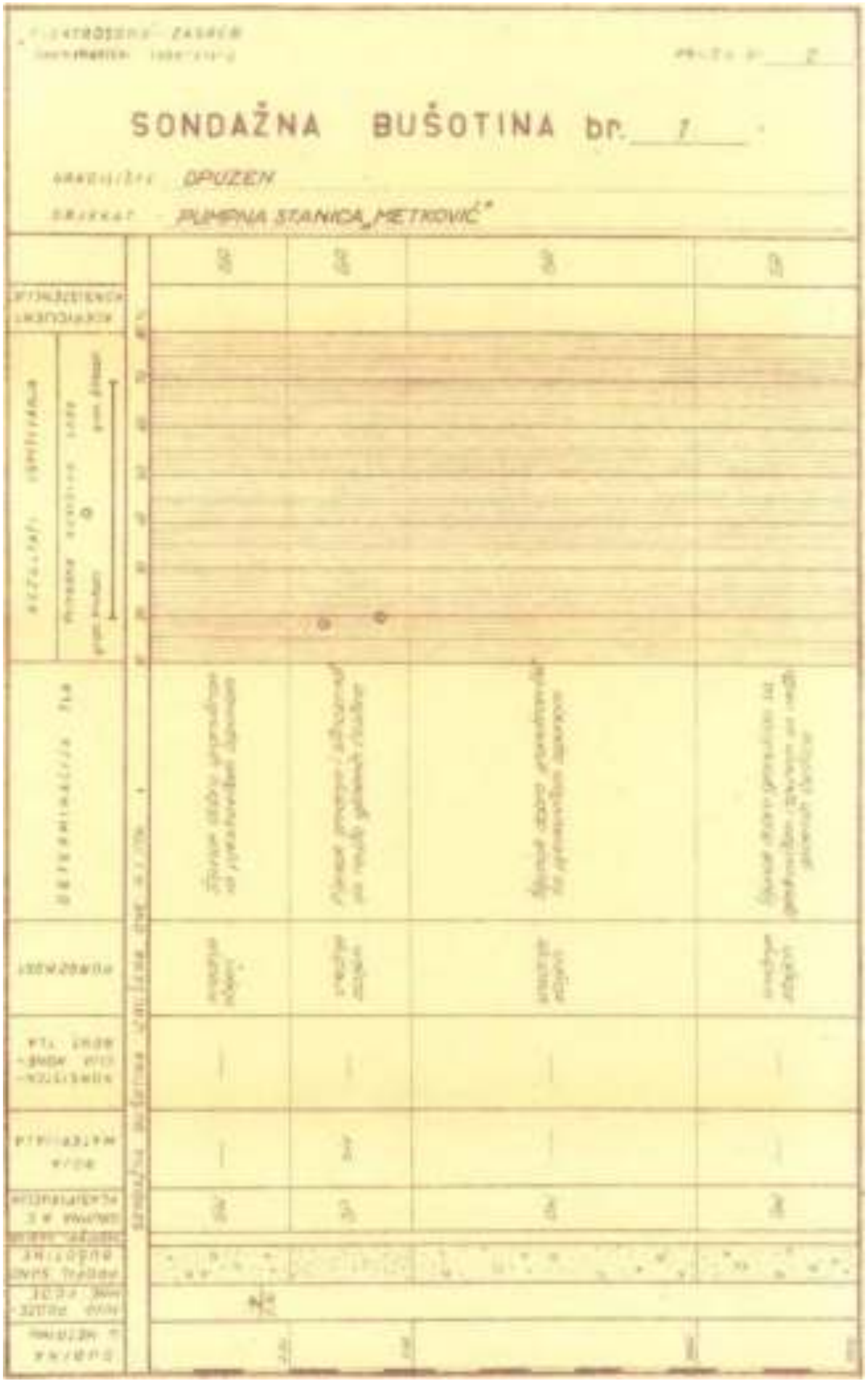


Figure 3.41 An example of borehole probe profile

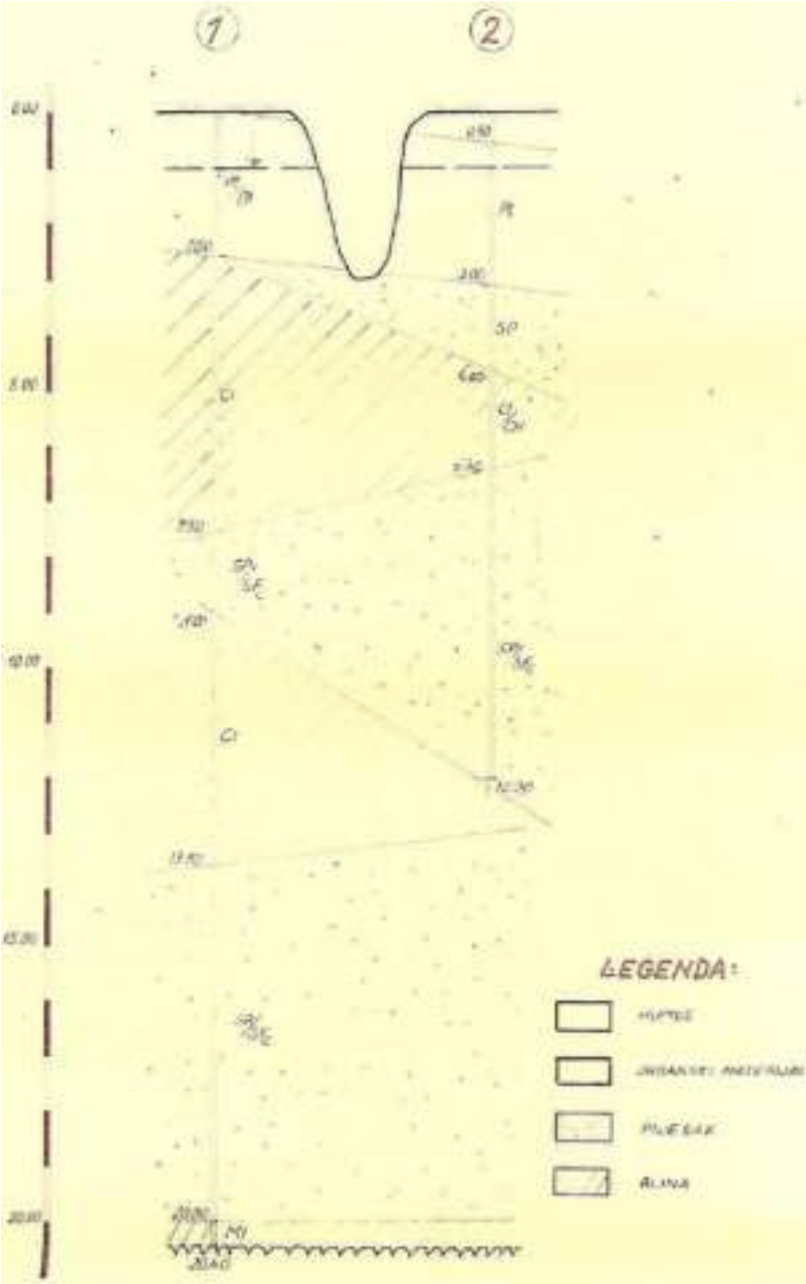


Figure 3.42 An example of longitudinal profile

3.16 Investigation works (Opuzen – Diga) (1966.)

Investigation works at the Diga embankment were taken to determine soil characteristics and water permeability. Geological composition makes fine to medium grained sand at the upper layer and below dusty silk, partly clayed or sandy. Water permeability test showed that in almost all cases water loss decreased with the duration of each interval.

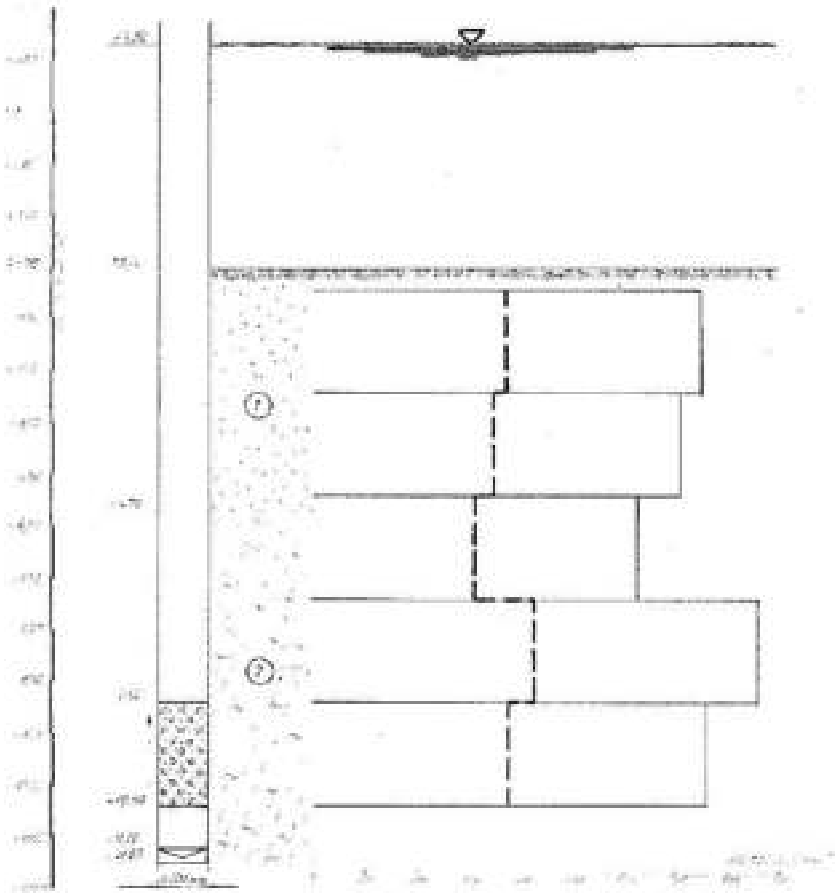


Figure 3.43 An example of water permeability tests

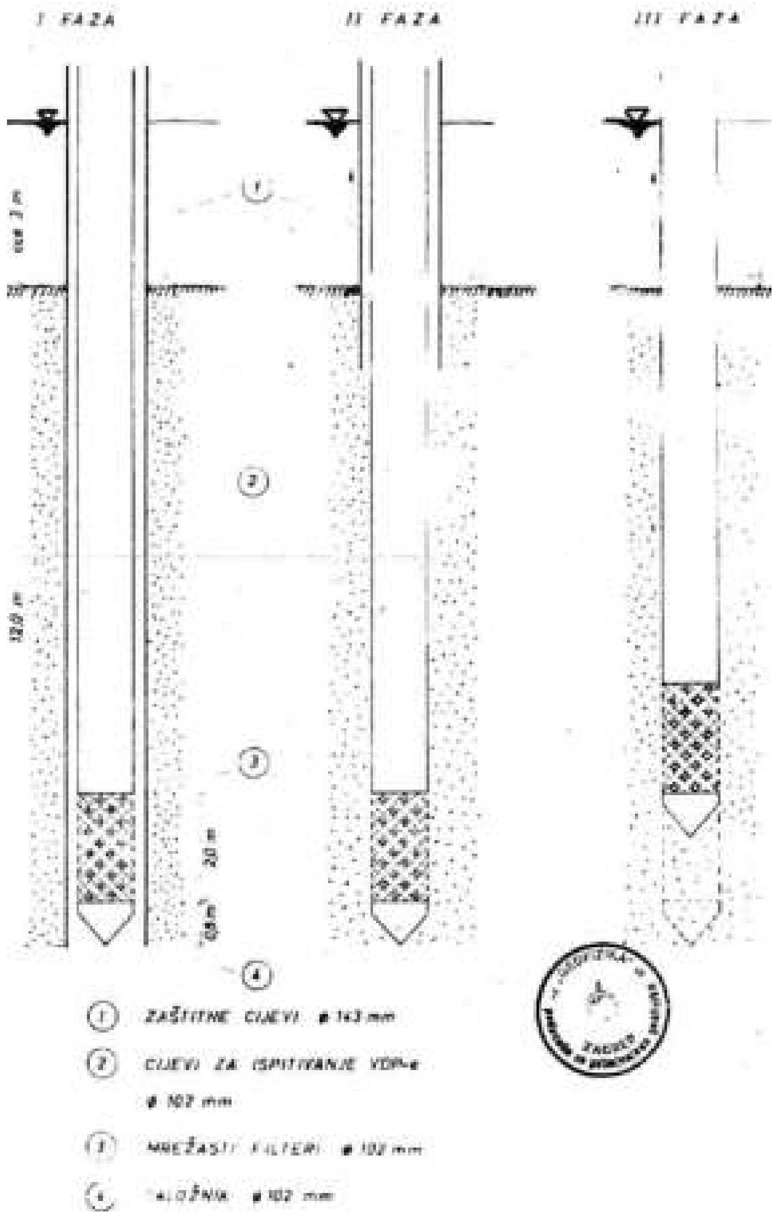


Figure 3.44 Working progress of water permeability tests

3.17 Water investigation works (Opuzen – Modrič) (1966.)

Water investigation works were taken at the Modrič area, where construction of pumping station was planned. It included well and observation boreholes (with installed piezometers) drilling, well pumping and observation of groundwater levels. Depression curves, yield and specific yield were determined based on appropriate lowering of water in the well. The main objective was to empirically determine the filtration coefficient which gives insight into the permeability of sand materials.

It is concluded that the dominant materials are fine to medium grained sands. The yield test was performed by test pumping in three stages, of which the third one achieved maximum yield of 8,50 l/s and the medium specific yield of the well is 1,44 l/s/m'. Hydraulic conductivity values range between 2,01*10^{-4} m/s and 2,68*10^{-4} m/s.

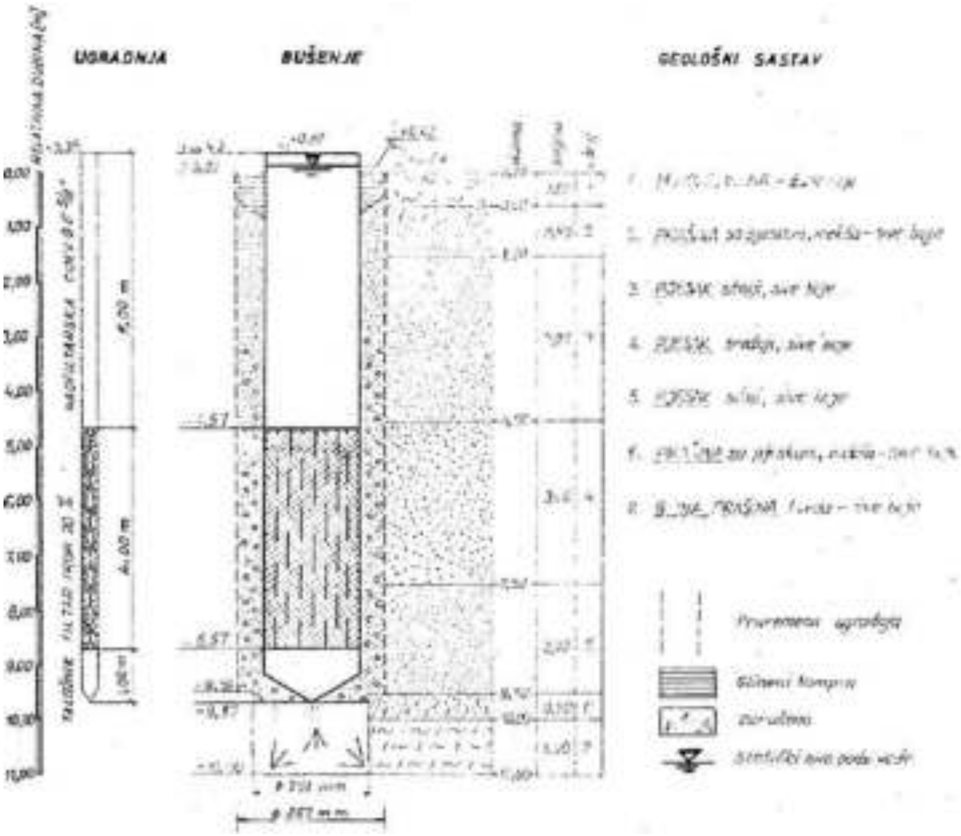


Figure 3.45 Geological-technical profile of the well

OSCILACIJE NIVOA PODZEMNE VODE UZ CRPLJENI BUNAR

OPUZEN
MODRIČ
OMB

[illegible]	[illegible]	[illegible]	OMB	OMP-1	OMP-2	OMP-3	OMP-4	OMP-5	OMP-6	OMP-7	OMP-8	PRIMJEDBE
			0,37	0,99	1,29	1,01	1,42	1,02	1,05	1,06	0,86	[illegible]
			0,620	0,59	0,58	0,57	0,52	0,57	0,57	0,60	0,56	[illegible]
			0,35	0,40	0,71	0,44	0,85	0,45	0,48	0,44	0,29	[illegible]
3. XI 66.	8,05	2,26	1,65	—	—	—	—	—	—	—	—	Crpljenje započelo 3. XI 1966. u 8[05] sati
	8,10	—	1,78	1,21	1,17	0,76		0,61		0,51	—	
	8,15	—	—	—	—	—	—	—	—	—	—	
	8,25	—	1,82	1,28	—	—	—	—	—	—	—	
	8,35	—	—	—	—	—	—	—	—	—	—	
	9,00	2,26	1,92	1,31	1,29	0,95	1,15	0,73	0,66	0,62	0,37	
	9,10	3,86	2,62	1,82	1,58	1,15	1,28	0,89		0,72	—	
	9,30	—	3,05	1,92	1,65	1,30	1,35	0,94	0,87	0,82	0,44	
	9,65	5,00	3,65	2,19	1,89	1,40	1,48	1,08	0,96	0,92	0,51	
	10,15	5,00	3,76	2,23	1,95	1,46	1,50	1,14	0,96	0,98	0,54	
	10,45	—	3,83	2,28	1,98	1,54	1,56	1,19	0,95	1,00	0,56	II faza crpljenja sa 4,7 l/sek s = 3,96 m
	11,15	4,72	3,87	2,31	2,00	1,53	1,64	1,22	1,00	1,05	0,61	
	12,00	4,72	3,98	2,35	2,01	1,55	1,63	1,24	1,06	1,08	0,60	
	13,00	—	4,04	2,39	2,06	1,58	1,67	1,27	1,05	1,11	0,66	
	14,00	4,72	4,06	2,59	2,09	1,59	1,67	1,29	1,04	1,13	0,65	
	16,00	4,91	4,19	2,39	2,06	1,59	1,65	1,29	1,04	1,12	0,61	
	18,00	5,00	4,21	2,40	2,05	1,69	1,65	1,29	1,01	1,12	0,61	
	20,00	4,93	4,20	2,41	2,05	1,63	1,65	1,32	1,02	1,12	0,61	
	22,00	4,72	4,22	2,43	2,07	1,53	1,66	1,31	1,01	1,12	0,62	
	24,00	5,00	4,22	2,44	2,08	1,63	1,64	1,33	1,01	1,12	0,65	
4. XI 66.	2,00	5,00	4,20	2,41	2,04	1,60	1,60	1,30	1,00	1,10	0,60	
	4,00	4,90	4,19	2,40	2,00	1,55	1,54	1,25	0,98	1,04	0,55	
	6,00	4,70	4,15	2,38	1,95	1,50	1,52	1,20	0,92	1,01	0,49	
	8,00	4,85	4,21	2,28	1,95	1,46	1,55	1,16	0,93	1,01	0,57	
	8,05	6,55	4,70	2,65	2,16	1,57	1,61	1,23	—	—	—	
	8,15	6,90	7,00	3,06	—	—	—	—	—	—	—	
	8,25	7,40	8,30	3,06	2,31	1,82	1,75	1,39	1,06	1,16	0,50	
	8,40	7,86	8,36	3,20	2,37	1,93	1,78	1,42	1,06	1,19	0,59	
	9,00	8,50	8,30	3,10	2,44	1,92	1,78	1,50	1,09	1,26	0,59	
	9,30	7,95	8,30	3,15	2,37	1,92	1,80	1,45	1,07	1,23	0,57	
	15,00	—	8,30	3,11	2,37	1,91	1,78	1,45	1,07	1,23	0,57	III faza crpljenja sa 7,0 l/sek s = 8,00 m
4. XI 66.	11,00	—	8,30	3,08	2,36	1,90	1,79	1,45	1,09	1,23	0,63	
	12,00	7,10	8,30	3,12	2,38	1,91	1,79	1,47	1,10	1,27	0,66	
	13,00	—	8,30	3,04	2,34	1,89	1,79	1,47	1,10	1,25	0,59	
	14,00	7,25	8,30	3,01	2,27	1,82	1,72	1,40	1,06	1,25	0,52	
	16,00	7,00	8,30	3,06	2,32	1,87	1,79	1,45	1,10	1,25	0,62	
	18,00	7,10	8,30	3,08	2,40	1,94	1,85	1,45	1,10	1,25	0,61	
	20,00	7,06	8,30	3,09	2,40	1,95	1,86	1,45	1,11	1,25	0,61	
	22,00	7,20	8,30	3,08	2,41	1,95	1,85	1,44	1,10	1,26	0,60	
	24,00	6,85	8,30	3,00	2,38	1,90	1,80	1,50	1,04	1,19	0,55	

Figure 3.46 Groundwater level fluctuations based on pumping tests

Naziv bušotine Vrijeme uzimanja uzorka Količina /l/sek/	0MB 29.XI 1966. u 14,00 sati 3,93	0MB 4.XI 1966. u 8,00 sati 4,5
pH	8,1	7,2
Isparni ostatak /mg/l/	26.251,0	25.715,0
p-alkalitet	1,56	ø
m-alkalitet	25,2	30,2
Agresivni CO_2 /mg/l/	ø	ø
Ukupni CO_2 /mg/l/	ø	4,6
H_2S /mg/l/	ø	ø
Cl' /mg/l/	13,090	12,880
SO_4'' /mg/l/	34,6	43,7
HNO_3 /mg/l/	1,540	1,844
Ca^{++}	115,9	77,6
Mg^{++}	1.069,0	1.116,0
CaO	162,4	108,7
MgO	1.772,0	1.850,
CaH°	16,2	10,9
UH°	263,2	268,4
Humusne kiseline /ppm/	80	100

Figure 3.47 Results of chemical analysis

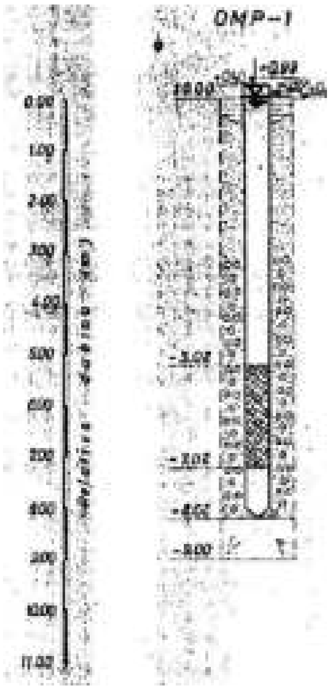


Figure 3.48 An example of technical profiles of the observation borehole

3.18 Geotechnical report
Embankment at the mouth of Mala Neretva (1966.)

The main object of these investigations was to define composition and geomechanical characteristics of soil for foundation conditions determination. Longitudinal profiles were specified using borehole profiles and visual AC classification of soil and soil samples were used for laboratory measurement of geomechanical soil characteristics. Laboratory tests were performed, including grain-size composition, volume weight and specific weight. Groundwater level observations were also measured.

It was concluded that micro location of the dam should be set based on the other technical conditions, because considering the foundation soil it is all the same. Soil subsidence is expected given the homogeneous composition of the underlying soil. The undermining of dam and rinse of the foundation soil by draining below the dam should be taken into account while designing.

Oznaka sonde	Dubina uzorka	Specifična težina	Zapreminska težina		Relativni porozitet
			Zbijen	Rahli	
	m	gr/cm³	gr/cm³	gr/cm³	ε
A-2	0,3-4,o	2,76	1,65	1,38	0,66
	4,o-1o,o	2,76	1,68	1,4o	0,64
A-3	0,4-4,5	2,74	1,66	1,35	0,65
	4,5-8,5	2,76	1,68	1,37	0,64
A-6	0,8-4,2	2,79	1,64	1,39	0,7o
	4,2-1o,o	2,79	1,67	1,39	0,67
A-7	1,o-5,o	2,77	1,65	1,39	0,68
	5,o-1o,o	2,77	1,69	1,4o	0,64

Figure 3.49 Numerical record of laboratory results

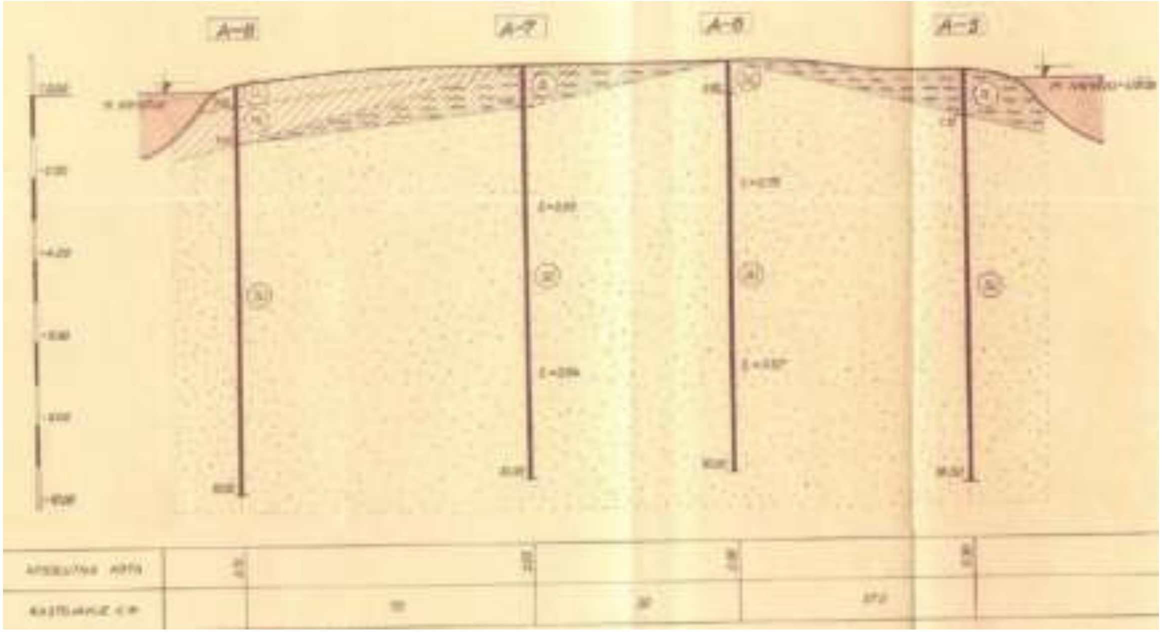


Figure 3.50 Longitudinal profiles at the mouth of the Mala Neretva River

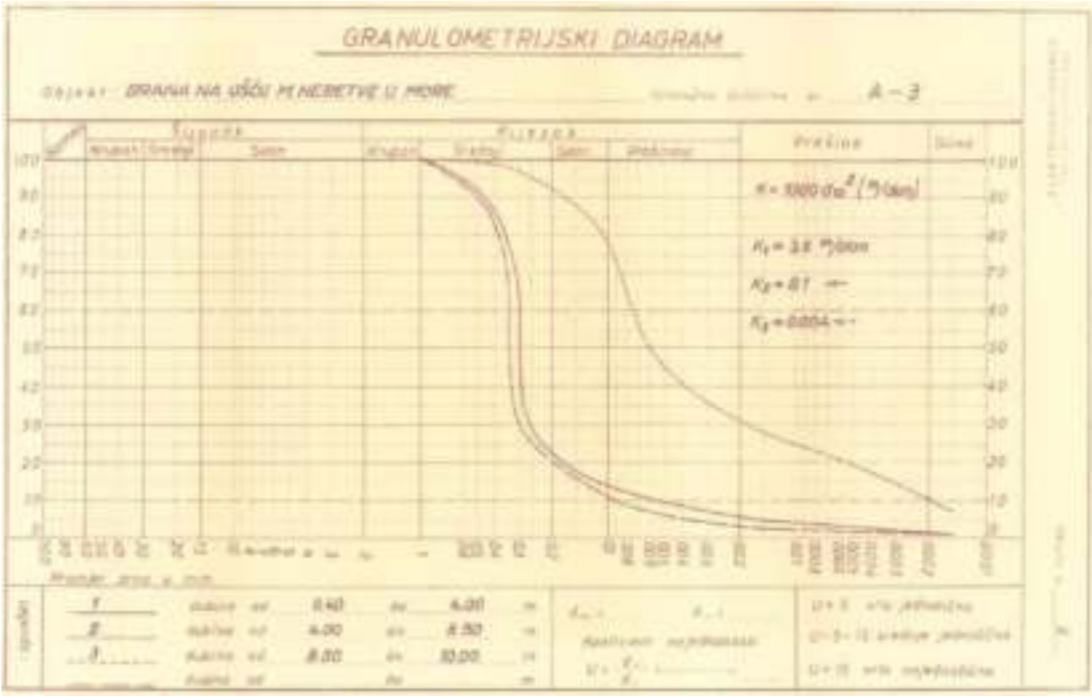


Figure 3.51 An example of grain-size diagram

SONDAŽNA BUŠOTINA
br. A–3

GRADILIŠTE OPUZEN – PIK „NERETVA"
OBJEKAT Brana na ušću M. Neretve u more
BUŠAĆA GARNITURA RUČNA

Figure 3.52 An example of borehole probe profile

3.19 Water investigation works
Opuzen – Šetka (1966.)

Central part between rivers Velika and Mala Neretva, near Crepina River was processed with observed boreholes, inside of which the depth of bedrock was determined using geophysical investigation. The objective was to determine geological composition and hydrogeological characteristics of aquifer layers including yield, static groundwater level and chemical structure of groundwater. Investigation on two boreholes performed as test wells including pumping and taking samples of water for chemical analysis.

Drilling of the first borehole was suspended at the depth of 63,00m by an order of the supervisory authority. From information of layers' structure and hydrogeological characteristics, it was concluded that the following layers may generally be distinguished:
- cover layer with loam and clay (silty, dusty and sandy) around 5m of thickness,
- shallow aquifer deposits of sand (generally fine grained) 2,5m of thickness,
- sandy-silt and dusty-silt clay representing generally waterproof or at certain locations poorly permeable layer around 24m of thickness,
- artesian aquifer containing gravel and conglomerate of 23,5m of thickness,
- dusty deposits representing waterproof layers, containing sand and clay with a small amount of peat substance, around 8m of thickness,
- subartesian aquifer containing gravel with coarse grained sand, probably representing the base of the Valley. Thickness of it was not determined, but it was estimated to be greater than 7m.

Inside of artesian aquifer, which begins at depth of 31m, water is held under pressure of 3,2 atm which causes groundwater level rise of +0,45m above the level of ground. Subartesian aquifer, which begins at depth of 56m, contains groundwater level -0,55m below the level of ground, with the pressure of 3,1atm. It is concluded that investigated area in hydrogeological sense consists out of three, mutually isolated layers.

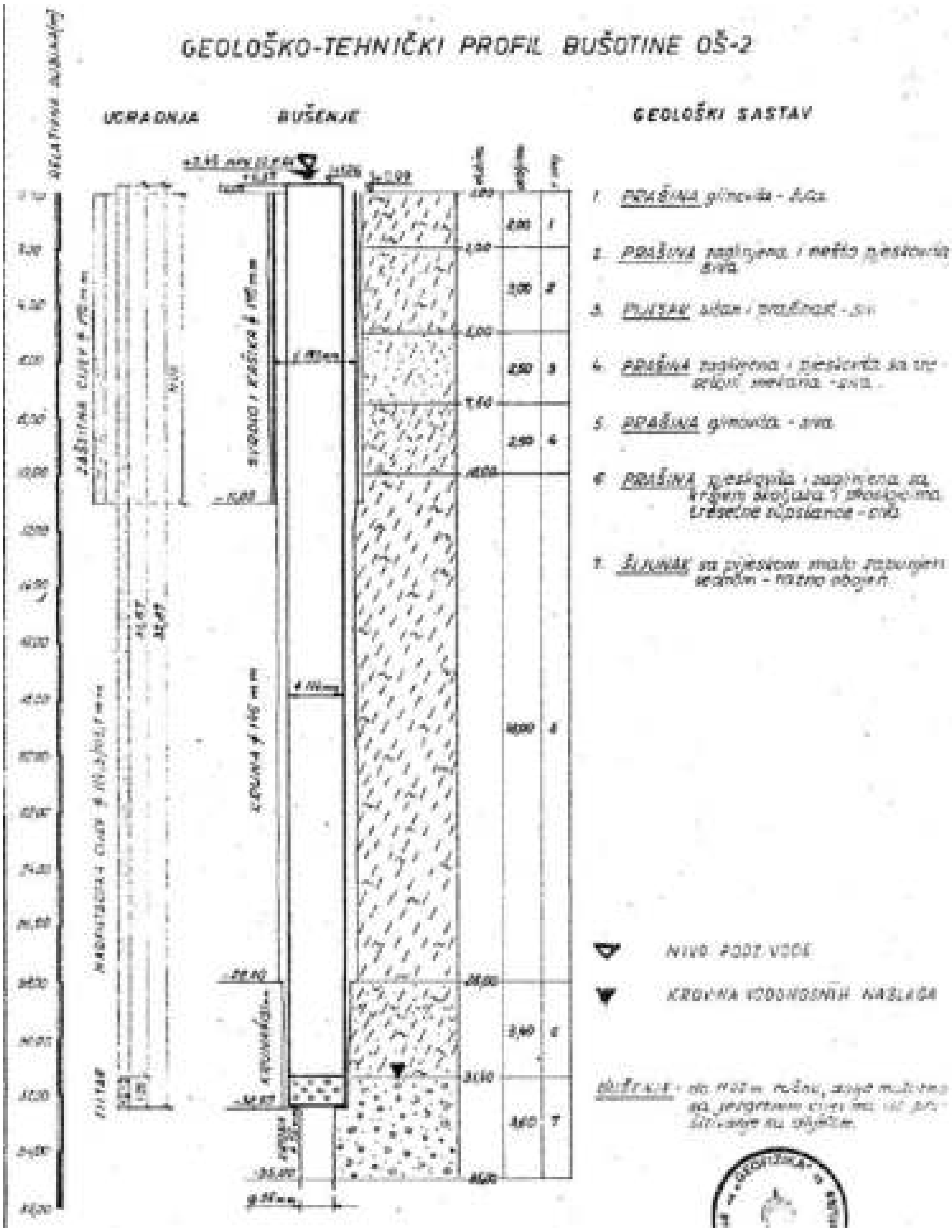


Figure 3.53 Geological-technical profile of borehole

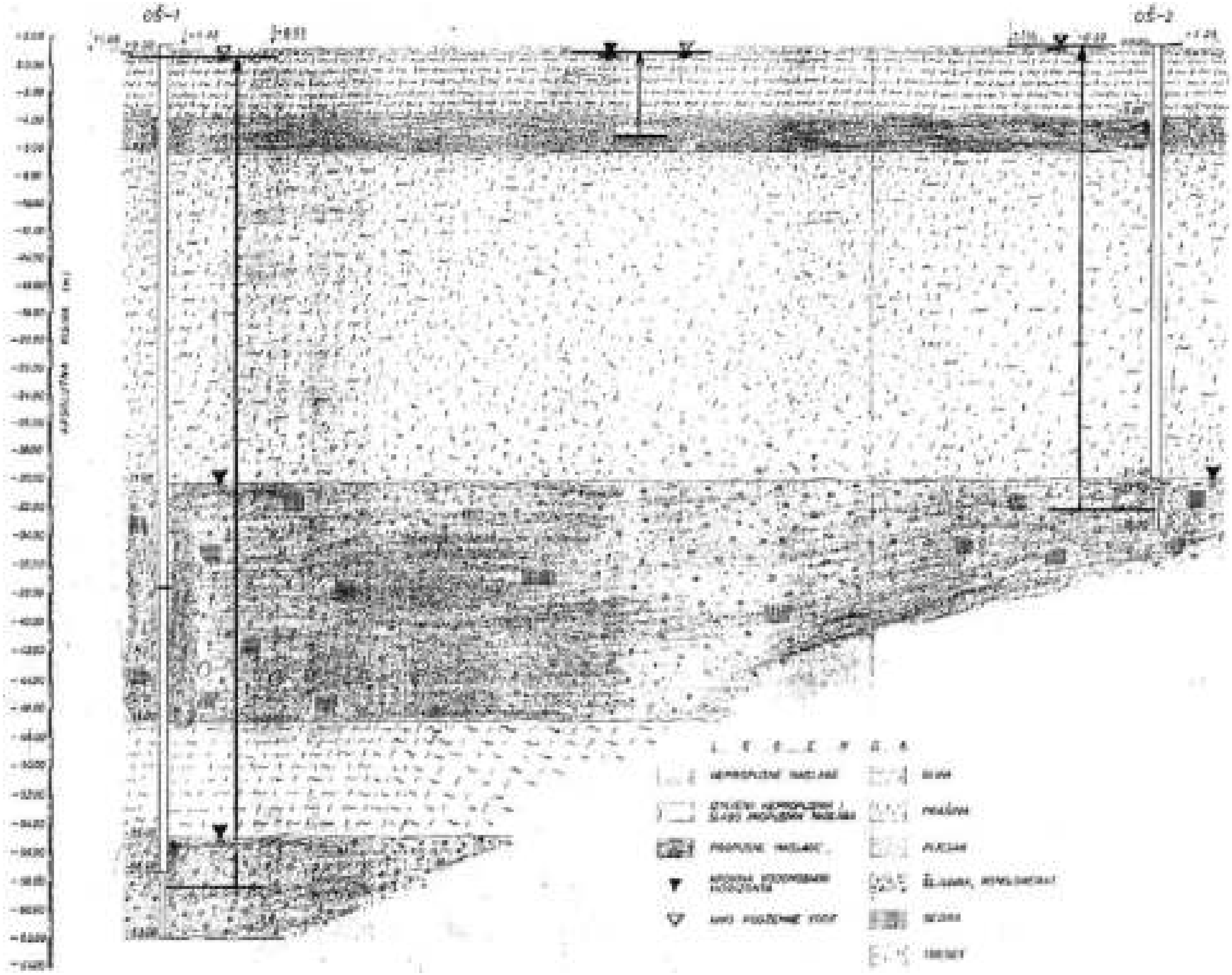


Figure 3.54 Hydrogeological profile

3.20 Water investigation works Opuzen – Vidrice (1966.)

This report includes investigation works at the area of Prag pumping station construction: drilling of observation boreholes with continuous coring, well drilling and installation of well pipes and filters as well as test pumping. Groundwater level observations, chemical structure of groundwater and grain-size were also investigated by sampling. Determination of hydraulic conductivity and yield was done.

Depending on permeability, three groups of deposits were distinguished: waterproof containing organic clays with peat, generally waterproof to poorly permeable deposits represented by sandy clay and dusty clay, and permeable deposits containing fine to medium grained sand with dust. It was concluded that static groundwater fluctuations were depending on the Mala Neretva River water level. Medium value of hydraulic conductivity is $1,84*10^{-5}$ m/s and of specific yield is 0,11 l/s/m'. Temperature of water during pumping test was 16,5°C.

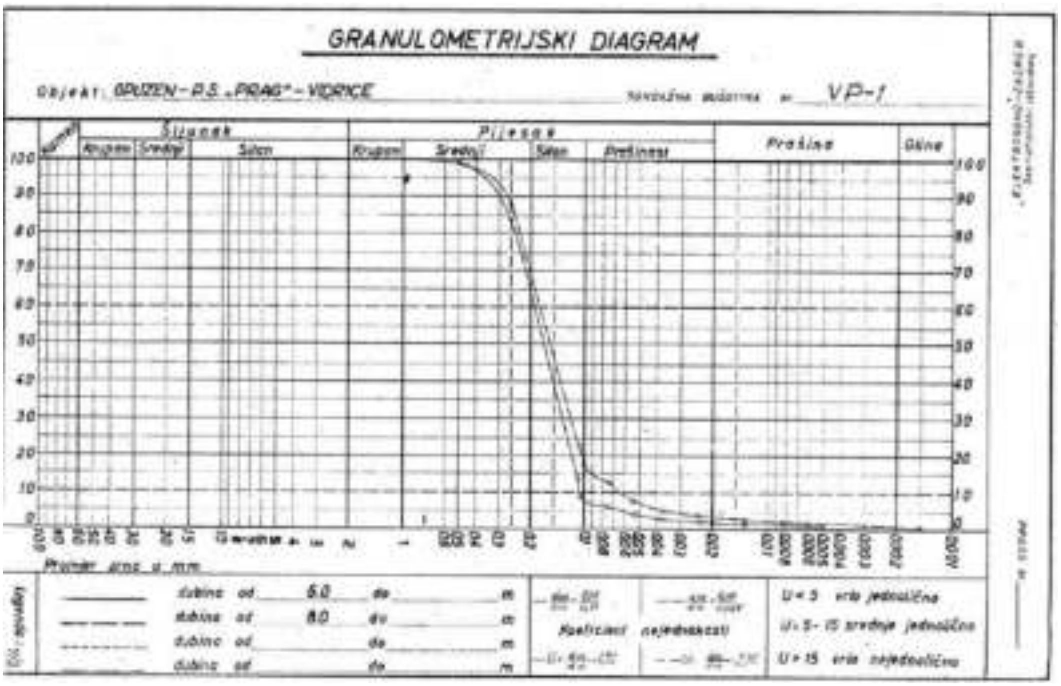


Figure 3.55 An example of grain-size diagram

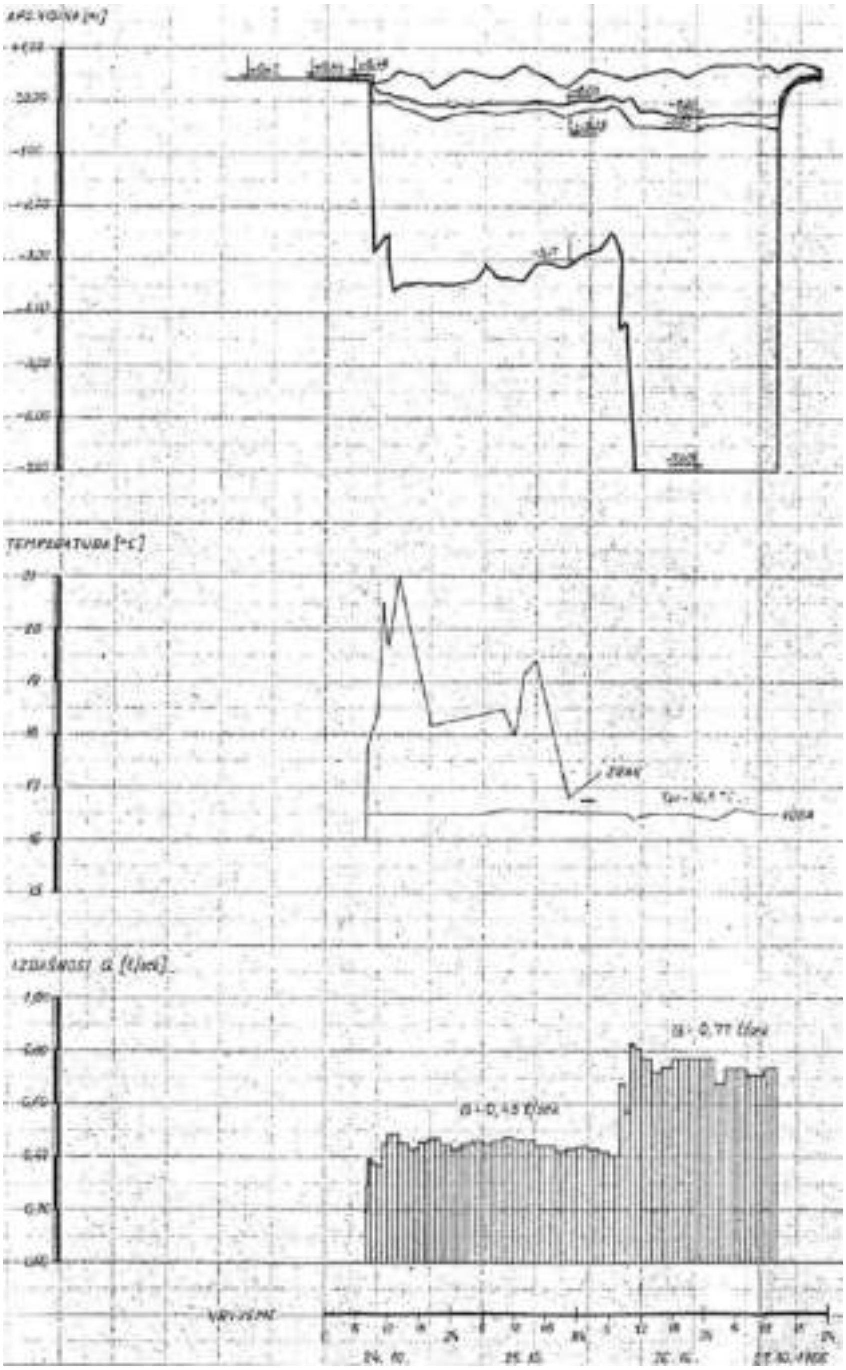


Figure 3.56 Diagram of well pumping

Naziv bušotine Vrijeme uzimanja uzorka Količina /1/sek/	OVB-1 26. X 1966. u 08,00 sati 0,43 1/sek	OVB-1 27. X 1966. u 10,00 sati 0,77 1/sek.
pH	7,8	7,5
Isparni ostatak /mg/1/	27.936,0	27.252,0
p-alkalitet	Ø	Ø
m-alkalitet	38,5	38,1
Agresivni CO_2 /mg/1/	Ø	Ø
Ukupni CO_2 /mg/1/	Ø	Ø
H_2S /mg/1/	0,95	0,72
Cl' /mg/1/	13,320,0	13,250,0
SO_4' /mg/1/	966,0	597,0
HCO_3 /mg/1/	2353	2330
Ca^{++} /mg/1/	132,6	128,0
Mg^{++} /mg/1/	1.168,0	1.105,0
CaO /mg/1/	185,9	179,2
MgO /mg/1/	1.938,0	1.833,0
CaH^o	18,6	17,9
UH^o	288,1	272,9
Humusne kiseline /ppm/	110	100

Figure 3.57 Results of chemical analysis

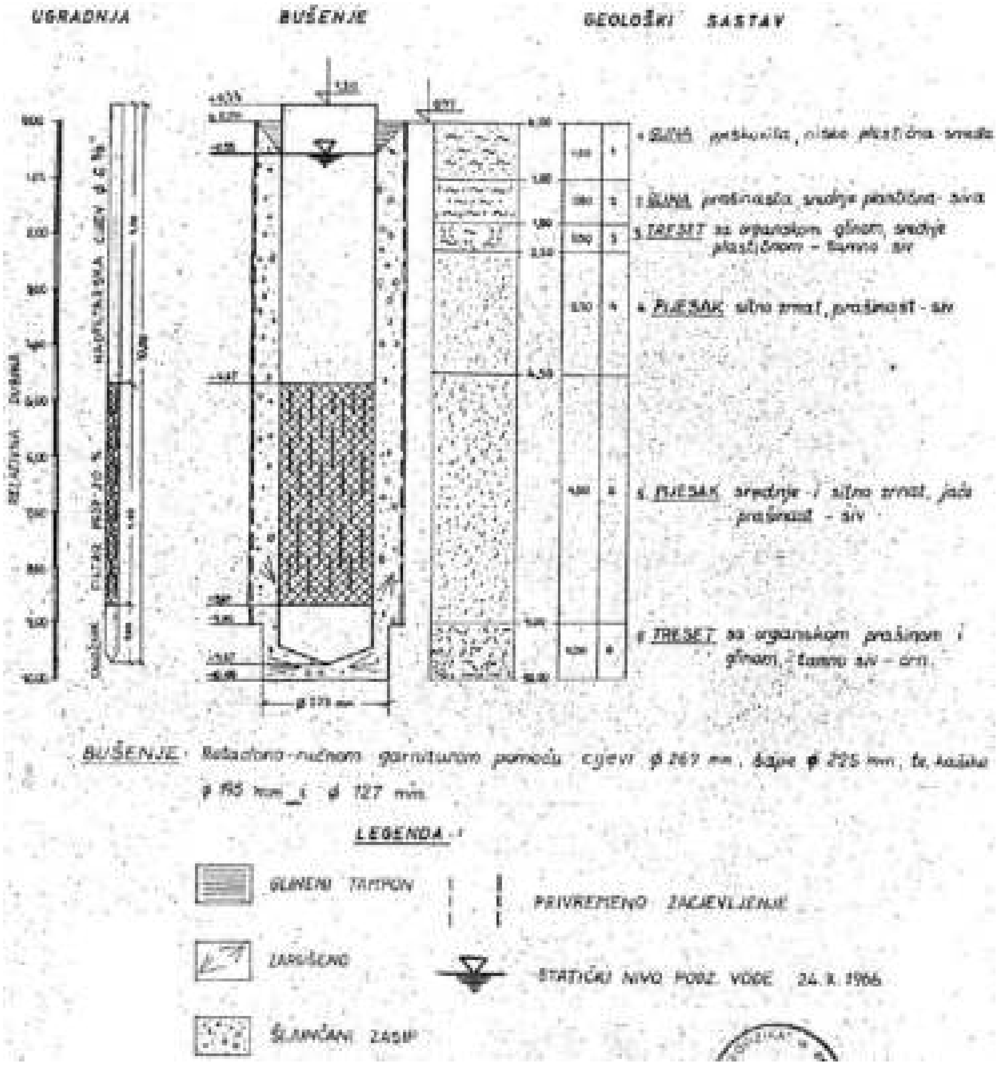


Figure 3.58 Geological-technical profile of the well

3.21 Conceptual design of the meliorated area Kuti /hydrogeology/ (1973.)

Engineering geological and hydrogeological investigations were performed including geological structure, physical and mechanical properties of materials at depth below 10m. Hydraulic conductivity, depth and thickness of aquifer layer and chemical structure of groundwater were determined, as well as temperature and yield.

One of the boreholes reached 68 m which contains four aquifer layers. The top layer consists dusty sand and the second and third aquifer layers are made of slightly sandy and dusty gravel, while the last one represents chalk limestone. It is concluded that on several smaller areas of investigated area Tertiary deposits below Quaternary cover could be expected, however these investigation works took relatively small drilling depths and did not register this occurrence.

Thickness of the first aquifer layer is between 2,4m and 6,7m and has permeability from 0,003m^2/day to 432 m^2/day, while the value of hydraulic conductivity is between 10^{-7}m/s and 8,3*10^{-4}m/s. Coefficient of permeability and hydraulic conductivity of the second and third aquifer layer have significantly higher values, respectively from 2304 to 3952 m^2/day and 5,8m/s to 9,6*10^{-3}m/s. Specific yield for the first layer is between 0,002 l/s/m' and 0,75 l/s/m'.

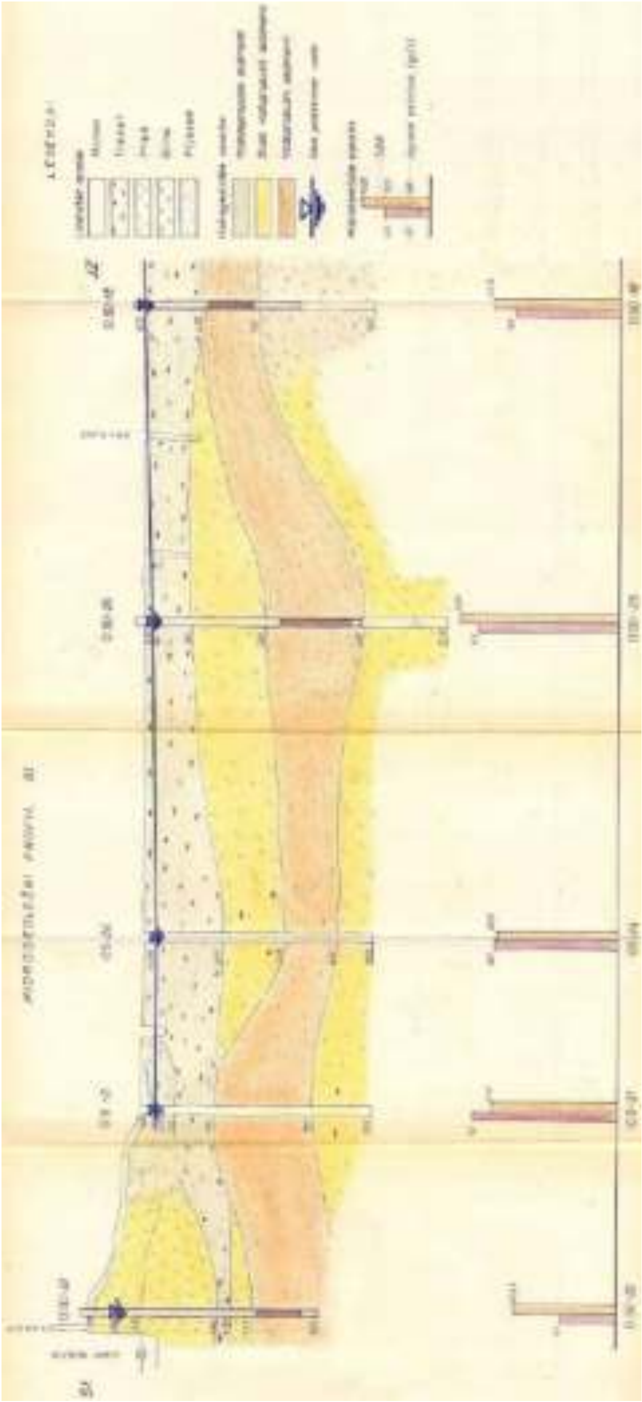


Figure 3.59 An example of hydrogeological profile

OZNAKA LOKACIJE	ISPARNI OSTATAK	KATIONI Ca mg/l		Mg mg/l		Na + K mg/l		ANIONI Cl mg/l		SO_4 mg/l		HCO_3 mg/l		Fe mg/l	SiO_2 mg/l	FORMULA KURLOVA	Natrijski adsorpcijski faktor SAR
O 50-2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-25 d=60-80 m	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-25 d=219-263 m	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-25 d= 507 m	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-25 d=65,0m	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O 50-26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
OPUZEN-Neretva kod Opuzena	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]
OPUZEN-Prunjak kod O50-4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]
OPUZEN-jezero Kuti	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]

Figure 3.60 Results of chemical analysis

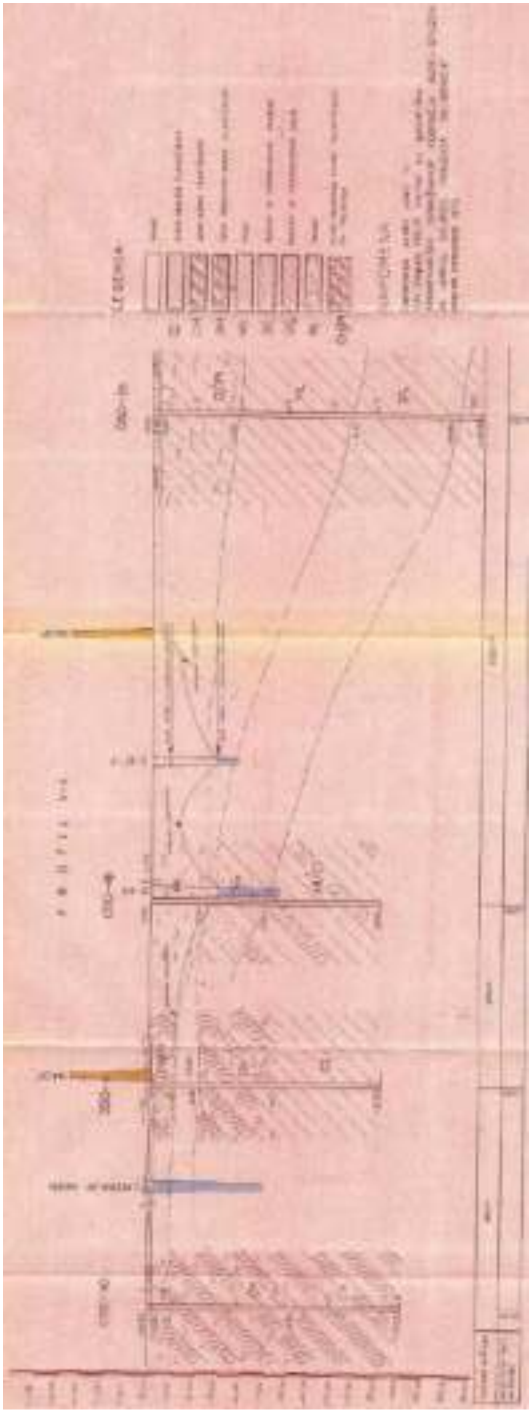


Figure 3.61 Geotechnical profiles and channels

3.22 Water management solution and arrangement of the Lower Neretva basin (1996.)

The present area downstream of the Neretva River was once the midstream of the River, which is known from the general geological development of the basin. The basic limestone dolomitic rock was already karstified with all the characteristics of today's middle stream flow, i.e. the markedly sinking flows of the tributary of the dominant NW - SE direction, but also with transverse communications, depositing the sediment in the way that can be seen upstream today.

Today's tributaries ended underground in the Neretva River, downstream at the time of the lower sea level, that is, the lower piezometric conditions that prevailed at that time. As the sea level rises and the relative descent of land increases, the downstream piezometric level has increased, which has led to the development of the new groundwater routes and the opening of new upstream sources.

Geological history indicates the formation of the first gravel layer, then the layer of clay and again the gravel layer. Later, probably at the time of the lakes formation, a formation of thick low-permeability layer was formed with clayey - silt sandy composition. A sandy layer was formed above this layer with a surface muddy layer corresponding to the river downstream of recent occurrence. This scheme (Figure 2.62) has been established by hydrogeological surveys to date in the Opuzen – Mouth of the Neretva River area (four deep boreholes), partly in the Kuti area (one deep borehole), in the Koševo and Vrbovci areas (three deep boreholes), on the right side of the Neretva from Metković towards Vid (two boreholes that entered the rock) while upstream is unproven.

With the relative rising of the sea, some of the former sources come under the sea. The piezometric pressure dictated by the sea level is transmitted to the former underground channels upstream, therefore, depending on the water permeability of these channels, salty sources appear far upstream today. During the rainy season, the piezometer elevation in the surrounding karst increases significantly, so the karst discharges at the input type wells and at the same time discharges through the cracks at higher elevations. Both gravel layers are pressurized and discharged through a poorly permeable clay layer into the surface sand layer. The longitudinal distribution of gravel deposits towards the sea is unknown, nor the possibility of discharging into the sea.

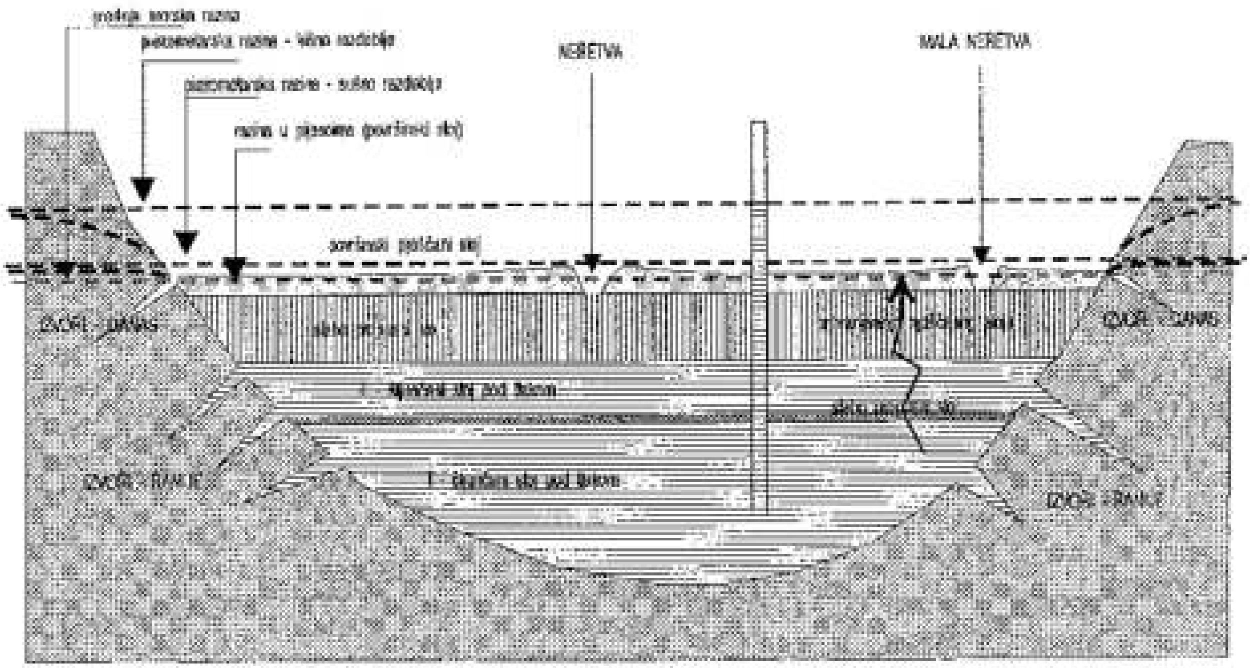


Figure 3.62 Cross section of the Neretva Valley

A gravel layer erupts somewhere in the sea on a slope that is steeper than the slope of the layer. This contact may be muddy or sandy or collimated, but due to the high pressure inside the layer during the rainy season, the contact is permeable. In the case of good connection with the sea, the formation of a salt water wedge can be assumed, which position is determined by the piezometric pressure from the karst massif. In the dry season, a wedge of salt water, due to the low pressure of the karst massif, is drawn deep into the area.

The piezometric state in the surface sand layer in natural conditions without constructions was determined by the boundary conditions dictated by surface waters, which are the sea level, the water levels of the Velika and Mala Neretva River and other rivers and lakes. The natural state before melioration was such that the groundwater levels in the rainfall were equalized with the surface, and in the dry season they were conditioned by the sea level and the dry inflow. Under the conditions of construction of hydrotechnically meliorative system, the water level corresponds to the water levels of the channel and is always lower than the natural regime. Therefore, there is a permanent leakage into the meliorative system, which in the dry season can be compensated by evaporation and evapotranspiration. Leakage can be relatively easily reduced by lowering the piezometer pressure in deeper layers, for example by pumping a number of well-spaced wells.

3.23 Drilling report of two pairs of piezometers downstream of the Neretva River (2005.)

Drilling of two shallow and two deep boreholes for piezometers installation (Figure 2.63 and Figure 2.64) was carried out with a continuous coring. The core is stacked into wooden crates and photographed. Field classification of soil materials was carried out on drilled core samples.

The following types of soil material were registered by drilling: surface clay, upper layer of sand, thick clay layer, bottom gravel and limestone (possibly limestone conglomerate). Because of the clayey upper layer of sand, it was difficult to define exact boundary between the thick clay layer. One of the boreholes reached bedrock at depth 35,50m. Groundwater level was also monitored during drilling.

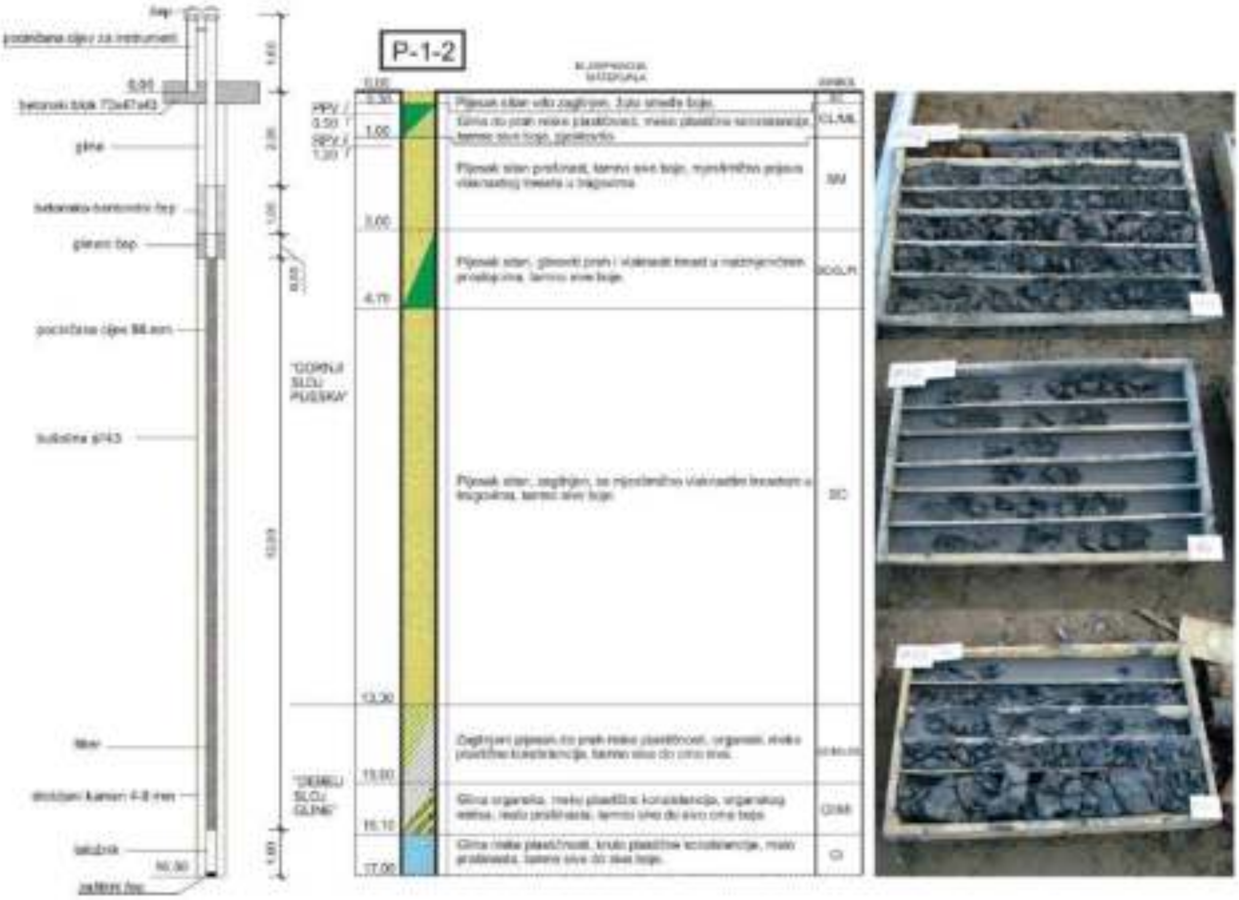


Figure 3.63 An example of the shallow borehole profile

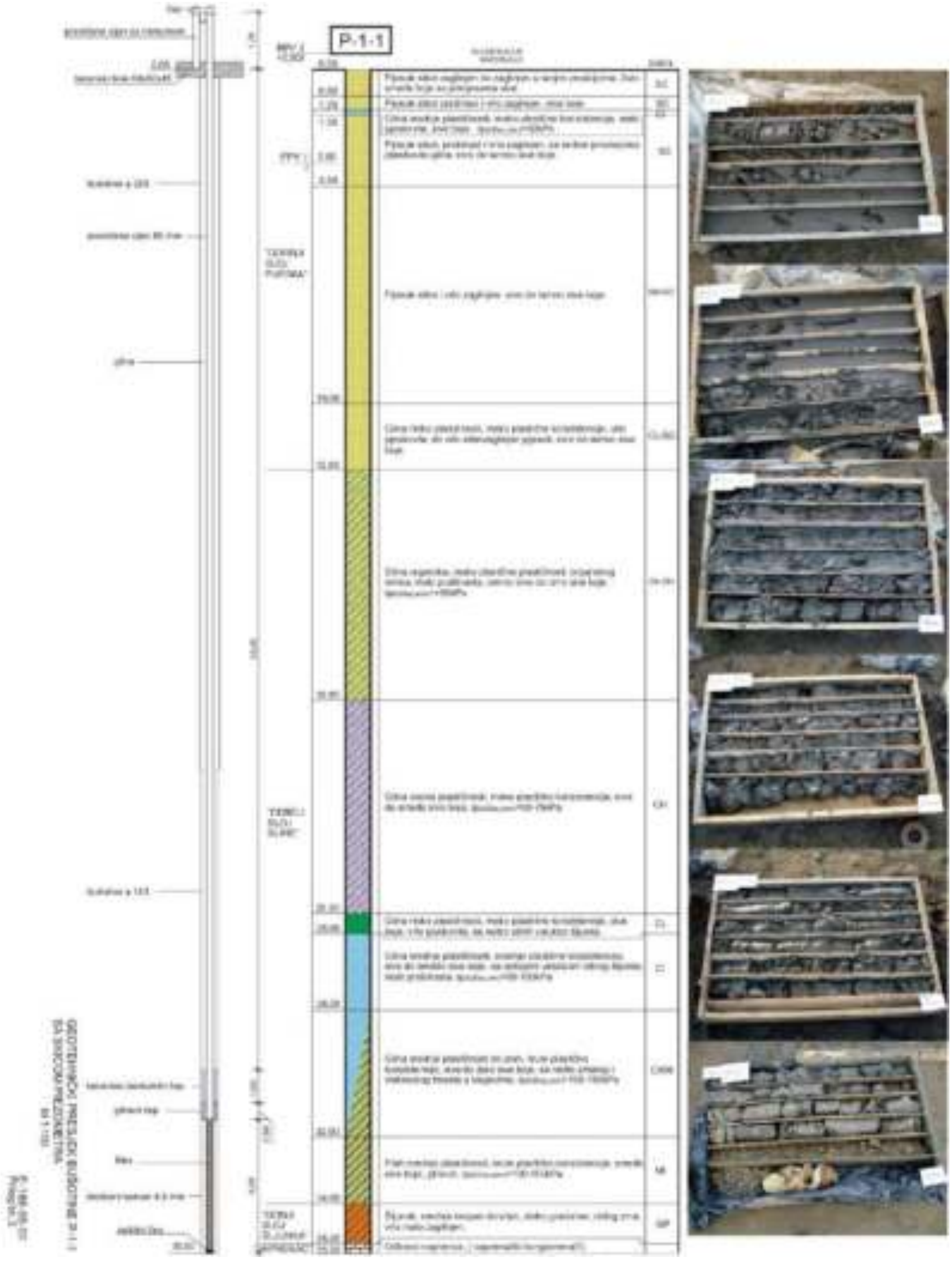


Figure 3.64 An example of deep borehole profile

3.24 Geotechnical investigation works for irrigation system conceptual design downstream of the Neretva River (2008.)

For the purpose of conceptual design of the irrigation system downstream of the Neretva River, round 1,5km downstream of Opuzen geotechnical investigation works were performed at positions of the following objects: partition on the Neretva River, pumping station Koševo-Vrbovci, micro accumulation Lađište and Opuzen pumping station. The aim of geotechnical investigation was to determine the composition and properties of the underlying soil at the positions of objects and to make recommendations for the design of the planned interventions. The following investigation works have been carried out: exploratory drilling, engineering-geological works and laboratory tests.

From the geological aspect, at partition on the Neretva River groups of materials can be classified as organogenesis-bar sediments and gravel into the alluvium of the Neretva River. Due to deposition in still environments in organogenesis-bar deposits sediment is dominated by fine particles (soft clays and dust, and fine sand) with peat. From the geotechnical point of view, the deposits of organogenesis-bar sediments (first four material groups) are weak, load-bearing capacity and high compressibility. These materials are generally of soft plastic consistency. Due to these geotechnical properties, these materials are not suitable for foundation. Better geotechnical properties have deeper material groups. The gravel has the property of good bearing capacity and low compressibility.

Due to the poor properties and conditions in the underlying soil, a geotechnical design should be made for the main project of the pumping station Koševo-Vrbovci. According to the results, two zones in the area of microaccumulation Lađište can be distinguished: substrate rock (limestone) medium to heavily fissured with high permeability, and high plasticity clay that covers a smaller part of the microaccumulation area and is poorly permeable.

The location of the Opuzen pumping station can be divided into two substantially different geotechnical environments: lowland swampy part of the terrain in the Neretva River valley, which is represented by low bearing capacity and very strong compressible organogenesis-bar sediments (clay, dust, sand and peat) and karst part of the terrain (hills) that is built of solid base rock - upper limestone.

OZNAKA UZORKA	DUBINA	PRIRODNA VLAGA	SPECIFIČNA TEŽINA	ZAPREMINSKA TEŽINA		GRANULOMETRIJSKI SASTAV					GRANICE PLASTIČNOSTI		INDEKS PLASTIČNOSTI	INDEKS KONZISTENCIJE	SIMBOL
	m	w [%]	G_s [g/cm³]	γ_d [g/cm³]	γ [g/cm³]	G [%]	S [%]	M [%]	C [%]	VDP USBR k [cm/s]	w_L [%]	w_P [%]	I_P [%]	I_c	
BUŠOTINA / JAMA	**S-062-08-01**														
S-062-08-01-01	0,60-0,80	–	–	–	–	0,0	43,3	44,9	11,8	5,41E-06	–	–	–	–	ML/SC
S-062-08-01-02	3,00-3,15	–	–	–	–	0,4	26,8	63,8	10,0	2,79E-06	–	–	–	–	ML/SC
S-062-08-01-03	6,60-6,75	–	–	–	–	6,5	50,1	38,5	10,7	3,98E-06	–	–	–	–	SM
S-062-08-01-04	7,90-8,00	–	–	–	–	0,0	17,0	67,3	15,5	5,67E-07	36,29	28,34	7,95	–	MI
S-062-08-01-05	13,40-13,50	40,64	–	–	–	–	–	–	–	–	46,80	21,85	24,95	0,25	CI
S-062-08-01-06	15,20-15,50	40,48	2,74	1,30	1,82	–	–	–	–	–	45,78	22,38	23,40	0,23	CI
S-062-08-01-07	18,50-18,80	43,82	2,74	1,25	1,79	–	–	–	–	–	45,29	21,88	23,41	0,06	CI
S-062-08-01-08	21,20-21,65	38,88	2,75	1,38	1,48	–	–	–	–	–	45,84	22,35	23,49	0,30	CI
S-062-08-01-09	23,60-23,80	66,89	–	–	–	–	–	–	–	–	99,75	38,43	61,32	0,67	CH
S-062-08-01-10	24,10-25,30	–	–	–	–	0,0	35,4	51,7	12,7	2,793E-06	–	–	–	–	CL/SC
S-062-08-01-11	25,60-25,80	32,52	–	–	–	–	–	–	–	–	43,12	21,70	21,42	0,49	CI
S-062-08-01-12	28,20-28,30	41,04	–	–	–	–	–	–	–	–	77,88	31,83	46,03	0,80	CH
S-062-08-01-13	27,00-30,00	–	–	–	–	70,1	18,2	8,8	2,9	3,686E-02	–	–	–	–	GC

Figure 3.65 Results of physical properties of soil material

OZNAKA UZORKA	DUBINA	DIREKTNO SMICANJE				TRIAKSIJALNO SMICANJE		PRITISNA ČVRSTOĆA		STIŠLJIVOSTI TLA					VDP IZ STIŠLJIVOSTI			SIMBOL
		STANDARDNO		REVERSNO						σ_{50}	σ_{100}	σ_{200}	σ_{400}	σ_{800}	σ_{100}	σ_{200}	σ_{400}	
	m	c [kPa]	φ[°]	c [kPa]	φ[°]	c [kPa]	φ[°]	qu [kPa]	ε [%]	Ms [MPa]					k [cm/s]			
BUŠOTINA / JAMA	**S-062-08-01**																	
S-062-08-01-06	15,20-15,50	4,40	28,50					52	12,18	1,50	2,40	3,00	4,50		6,53E-08	3,94E-08	3,24E-08	CI
S-062-08-01-07	18,50-18,80	2,90	27,70					69	15,19	1,90	2,80	2,60	3,30	0,90	5,22E-08	3,96E-08	1,32E-08	CI
S-062-08-01-08	21,20-21,65							37	15,54									CI
BUŠOTINA / JAMA	**S-062-08-02**																	
S-062-08-02-05	9,60-10,05							41	17,29									MI
S-062-08-02-06	13,05-13,50							27	11,69									CI
S-062-08-02-08	15,40-15,85							43	12,23									CI
S-062-08-02-09	18,10-18,40	18,70	24,20					85	6,70	1,10	2,10	2,60	4,10	0,80	3,66E-08	2,81E-08	1,67E-08	CI
S-062-08-02-10	21,70-22,15							70	9,97									CI
S-062-08-02-13	24,60-25,05							93	13,84									CI

Figure 3.66 Results of mechanical properties of soil material

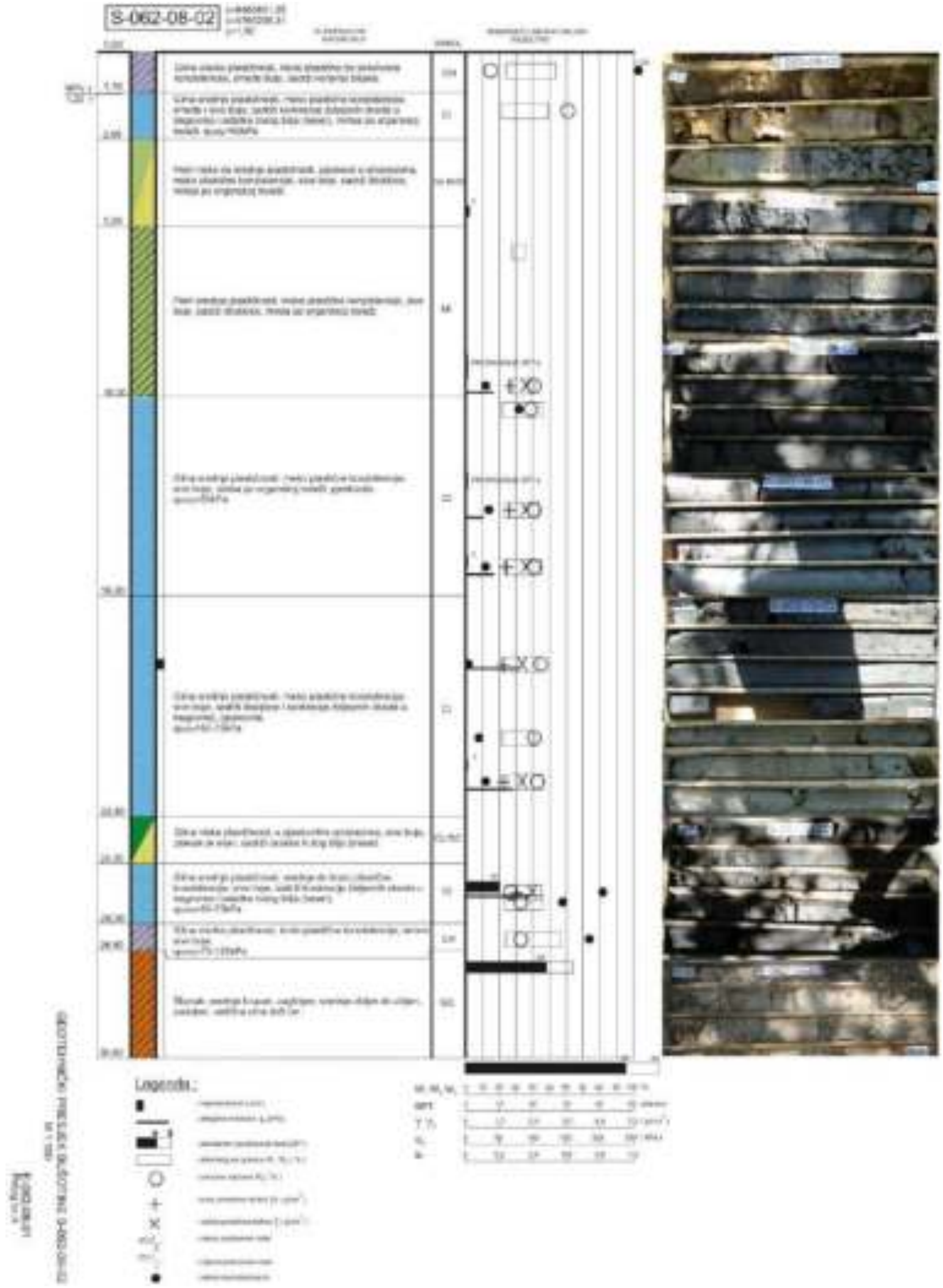


Figure 3.67 An example of borehole profile

grupa i vrsta materijala	zapreminska težina γ (Kn/m³)	kohezija c (kPa)	kut trenja ϕ (°)	modul stišljivosti M_s (MPa)	jednoosna pritisna čvrstoća q_u (kPa)	SPT N (udaraca/ 30cm)	vodo propusnost k (cm/s)
(1) POVRŠINSKA GLINA SREDNJE DO VISOKE PLASTIČNOSTI – CI, CH	18	5-15	17-25	0,5-2	-	-	10^{-8}
(2) PRAH NISKE DO SREDNJE PLASTIČNOSTI S PJESKOVITIM PROSLOJCIMA - ML-MI/SC, ML/SC	18	1-3	22-28	0,5-1,5	-	od propadanja do 1	10^{-6}
(3) PRAH SREDNJE PLASTIČNOSTI - MI	18	1-5	19-25	0,5-2	41	od propadanja do 1	10^{-7}
(4) GLINA SREDNJE PLASTIČNOSTI - CI	18	2-10	20-27	0,5-3	27-85	1-3	10^{-8}
(5) GLINA NISKE PLASTIČNOSTI S PJESKOVITIM PROSLOJCIMA – CL/SC	18	1-3	22-28	1,5-5	-	14	10^{-6}
(6) GLINA SREDNJE DO VISOKE PLASTIČNOSTI – CI, CH	18	5-15	17-25	1,5-5	93	10	10^{-8}
(7) ŠLJUNAK - GC	20-21	0-1	33-38	20-40	-	18-48	10^{-2} – 10^{-3}
Zapreminska težina materjala ispod razine podzemne vode umanjuje se za težinu vode (γ'=$γ_s$-10 kN/m³).							

Figure 3.68 Soil parameters at partition on the Neretva River

grupa i vrsta materijala	zapreminska težina γ (Kn/m³)	kohezija c (kPa)	kut trenja ϕ (°)	modul stišljivosti M_s (MPa)	jednoosna pritisna čvrstoća q_u (kPa)	SPT N (udaraca/ 30cm)	vodo propusnost k (cm/s)
(1) POVRŠINSKA GLINA VISOKE PLASTIČNOSTI - CH	18	10-20	18-25	2-3	-	-	10^{-8}
(2) SITNI ZAGLINJENI PIJESAK DO GLINA NISKE PLASTIČNOSTI – SC/CL	18	0-1	20-27	0,2-1	-	propadanje	10^{-6}
(3) GLINA SREDNJE PLASTIČNOSTI - CI	18	2-10	20-22	0,5-1,5	-	-	10^{-8}
(4) SITNI ZAGLINJENI PIJESAK DO GLINA NISKE PLASTIČNOSTI – SC/CL	18	1-3	22-28	0,5-2	-	-	10^{-5}
(5) ZAGLINJENI PIJESAK - SC	19	0-5	29-30	4-8	-	2-9	10^{-4}
(6) ŠLJUNAK – GP-GC	20-21	0-1	32-34	15-30	-	19	10^{-2} – 10^{-3}
Zapreminska težina materijala ispod razine podzemne vode umanjuje se za težinu vode (γ'=$γ_s$-10 kN/m³).							

Figure 3.69 Soil parameters at pumping station Koševo-Vrbovci

3.25 Geotechnical investigation works for the construction of sidewalks (promenades) along the left riverside of the Crna River in Rogotin from km 0+162,96 to km 0+386,57 (2008.)

Geotechnical investigation works were carried out along the left riverside of the Crna River in Rogotin, consisting of field investigations and laboratory tests. The objective was to obtain data on the composition and characteristics of the soil base material for building foundation needs.

In accordance with the investigations carried out, it was determined that the foundation soil at the location in question consists of the following groups of materials, sorted by properties and depth of appearance: embankment, clay sandy to sand clayey and limestone.

The measured groundwater level in all wells was at a depth of 0.50 m. The following recommendations and guidelines are given on the basis of the investigations carried out: respecting the layering and characteristics of the underlying soil material and the location of the sidewalk construction, it is recommended to base the facility on reinforced concrete piles. The foundation of reinforced concrete piles should be made in substrate material (rocks – limestone). It should be counted that the upper zone of the rock (the first approx. 1.0 m) is more durable, more cracked and cavernous. Therefore, the foundation of the piles should be carried out below this more durable rock zone.

OZNAKA UZORKA	DUBINA	PRIRODNA VLAGA	SPECIFIČNA TEŽINA	ZAPREMINSKA TEŽINA		GRANULOMETRIJSKI SASTAV					GRANICE PLASTIČNOSTI		INDEKS PLASTIČNOSTI	INDEKS KONZISTENCIJE	SIMBOL
	m	w [%]	γ_s [g/cm³]	γ_d [g/cm³]	γ [g/cm³]	G [%]	S [%]	M [%]	C [%]	VDP USBR k [cm/s]	WL [%]	WP [%]	IP [%]	Ic	
BUŠOTINA / JAMA		**S-131-08-01**													
S-131-08-01-01	2,40-2,50	38,80	–	–	–	–	–	–	–	–	42,86	22,62	20,23	0,20	CI
S-131-08-01-02	7,00-12,00	33,15	–	–	–	0,7	45,1	37,4	16,8	–	44,16	22,83	21,33	–	CI/SC
BUŠOTINA / JAMA		**S-131-08-03**													
S-131-08-03-01	5,80-5,90	36,55	–	–	–	–	–	–	–	–	40,46	21,84	18,62	0,21	CI/SC
S-131-08-03-02	8,00-9,00	–	–	–	–	0,0	85,4	7,8	6,6	2,154E-03	–	–	–	–	SC

Figure 3.70 Results of physical properties of soil material

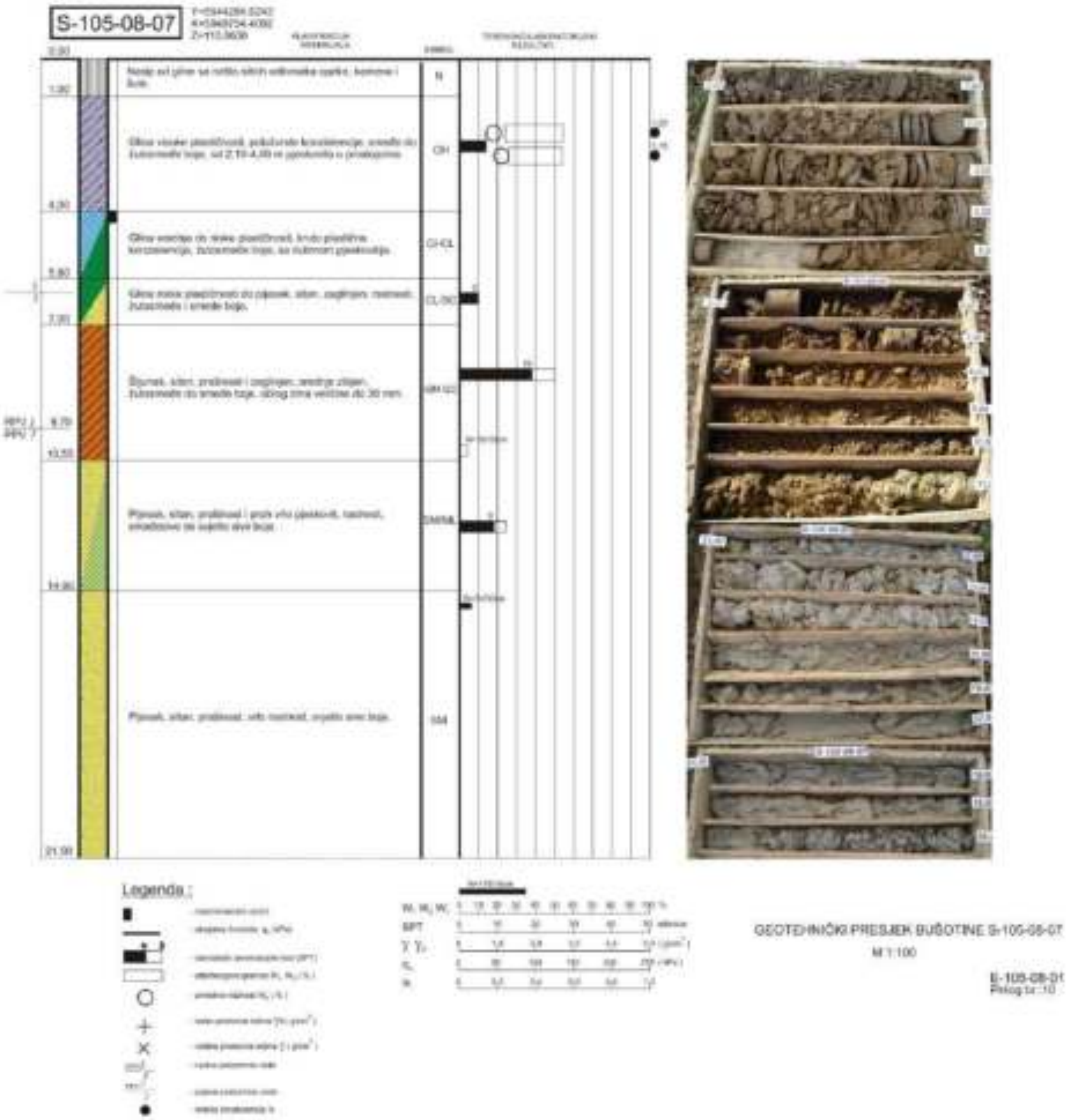


Figure 3.71 An example of borehole profile

3.26 Preliminary geotechnical investigation works for the Neretva Bridge near Opuzen (2008.)

For the purpose of conceptual design of the Neretva Bridge upstream of Opuzen, preliminary geotechnical investigation works were implemented in the area of the planned corridor. The area is structured of Quaternary deposits in which significant thickness of organogenesis-bar sediments is determined at depths below 20m. As a part of the investigation, two boreholes were constructed, each reaching approx. 50 m depth (or up to the bedrock).

According to investigations carried out for the Neretva Bridge, the following was concluded: the registered thickness of surface organogenesis-bar sediments is around 20m. Below these deposits is gravel up to depth of 40m, where the rock is registered. In the other borehole gravel is registered up to the depth of drilling, up to 37m with coring and up to 54m without coring.

Groundwater level in open boreholes measured from the surface of the terrain is -0.2m at the first and +0.5 m at the second borehole, where artesian pressure exists and groundwater level was measured in a protective column that is elevated above the level of ground. Groundwater in the gravel layer is pressurized, so in case of foundation in these deposits, attention should be taken to buoyancy. According to data from one of the boreholes, hydrostatic pressure corresponds to the water column of 20,7m + 0.5m = 21.2m.

Field conditions are represented by compressible surface deposits, large thickness of gravel that rises in the protective column due to buoyancy, the appearance of gravel (pebbles) up to 10cm in diameter and bedrock depth of more than 40 m.

Figure 3.72 An example of borehole profile

grupa i vrsta materijala	zapreminska težina γ (Kn/m^3)	kohezija c (kPa)	kut trenja ϕ (°)	modul stišljivosti M_s (MPa)	jednoosna pritisna čvrstoća q_u (kPa)	SPT N (udaraca/ 30cm)	vodo propusnost k (cm/s)
(1) POVRŠINSKA GLINA VISOKE PLASTIČNOSTI - CH	18	10-20	18-25	2-3	-	-	10^{-8}
(2) SITNI ZAGLINJENI PIJESAK DO GLINA NISKE PLASTIČNOSTI – SC/CL	18	0-1	20-27	0,2-1	-	propadanje	10^{-6}
(3) GLINA SREDNJE PLASTIČNOSTI - CI	18	2-10	20-22	0,5-1,5	-	-	10^{-8}
(4) SITNI ZAGLINJENI PIJESAK DO GLINA NISKE PLASTIČNOSTI – SC/CL	18	1-3	22-28	0,5-2	-	-	10^{-5}
(5) ZAGLINJENI PIJESAK - SC	19	0-5	29-30	4-8	-	2-9	10^{-4}
(6) ŠLJUNAK – GP-GC	20-21	0-1	32-34	15-30	-	19	10^{-2} – 10^{-3}
Zapreminska težina materijala ispod razine podzemne vode umanjuje se za težinu vode ($\gamma'=\gamma_w$-10 kN/m^3).							

Figure 3.73 Soil parameters by layers

3.27 Geotechnical investigation works for the development of a design solution for the reconstruction and renovation of concrete structures and hydromechanical equipment of the embankment at the mouth of Mala Neretva (2011.)

At the dam site at the mouth of the Mala Neretva geotechnical investigation works were carried out, consisting of investigative drilling in which sampling of undisturbed and disturbed soil samples were taken, standard penetration test (SPT) and testing of undrained shear strength of the ground by the wing probe test. Laboratory testing of samples and development of geotechnical study have been done.

The aim of the geotechnical exploration work was to collect relevant geotechnical data for purposes of preliminary design project for restoration and renovation of concrete structures and hydro-mechanical design equipment.

The top layer is fine to medium coarse sand, very loose to loose registered in all boreholes up to the depth between 5m and 9m. Below sand there is clay of medium, very little and high plasticity, mostly of medium plastic consistencies, with some concretion of iron oxides and shell remnants (5m to 24m of thickness). Under clay of medium plasticity stands a clay of high plasticity 21,5m to 26m of thickness, somewhere to medium plasticity, of rigid plastic consistency with some iron oxide concretions, containing fragments of substrate rock at the bottom of the layer at one of the boreholes. Bedrock contains limestone detected at 19,8m to 23,3 m, depending on the location.

grupe i vrsta materijala	zapreminska težina γ (Kn/m³)	efektivna kohezija c' (kPa)	efektivni kut trenja φ' (°)	modul stišljivosti M_s (MPa)	nedrenirana čvrstoća c_u (kPa)	jednoosna tlačna čvrstoća q_u (kPa)	SPT N (udaraca/30cm)	vodo propusnost k (cm/s)
(1) PIJESAK	19 - 20	0 - 2	25 - 30	2 - 6	–	–	4 - 7	10^{-3} - 10^{-5}
(2) GLINA SREDNJE PLASTIČNOSTI	19	10 - 18	20 - 28	1 - 4	10 - 50	15 – 42 (prosj 33)	3 – 10 (prosj 6)	10^{-7} - 10^{-9}
(3) GLINA VISOKE PLASTIČNOSTI	19,5	20 - 25	15 - 20	3 - 8	50 - 150	286 - 286	–	10^{-8} - 10^{-9}
STIJENA PODLOGE								
(4) VAPNENAC	Čvrsta podloga							
Zapreminska težina materijala ispod razine podzemne vode umanjuje se za težinu vode (γ=10 kN/m³).								

Figure 3.74 Soil parameters by layers

OZNAKA UZORKA	DUBINA	DIREKTNO SMICANJE				TRIAKSIJALNO SMICANJE		PRITISNA ČVRSTOĆA		STIŠLJIVOSTI TLA					VDP IZ STIŠLJIVOSTI				PROCTOROV POKUS		SIMBOL
		STANDARDNO		REVERSNO						σ_{50}	σ_{100}	σ_{200}	σ_{400}	σ_{800}	σ_{100}	σ_{200}	σ_{400}	σ_{800}			
	m	c [kPa]	ϕ [°]	c [kPa]	ϕ [°]	c [kPa]	ϕ [°]	qu [kPa]	ε [%]	Ms [MPa]					k [cm/s]				γ_{dmax} (kN/m³)	w_{opt} (%)	
BUŠOTINA		**S-006-11-01**																			
S-006-11-01-03	9,60-9,90	8.90	29.30							1.20	2.10	3.50	5.80		5.76E-08	3.94E-08	2.72E-08				CI
S-006-11-01-04	16,00-16,30							15	14.44												CI
S-006-11-01-07	21,50-21,80									1.60	3.10	2.70	5.10	8.80	1.57E-07	1.21E-07	7.72E-08	5.78E-08			CI
S-006-11-01-09	24,70-24,90	37.70	18.40					286	16.77												CI

Figure 3.75 Results of mechanical properties of soil material

OZNAKA UZORKA	DUBINA	PRIRODNA VLAGA	SPECIFIČNA TEŽINA	ZAPREMINSKA TEŽINA		GRANULOMETRIJSKI SASTAV					GRANICE PLASTIČNOSTI		INDEKS PLASTIČNOSTI	INDEKS KONZISTENCIJE	SIMBOL
	m	w [%]	γ_s [g/cm³]	γ_d [g/cm³]	γ [g/cm³]	G [%]	S [%]	M [%]	C [%]	VDP USBR k [cm/s]	W_L [%]	W_P [%]	IP [%]	Ic	
BUŠOTINA		**S-006-11-01**													
S-006-11-01-01	0,00-4,00					0.00	80.40	11.80	7.90	9.05E-04					SC
S-006-11-01-02	4,00-8,00	28.51				0.00	35.80	45.70	18.50	3.29E-07	33.91	22.51	11.40	0.47	CL
S-006-11-01-03	9,60-9,90	41.43	2.75	1.34	1.83						45.14	23.99	21.15	0.18	CI
S-006-11-01-04	16,00-16,30	41.47	2.71	1.28	1.81						48.24	25.56	22.68	0.30	CI
S-006-11-01-05	18,60-18,80	38.84									51.46	26.10	25.36	0.50	CH
S-006-11-01-06	20,80-21,00	32.69									37.02	20.82	16.20	0.27	CI
S-006-11-01-07	21,50-21,80	40.55	2.74	1.29	1.82						41.91	21.87	20.04	0.07	CI
S-006-11-01-08	23,20-23,40	38.99									43.57	24.95	18.62	0.25	CI
S-006-11-01-09	24,70-24,90	22.93	2.73	1.67	2.05						47.31	20.88	26.43	0.92	CI

Figure 3.76 Results of physical properties of soil material

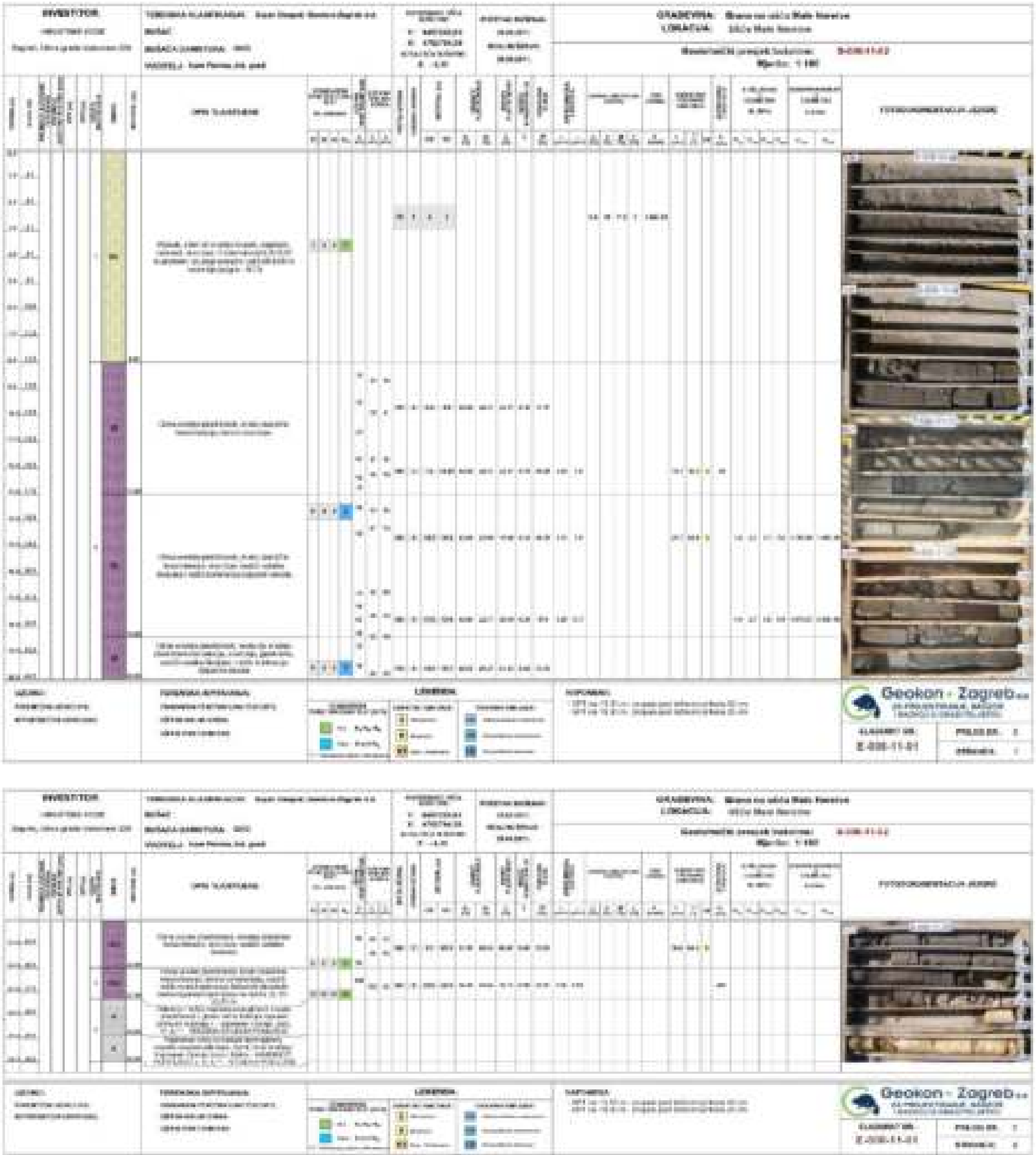


Figure 3.77 An example of results

3.28 /Study 095-12-01/ (2012.)

The documentation is incomplete and includes several borehole profiles, containing all information of laboratory and field test and measurements. One of the result examples is given below.

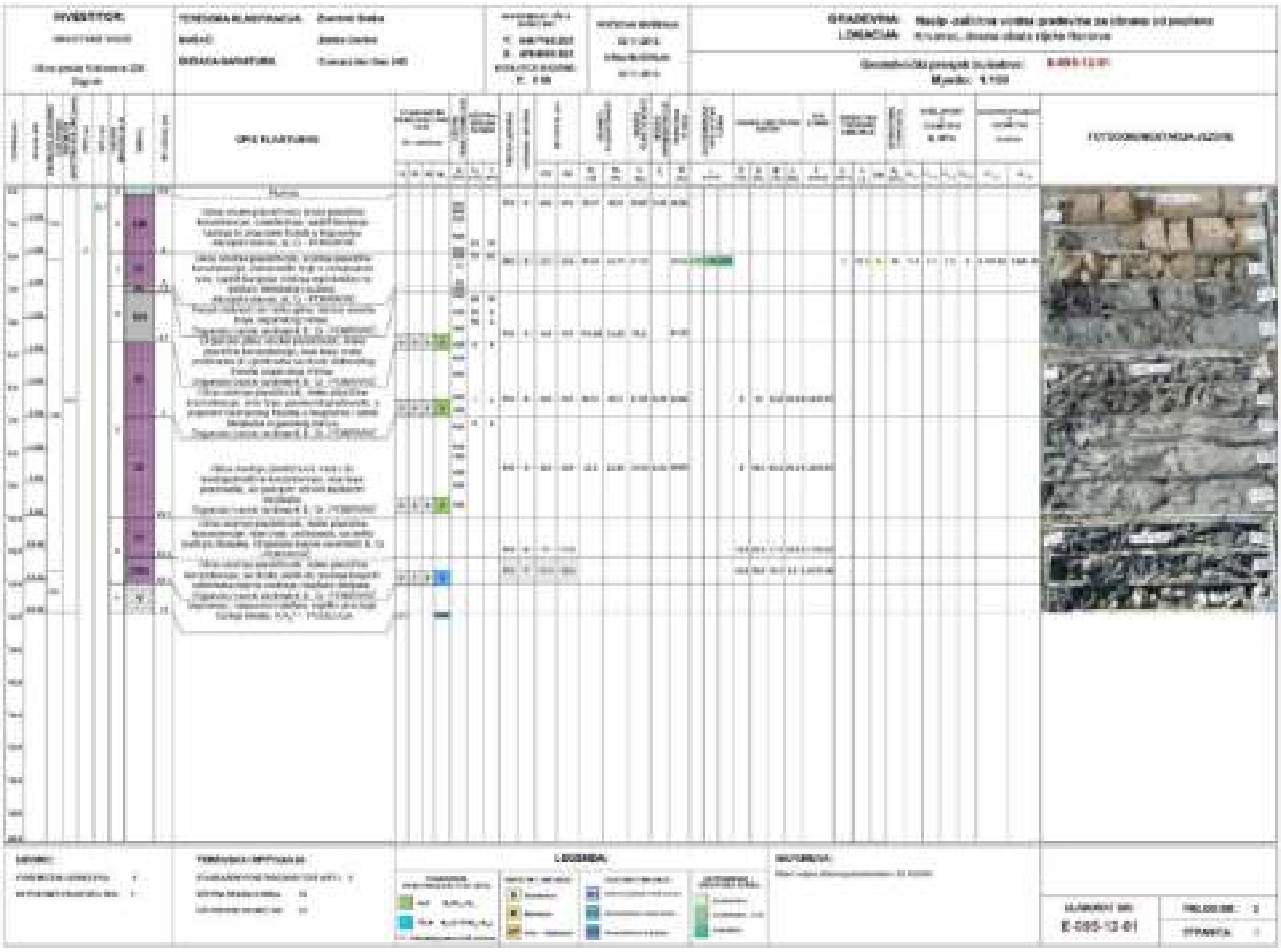


Figure 3.78 An example of borehole results

3.29 Geotechnical investigation works for renovation of the separation embankment Subsystem Mislina – Kuti (2012.)

The unfinished melioration system of the area Kuti is located in the left river bank of the Neretva River between Metković, Opuzen and Kuti Lake. The Mislina-Kuti subsystem was built extending from Hum hill to the river Mislina. On the east side, the subsystem is protected by an embankment by the Mislina River and on the west side by 3,9 km long separation embankment. Because of the poor quality of material embedded in the embankment and poor load-bearing and compressible foundation of soil, the geometry of the embankment is mostly irregular, and at the critical parts embankment started to slide and subsidence. The main goal was to collect relevant geotechnical data on the underlying soil for the need of the main design of the embankment rehabilitation.

The following works were performed: positioning of boreholes and CPTU probes, geodetic survey of the embankment route for the purpose of designing the geodetic project base, in-situ soil penetration testing (CPTU) with pore pressure dissipation measurements, geodetic surveying of boreholes and CPTU probes and laboratory tests. Investigative drilling was done including field identification and classification of drilling core as well as sampling of undisturbed and disturbed soil samples, standard penetration test (SPT), test with a pocket penetrometer and a pocket wing probe at the core, testing the undrained shear strength of the ground with a field wing probe and monitoring of occurrence and level of groundwater in wells.

It was concluded the soil at this location consists of the following groups of materials, sorted by properties and depth of appearance: humus 0,2m thick, high plasticity organic clays and dust with small amount of peat and thickness between 1m and 2,5m, high plasticity organic clays and dust with high amount of peat and thickness between 2m and 4,8m, low to middle plasticity clays and dust with thickness between 1,1m and 5,4m and the last layer consisting clayey to dusty sand, fine to medium grained and thickness between 1,2m to 3,3m. The following diagrams show soil parameters and the results of the SPT, uniaxial compressive strength pocket test penetrometer, peak and residual undrained strengths with a field wing probe and pocket wing probe of that CPT.

	TIJELO NASIPA ORGANSKE GLINE I PRAH VISOKE PLASTIČNOSTI SA NEŠTO TRESETA	*TEMELJNO TLO* ORGANSKE GLINE I PRAH VISOKE PLASTIČNOSTI SA DOSTA TRESETA	*TEMELJNO TLO* GLINE I PRAHOVI NISKE DO SREDNJE PLASTIČNOSTI	*TEMELJNO TLO* GLINOVITO-PRAŠINASTI PIJESAK
	GRUPA MATERIJALA (2.1.)	**GRUPA MATERIJALA (2.2.)**	**GRUPA MATERIJALA (3)**	**GRUPA MATERIJALA (4)**
Zapreminska težina γ (kN/m³)	15 - 17	9 - 15	18 - 19	19 - 20
Indeks konzistencije Ic (-)	0,8 – 1,38 (prosječno 1,0)	0,1 – 0,8 (prosječno 0,48)	0,02 – 0,28 (prosječno 0,15)	–
Indeks plastičnosti Ip (%)	24 – 60 (prosječno 47)	39 – 445 (prosječno 115)	9 – 24 (prosječno 16)	6 – 13 (prosječno 9)
Prirodna vlaga w (%)	25 – 68 (prosječno 45)	54 – 485 (prosječno 171)	35 – 76 (prosječno 45)	34 – 46 (prosječno 39)
Efektivna kohezija c' (kPa)	Lab dir smic=20 – 25 Lab triaxCU=14	Lab triaxCU=8	10 - 15*	0 - 2
Efektivni kut unutrašnjeg trenja φ' (°)	Lab dir smic=25 – 27 Lab triaxCU=35	Lab triaxCU=36	20 - 25*	CPT=30 - 40
Nedrenirana čvrstoća Cu (kPa)	Lab (q_u/2) =30 – 50 CPT=10 - 60	Lab (q_u/2)=2 – 12 CPT=5 – 20 Dž.i Ter.k.s=10 -33 Lab triaxUU=12 - 69	CPT=10 - 25 Dž.i Ter.k.s=7 - 38	CPT=20 - 120 Dž.i Ter.k.s=8 - 42
Jednoosna tlačna čvrstoća q_u (MPa)	Lab=62 – 107 Dž.pen=50 – 450	Lab=3 – 24 Dž.pen=50 - <50	Dž.pen=<50	–
SPT N (ud/30cm)	4 - 6	0	0 – 5 (prosjek 0,5)	1 – 11 (prosjek 6)
Modul stišljivosti Ms (MPa)	Lab Edometar σ_{50}= 3,0–3,5 σ_{100}= 2,8–3,5 σ_{200}= 3,4-3,8 σ_{400}= 4,1-5,1 CPT=2 - 10	Lab Edometar σ_{50}= 0,2-0,5 σ_{100}= 0,4-0,7 σ_{200}= 0,7-1,0 σ_{400}= 1,7-2,4 CPT=1 - 4	CPT=1 - 5	CPT=5 - 40
Vodopropusnost k (cm/s)	troosna ćelija=10^{-7} - 10^{-8} edometar=10^{-7} - 10^{-8}	edometar=10^{-9} - 10^{-8}	10^{-8} - 10^{-7}	prema USBR-u 10^{-3} - 10^{-8} (prosječno 10^{-4})
Sadržaj organske materije (%)	13 - 31	8 - 72	4,66	8,83

Figure 3.79 Soil parameters by layers

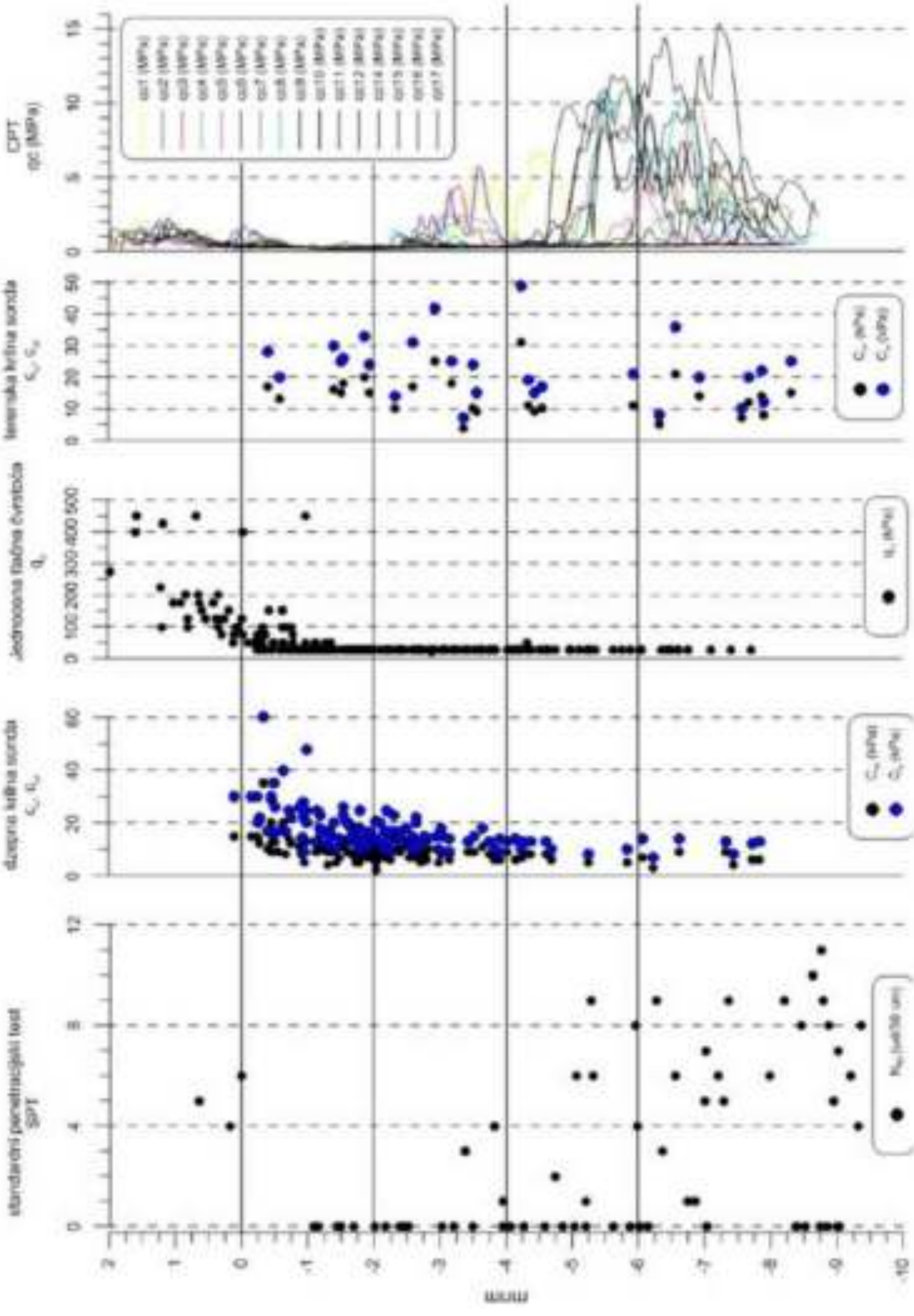


Figure 3.80 Test results of field measurements

Figure 3.81 An example of borehole results

3.30 Geotechnical investigation works for renovation of the Neretva River bank slopes at six critical locations from the mouth to the town of Metković (2013.)

After the two large water waves in January and December 2010, significant damage to the river bank of Neretva River was observed. After a detailed tour by boat and inspection by the diver, a series of instabilities were recorded on the left and right bank from the mouth to the town of Metković, which are divided into the following six critical zones / locations:

- The first zone of instability (P-0 to P-1) includes rock groins, left and right banks from the mouth of the Neretva upstream, approximately 280 m in length
- The second instability zone (P-5 to P-15) of approx. 2500m length includes the left and right bank on the part of the Neretva River from Galičak Hill to Rogotin Bridge
- The third instability zone (P-81A to P-85) includes a stretch of the right bank of the Neretva River, approximately 1300 m long, between the settlements Krvavac and Kula Norinska
- The fourth instability zone (P-86 to P-91) includes the left bank of the Neretva River near the settlement Kula Norinska, in the length of approx. 540 m
- The fifth instability zone (P-91 to P-98) includes both banks of the Neretva River, approx. 1800m long, from the Norin watercourse to the Duvrat channel
- Sixth instability zone (P-100 to P-102) includes the right bank of the Neretva River from the Duvrat Canal to the Jerkovac Canal, approximately 530 m long.

Geotechnical investigation works were carried out, which include the following research segments: positioning of boreholes and CPTU probes in consultation with the investor representative, in-situ soil penetration tester (CPTU) with pore pressure dissipation measurements, laboratory tests and development of geotechnical study. Test drilling includes field identification and classification of drilling core, sampling of undisturbed and disturbed soil samples, standard penetration test (SPT), penetration test with a pocket penetrometer and a pocket wing probe at the core and monitoring of occurrence and level of groundwater in wells. The aim of the work was to collect relevant geotechnical data on the underlying soil for the purpose of designing a rehabilitation project for critical locations of the Neretva river bank.

The following material groups were identified: humus 20cm thick, embankment between 0,3m and 2,3m of thickness containing of gravel, crushed stone, clay, sand and dust; low to high plasticity surface clayey-dusty materials appearing between 1,1m and 3,9m of depth; medium to high plasticity clay between 0,3m and 1,6m of thickness; clay clayey-dusty sandy materials of low to medium plasticity approx. 6,7m thick under which stands the last layer consisting sand.

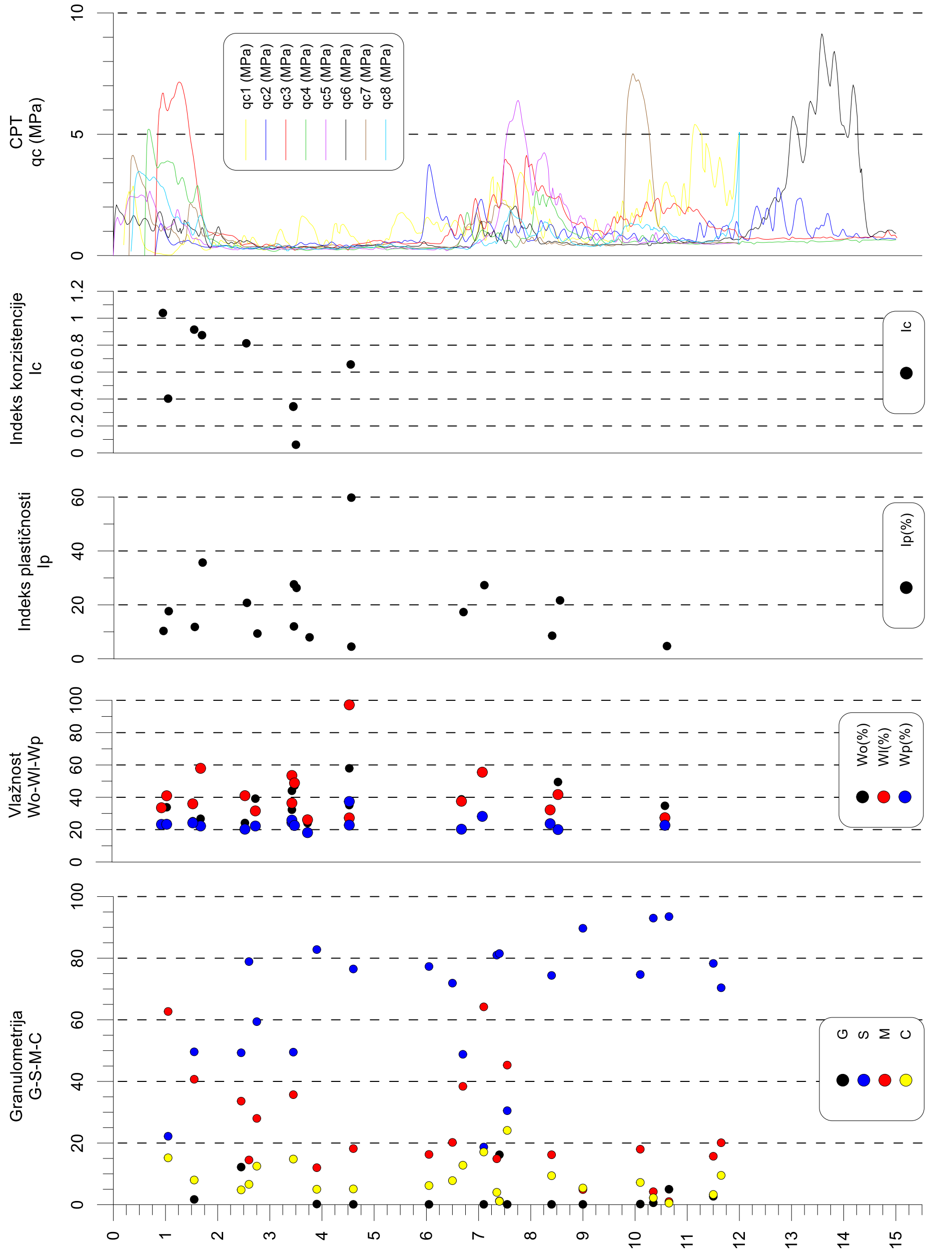


Figure 3.82 The results of laboratory testing and CPTU sounding

	POVRŠINSKI GLINENO-PRAŠINASTI MATERIJALI NISKE DO VISOKE PLASTIČNOSTI	GLINA SREDNJE DO VISOKE PLASTIČNOSTI	PJESKOVITI GLINENO-PRAŠINASTI MATERIJALI NISKE DO SREDNJE PLASTIČNOSTI	ORGANSKA GLINA I PRAH SREDNJE DO VISOKE PLASTIČNOSTI I TRESET	PIJESAK
GRUPA MAT.	(3)	(4)	(5)	(6)	(7)
Zapreminska težina γ (kN/m^3)	19	19	19 - 20	14 - 18	20
Efektivna kohezija c' (kPa)	10 - 25	15 -20	5 - 10	5 - 10	0 - 3
Efektivni kut unutrašnjeg trenja ϕ' (°)	15 - 25	15 - 25	20 - 25	10 - 15	28 - 33
Nedrenirana čvrstoća Cu (kPa)	40 - 90	10 - 30	15 - 35	15 - 25	--
Modul stišljivosti Ms (MPa)	4 - 10	0,5 – 2	0,5 - 3	0,5 - 3	3 - 10
Vodopropusnost k (cm/s)	10^{-7} - 10^{-9}	10^{-8} - 10^{-9}	10^{-5} - 10^{-7}	10^{-6} - 10^{-8}	10^{-2} - 10^{-4}
SPT N (ud/30cm)	8 - 12	0 (propadanje pribora)	0 - 2	0 i 2	1 – 15 (prosj 5)

Figure 3.83 Soil parameters by layers

OZNAKA UZORKA	DUBINA	PRIRODNA VLAGA	SPECIFIČNA TEŽINA	ZAPREMINSKA TEŽINA		GRANULOMETRIJSKI SASTAV						GRANICE PLASTIČNOSTI		INDEKS PLASTIČNOSTI	INDEKS KONZISTENCIJE	SIMBOL
	m	w [%]	γ_s [g/cm^3]	γ_d [g/cm^3]	γ [g/cm^3]	G [%]	S [%]	M [%]	C [%]	M + C [%]	VDP USBR k [cm/s]	w_L [%]	w_P [%]	IP [%]	Ic	
BUŠOTINA		**S-030-13-01**														
S-030-13-01-01	0,90-1,00	22.83										33.54	23.23	10.31	1.04	ML
S-030-13-01-02	2,00-3,20						78.90	14.50	6.60		4.39E-04					SM
S-030-13-01-03	3,00-6,20					0.10	76.50	18.20	5.10		2.96E-04					SM
S-030-13-01-04	6,20-6,80						71.90	20.20	7.80		1.29E-05					SM
S-030-13-01-05	7,00-11,00					0.10	89.70	4.90	5.40		1.59E-02					SM

Figure 3.84 Results of physical properties of soil material

OZNAKA UZORKA	DUBINA	DIREKTNO SMICANJE				TRIAKSIJALNO SMICANJE		PRITISNA ČVRSTOĆA		STIŠLJIVOSTI TLA				VDP IZ STIŠLJIVOSTI			PROCTOROV POKUS		SIMBOL
		STANDARDNO		REVERSNO						σ_{50}	σ_{100}	σ_{200}	σ_{400}	σ_{100}	σ_{200}	σ_{400}			
	m	c [kPa]	ϕ [°]	c [kPa]	ϕ [°]	c [kPa]	ϕ [°]	qu [kPa]	ε [%]	Ms [MPa]				k [cm/s]			γ_{dmax} (kN/m^3)	w_{opt} (%)	
BUŠOTINA		**S-030-13-06**																	
S-030-13-06-02	3,60-3,90	16.10	32.70					70	9.24	1.90	3.40	3.90	8.40	3.5E-08	2.7E-08	2.2E-08			CL

Figure 3.85 Results of mechanical properties of soil material

Figure 3.86 An example of borehole results

3.31 Geotechnical investigation works for project of Mala Neretva banks arrangement (2013.)

For the purpose of designing a project for the arrangement of the banks of the Neretva River on the stretch from the constitution in Opuzen (km 9 + 850,47) to the Crepina watercourse on the right bank (km 5 + 592,40) and the pumping station Prague on the left bank (km 5 + 024, 47) geotechnical investigation works were carried out. It consisted of boreholes and CPTU probes positioning, in-situ soil penetration test (CPTU) with pore pressure dissipation measurements, engineering-geological works, professional geotechnical supervision of works, laboratory testing of soil samples and preparation of geotechnical study with synthesis of conducted exploration works. Investigative drilling included field identification, AC classification and geological determination of the drilling core, sampling of soil samples, standard penetration test (SPT), penetration test with a pocket penetrometer and a pocket wing probe at the core, monitoring of occurrence and level of groundwater in wells during works. The aim was to collect relevant data on the characteristics of the underlying soil for the purpose of designing the main and the execution design.

The following groups of materials were identified: embankment consisting a mixture of gravel and crushed stone, with clay, sand and dust, reaching to the depth between of 1m and 2,4m; low to medium plasticity clayey-dusty sand materials appearing between 1m and 7,4m of depth depending on the location and the last layer consisting clayed sand, mainly fine grained appearing at the depth between 3,7m and 7,4m. Thickness of sand was not registered because the drilling was completed inside of it.

Based on the results of fieldwork, CPTU sounding and laboratory testing, the range of soil parameter values is provided as a framework for further design purposes (Figure 86).

	PJESKOVITI GLINENO-PRAŠINASTI MATERIJALI NISKE DO SREDNJE PLASTIČNOSTI *organogeno-barski sedimenti kvartar, b_1Q_2* - ***POKRIVAČ***	PIJESAK *organogeno-barski sedimenti kvartar, b_1Q_2* - ***POKRIVAČ***
	GRUPA MATERIJALA (2)	**GRUPA MATERIJALA (3)**
Zapreminska težina γ (kN/m³)	19*	20*
Indeks konzistencije Ic (-)	0,19 – 0,25 (prosječno 0,21)	–
Indeks plastičnosti Ip (%)	9 – 29 (prosječno 16)	–
Prirodna vlaga w (%)	30 – 72 (prosječno 41)	–
Efektivna kohezija c' (kPa)	5 – 15*	0 – 2*
Efektivni kut unutrašnjeg trenja φ' (°)	15 – 25*	30 – 38* CPT= 35 - 45
Nedrenirana čvrstoća Cu (kPa)	D2.k.s= 7 - 19 CPT= 12 - 80	–
Jednoosna tlačna čvrstoća q_u (MPa)	D2.pen= <50	–
SPT N (ud/30cm)	0 (propadanje pribora)	1 – 20 (prosječno 9)
Modul stišljivosti Ms (MPa)	CPT=0,5 - 4	CPT=3 - 50
Vodopropusnost k (cm/s)	prema USBR-u 10^{-4} - 10^{-8} (prosječno 10^{-5})	prema USBR-u 10^{-3} - 10^{-6} (prosječno 10^{-3})
Sadržaj organskih tvari (%)	0,80 – 3,75**	12,7***

Figure 3.87 The range of soil parameter values for further design purposes

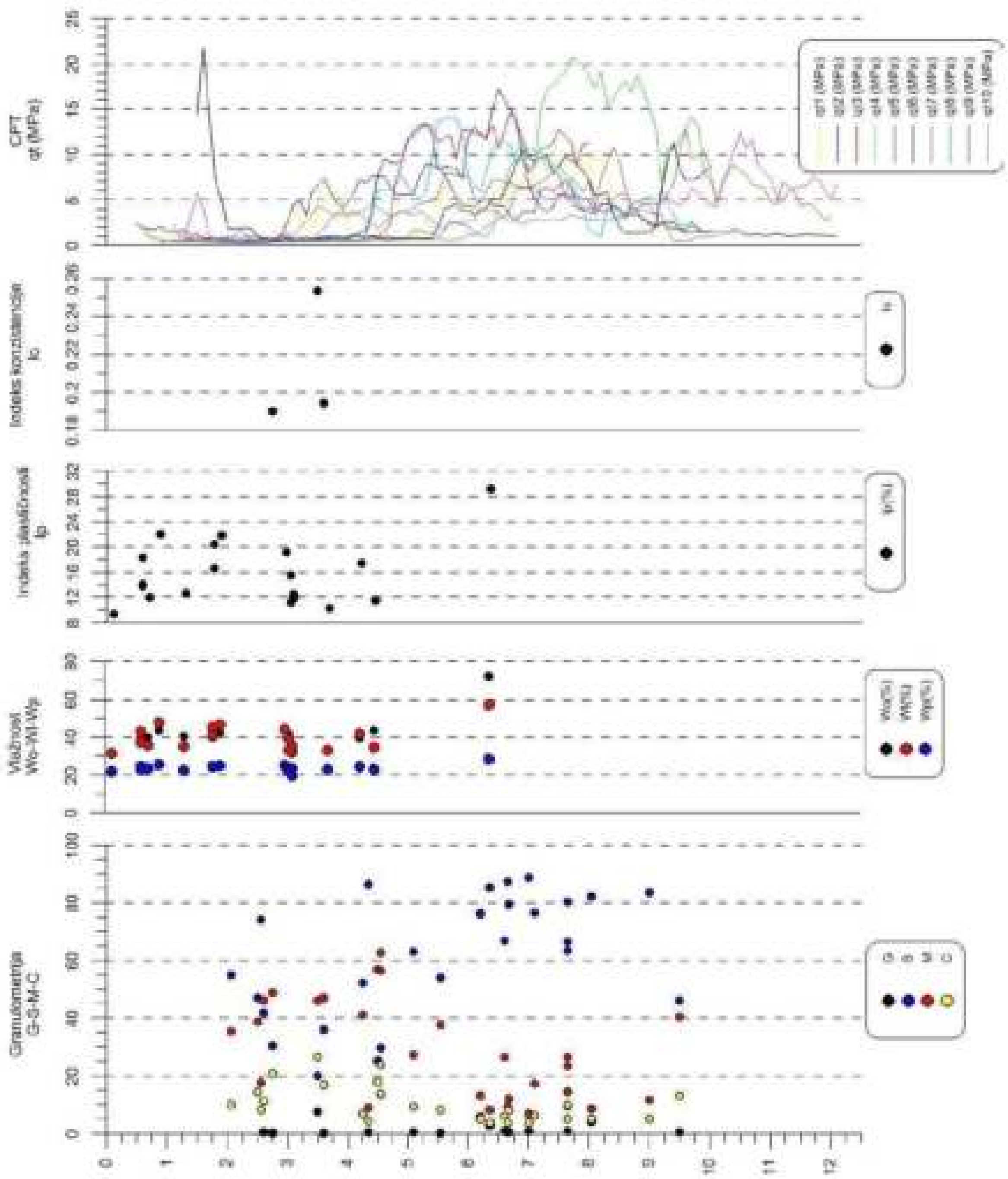


Figure 3.88 The results of laboratory testing and CPTU sounding

OZNAKA UZORKA	DUBINA	PRIRODNA VLAGA	SPECIFIČNA TEŽINA	ZAPREMINSKA TEŽINA		GRANULOMETRIJSKI SASTAV						GRANICE PLASTIČNOSTI		INDEKS PLASTIČNOSTI	INDEKS KONZISTENCIJE	SIMBOL
	m	w [%]	γ_s [g/cm³]	γ_d [g/cm³]	γ [g/cm³]	G [%]	S [%]	M [%]	C [%]	M + C [%]	k [cm/s]	wL [%]	wP [%]	IP [%]	Ic	
BUŠOTINA		**S-048-13-01**														
S-048-13-01-01	2,40-2,60	37,83					46,90	38,70	14,40		1,34E-06	36,93	23,13	13,80		CI/SC
S-048-13-01-02	4,20-4,30						52,30	41,00	6,80		6,38E-06					CI/SC
S-048-13-01-04	6,35-7,00					0,70	79,30	12,10	7,90		5,51E-04					SC

Figure 3.89 Results of physical properties of soil material

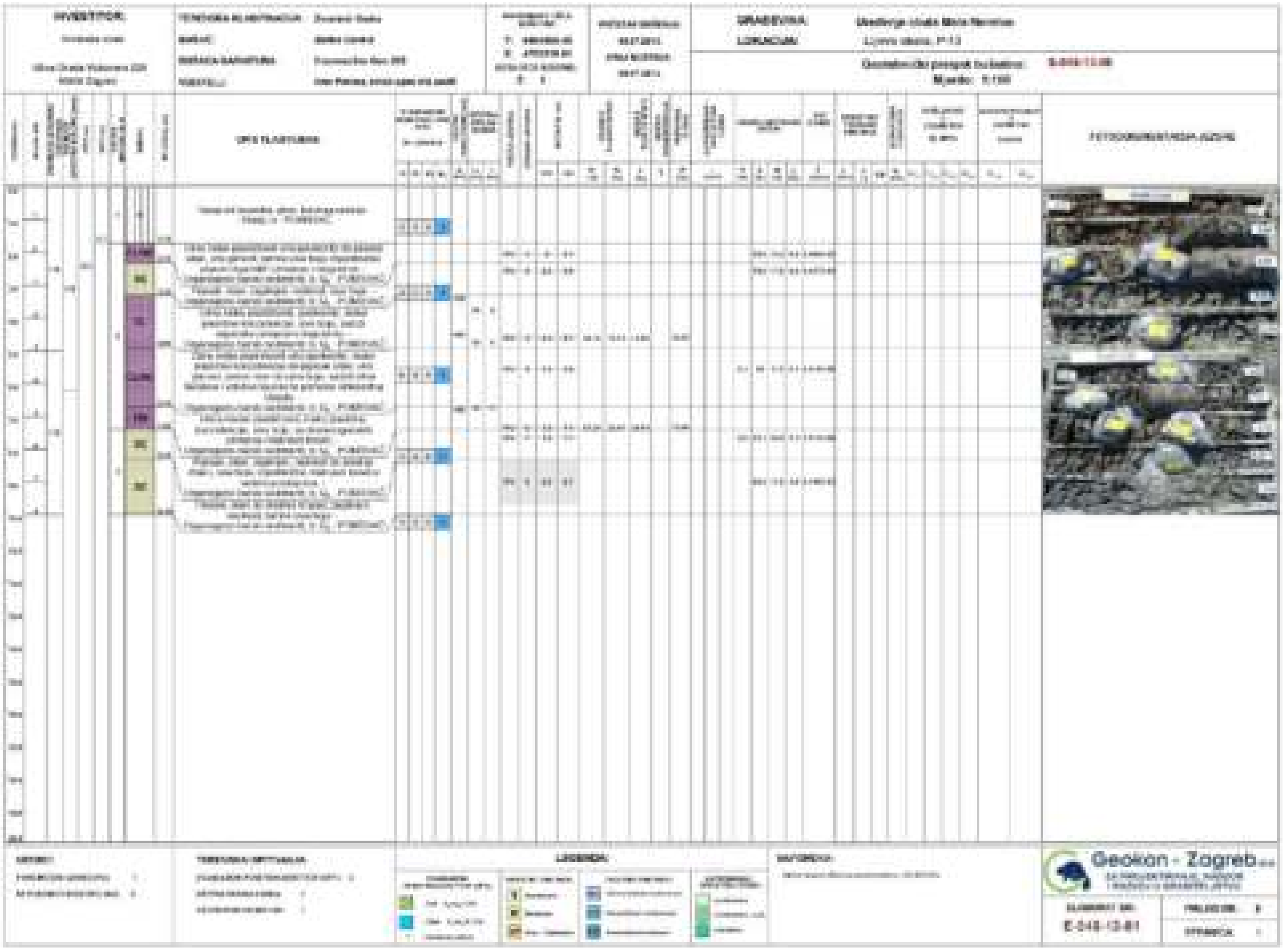


Figure 3.90 An example of borehole results

3.32 Geotechnical investigation works for siphon below Mala Neretva at the pumping station Prag (Vidrice) (2013.)

Large portion of the area Vidrice was occupied by a swamp by the mid-1970s and a smaller portion covered with agricultural land on elevated terrain. Today, this area of 500ha is partially protected from floods by embankment and lateral channel on the east and south sides, as well as embankment on its western and northern edges. Relatively low terrain gradients, the occurrence of saline sources and high groundwater levels require continuous pumping to drain excess water and protect against salinization. For this purpose, pumping station Prag was built in 1975.

In the autumn-winter mode of the pumping station, up to 7,5m³/s of water is transferred to the Mala Neretva out of Vidrice area. In the summer mode evacuation of saline waters from the Vidrice area should, in accordance with the design from 1972, run through a siphon below the Mala Neretva River into the Glog Lake system and continue across the Modrič pumping station into the sea. The siphon below the Mala Neretva was never built, so the salty water is discharged directly into the Mala Neretva river basin, precisely during the period when Mala Neretva represents a reservoir of fresh water for irrigation. In order to ensure required water quality downstream of the Mala Neretva River, it was necessary to construct the intended siphon below the Mala Neretva River and its associated pipeline. The siphon and pipeline would have been used in summer mode to evacuate saline water from the pumping station Prag to the drainage system of the Glog area.

Geotechnical investigation work consists investigative drilling as part of the field identification and classification of the drilling core, soil sampling, standard penetration test (SPT), pocket penetrometer and pocket-core probe drilling test and monitoring occurrences and levels of groundwater in wells during exploration. It also consists testing with light penetration “Häfeli” probe in the Mala Neretva riverbed, expert geotechnical supervision of works, laboratory testing of soil samples and preparation of geotechnical study with synthesis of conducted research works.

The following material groups were identified: humus 30cm thick, embankment 0,4m of thickness containing of crushed stone mixed with clay; medium to high plasticity surface clay appearing up to 0,9m and 2m of depth; clayey-dusty sand below the layer of clay.

OZNAKA UZORKA	DUBINA	PRIRODNA VLAGA	SPECIFIČNA TEŽINA	ZAPREMINSKA TEŽINA		GRANULOMETRIJSKI SASTAV						GRANICE PLASTIČNOSTI		INDEKS PLASTIČNOSTI	INDEKS KONZISTENCIJE	SIMBOL
	m	w [%]	ρ_s [g/cm^3]	ρ_d [g/cm^3]	ρ [g/cm^3]	G [%]	S [%]	M [%]	C [%]	M + C [%]	k [cm/s]	w_L [%]	w_P [%]	I_P [%]	I_c	
BUŠOTINA		**S-049-13-01**														
S-049-13-01-01	1,70-1,85	37,59					3,00	58,40	38,70			68,79	24,95	43,84	0,71	CH
S-049-13-01-02	2,00-5,60					0,40	55,70	30,80	13,10		4,90E-06	32,97	22,03	10,96		SC/CL
S-049-13-01-03	6,60-8,10					0,10	77,80	14,80	7,30		3,77E-04					SC/CL
S-049-13-01-04	8,10-12,00	32,35				0,50	60,70	25,10	13,70		1,50E-06	28,58	23,52	5,05		SM/ML
BUŠOTINA		**S-049-13-02**														
S-049-13-02-01	0,60-0,70	32,52					39,40	41,10	19,00			36,22	18,97	17,25	0,21	CI
S-049-13-02-02	2,40-2,80					0,30	36,70	46,10	16,90		6,67E-07	30,74	24,21	6,53		ML/SM
S-049-13-02-03	3,30-3,80						88,80	7,00	4,20		2,79E-03					SM/ML
S-049-13-02-04	4,40-4,80	38,99										28,46	23,76	4,70		ML/SM
S-049-13-02-05	6,30-7,70					0,10	86,50	8,90	4,40		2,29E-03					SM/ML
S-049-13-02-06	7,90-8,00	37,24				0,70	70,30	21,90	7,20		1,56E-04	30,07	21,13	8,94		SC/CL
S-049-13-02-07	9,40-9,80					0,40	68,50	23,90	7,20		1,59E-04					SM/ML
S-049-13-02-08	11,40-11,50	38,64					32,60	51,20	16,30		7,80E-07	35,06	26,17	8,89		ML/SM

Figure 3.91 Results of mechanical properties of soil material

	POVRŠINSKA GLINA SREDNJE DO VISOKE PLASTIČNOSTI	GLINOVITO-PRAŠINASTI PIJESAK
	GRUPA MATERIJALA (3)	GRUPA MATERIJALA (4)
Zapreminska težina □(kN/m³)	18*	19 - 20*
Indeks konzistencije Ic (-)	0,21 – 0,76 (prosječno 0,46)	–
Indeks plastičnosti Ip (%)	17 - 44 (prosječno 30,5)	5 - 11 (prosječno 7,5)
Prirodna vlaga w (%)	32 – 38 (prosječno 35)	37 – 52 (prosječno 42)
Efektivna kohezija c' (kPa)	15 – 25*	0 – 2*
Efektivni kut unutrašnjeg trenja □' (°)	10 – 20*	28 – 34*
Nedrenirana čvrstoća Cu (kPa)	D2.k.s= 14 - 18	D2.k.s= 8 - 15
Jednoosna tlačna čvrstoća q_u (MPa)	D2.pen= <50	D2.pen= <50
SPT N (ud/30cm)	–	0 – 11 (prosječno 3)
Modul stišljivosti Ms (MPa)	3 - 7*	0,5 - 4*
Vodopropusnost k (cm/s)	10^{-7} - 10^{-9}*	prema USBR-u = 10^{-3} - 10^{-7} (prosječno 10^{-4})
Sadržaj organskih tvari (%)	–	19,8**

Figure 3.92 Soil parameters by layers

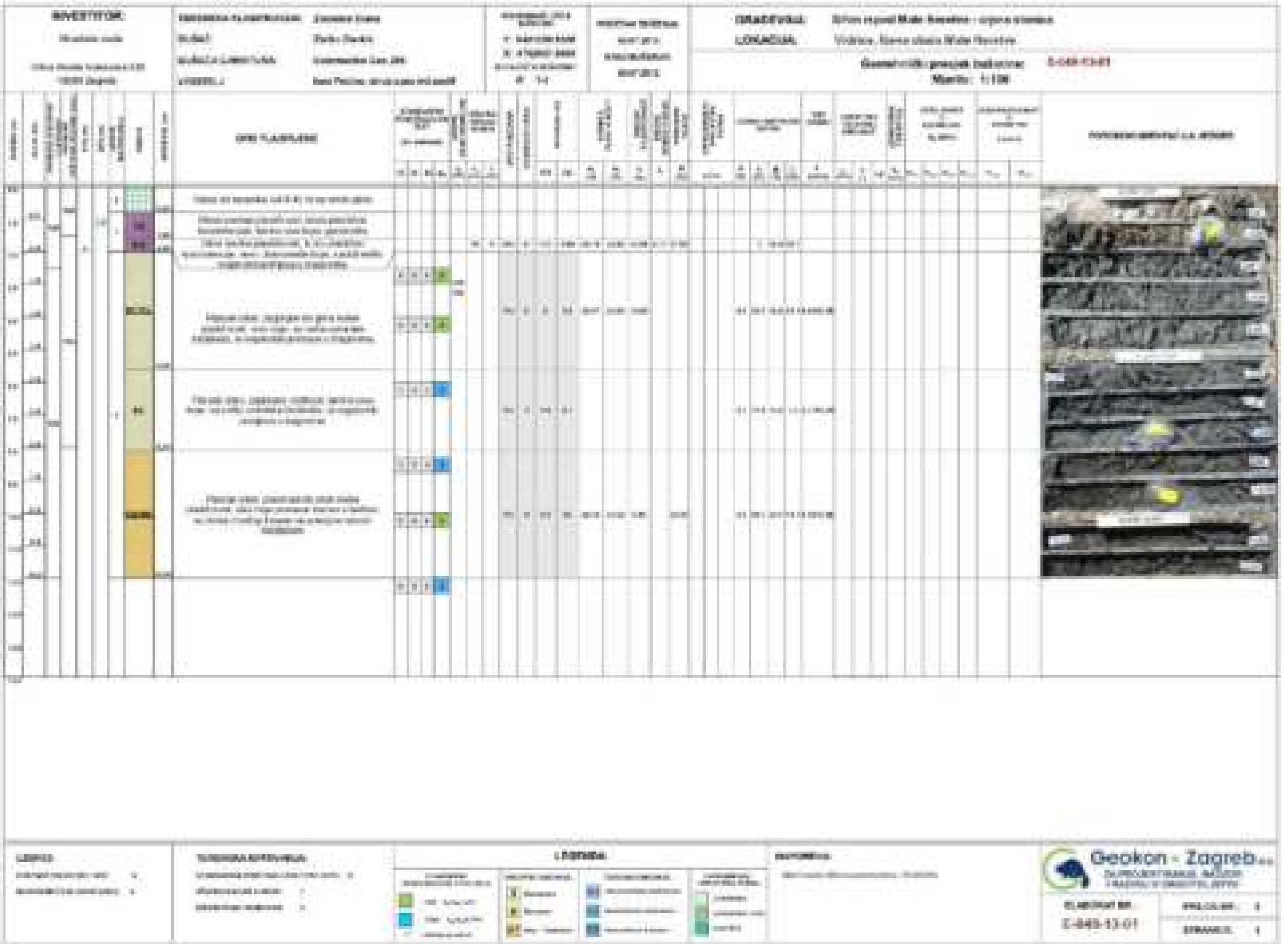


Figure 3.93 An example of borehole results

3.33 Geotechnical study for irrigation system - Subsystem Opuzen (Phases A and J) (2013.)

For the purpose of designing a geotechnical study, geotechnical, geological and geophysical investigation works and laboratory tests were done for the Opuzen pumping station (phase A), mobile partition at the Neretva River (phase J) and microaccumulation Lađište (phase A). The basic purpose was to determine the mechanical characteristics of materials (strength parameters in undrained and drained condition, soil deformability) and permeability characteristics in order to determine the optimal way of foundation and protection of the pumping station construction pit of mobile partition on the Neretva River, improvements in mechanical characteristics of foundation soil and acceleration of facility consolidation, as well as geological and geophysical analysis of the future microaccumulation area.

Geotechnical work has determined the soil profile and investigation works have confirmed the works carried out in 2008 used for analyses. Recommendations were given for the design of the construction pit protection and foundation of objects. It was concluded that it is not possible to resolve the foundation of the objects and soil improvement before defining clear criteria for total and differential settlements. Given the adverse geotechnical conditions at the site, as part of the design of main and design project was required to anticipate the appropriate geotechnical deep foundation projects and construction pit protection projects.

At Opuzen pumping station and mobile partition at the Neretva River borehole drilling was performed including static penetration test (SPT) with measuring pore pressure (CPTU), field USCS core classification and laboratory testing on disturbed and undisturbed soil samples. Geophysical tests using shallow refractive seismic on two profiles and geological mapping was performed on microaccumulation Lađište area.

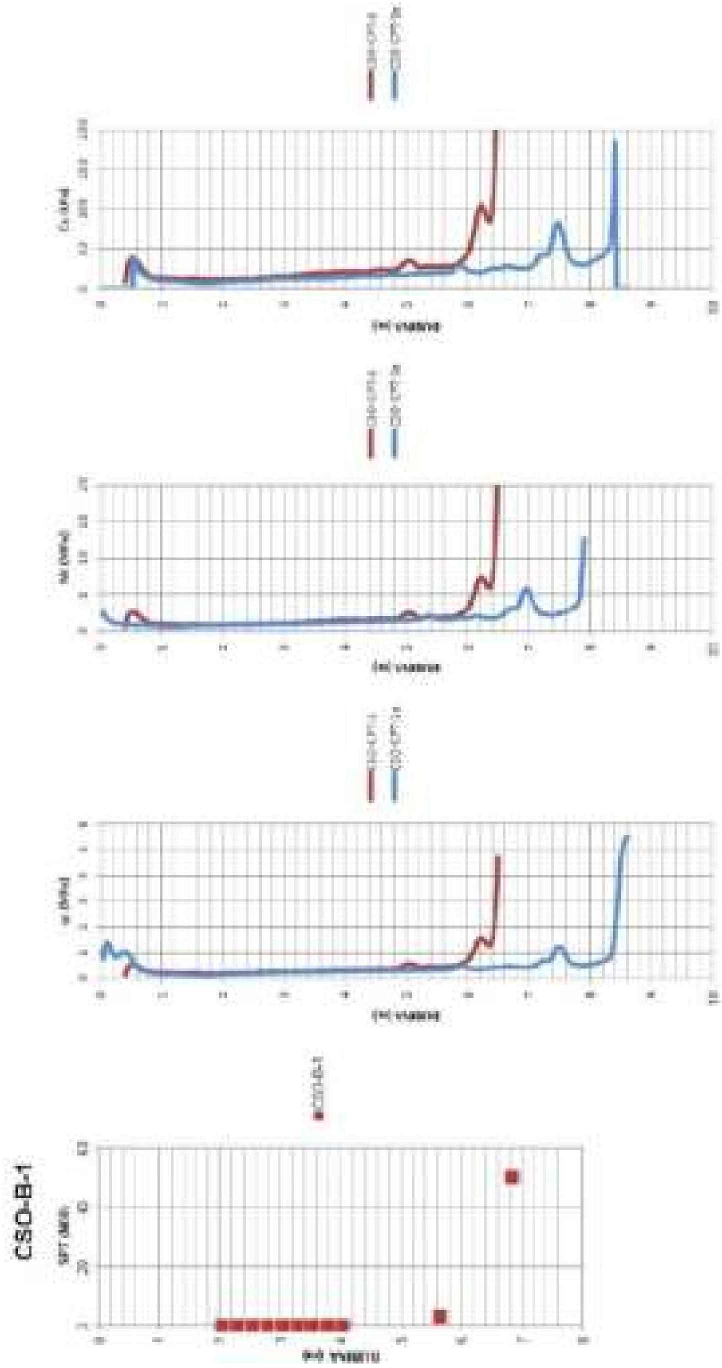


Figure 3.94 An example of SPT, q_C, M_Z, and Cu diagrams

Bušotina CSO-B-1				
Dubina ispitivanja (m)	G (%)	S (%)	M (%)	C (%)
1,40-2,00	0	9	74	17
3,40-3,60	0	8	73	19
4,50-5,00	0	19	66	15
5,70-5,90	19	42	30	9

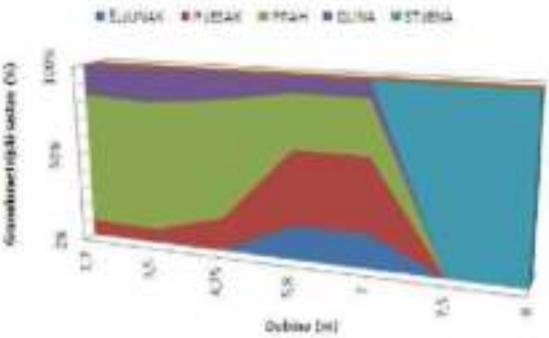


Figure 3.95 The change in grain-size composition by depth

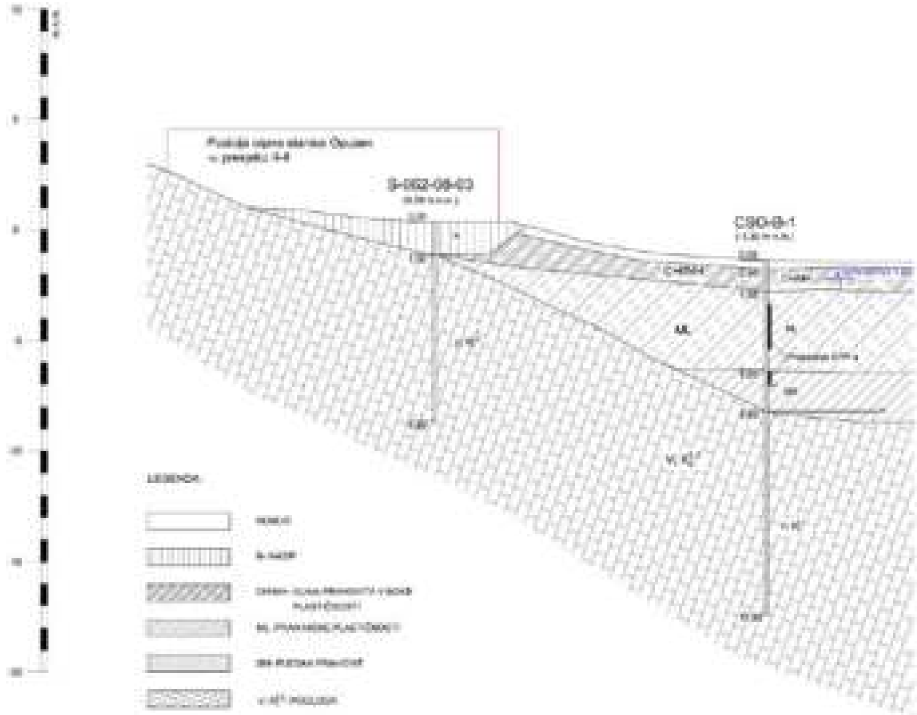


Figure 3.96 Geotechnical profile

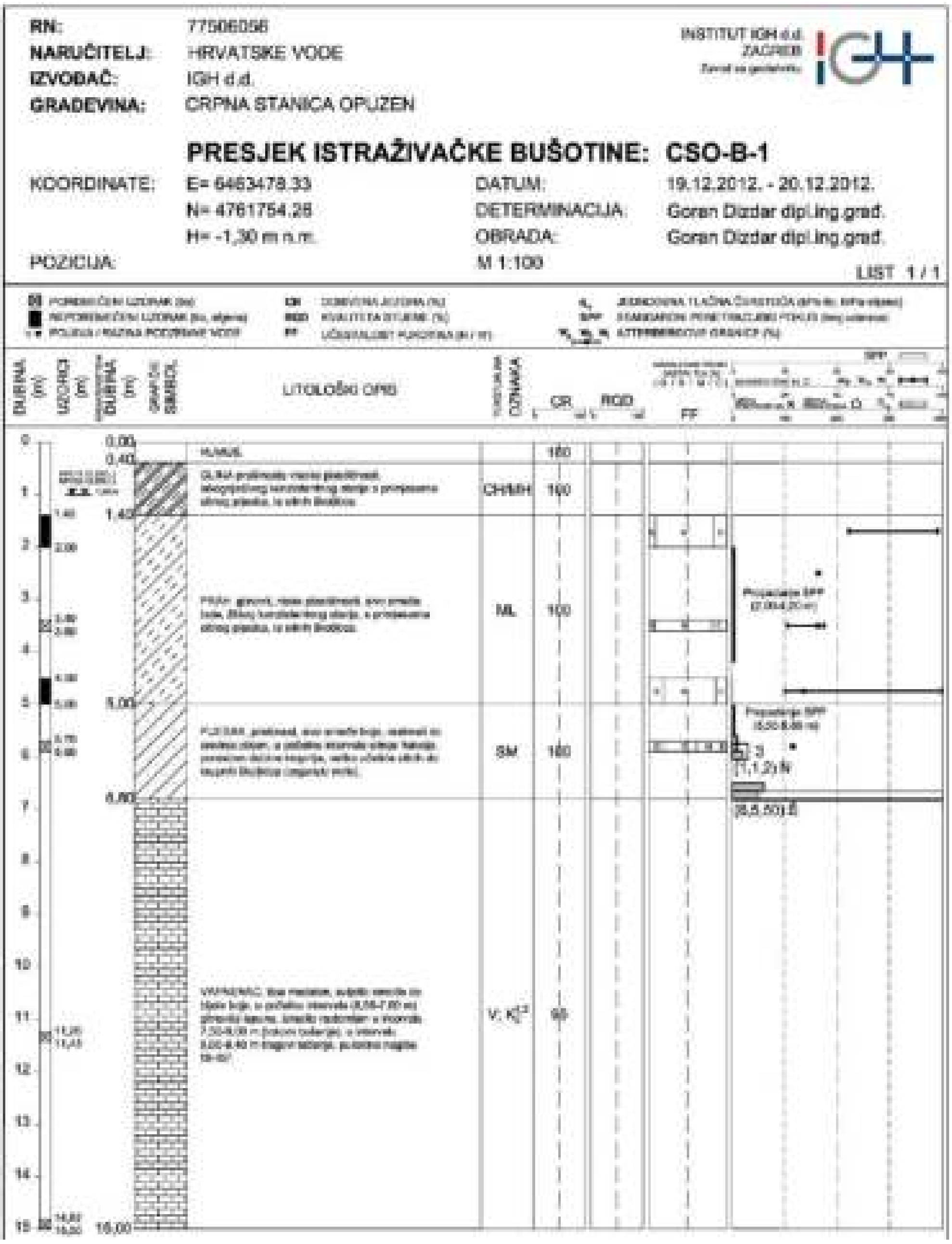


Figure 3.97 An example of borehole profile

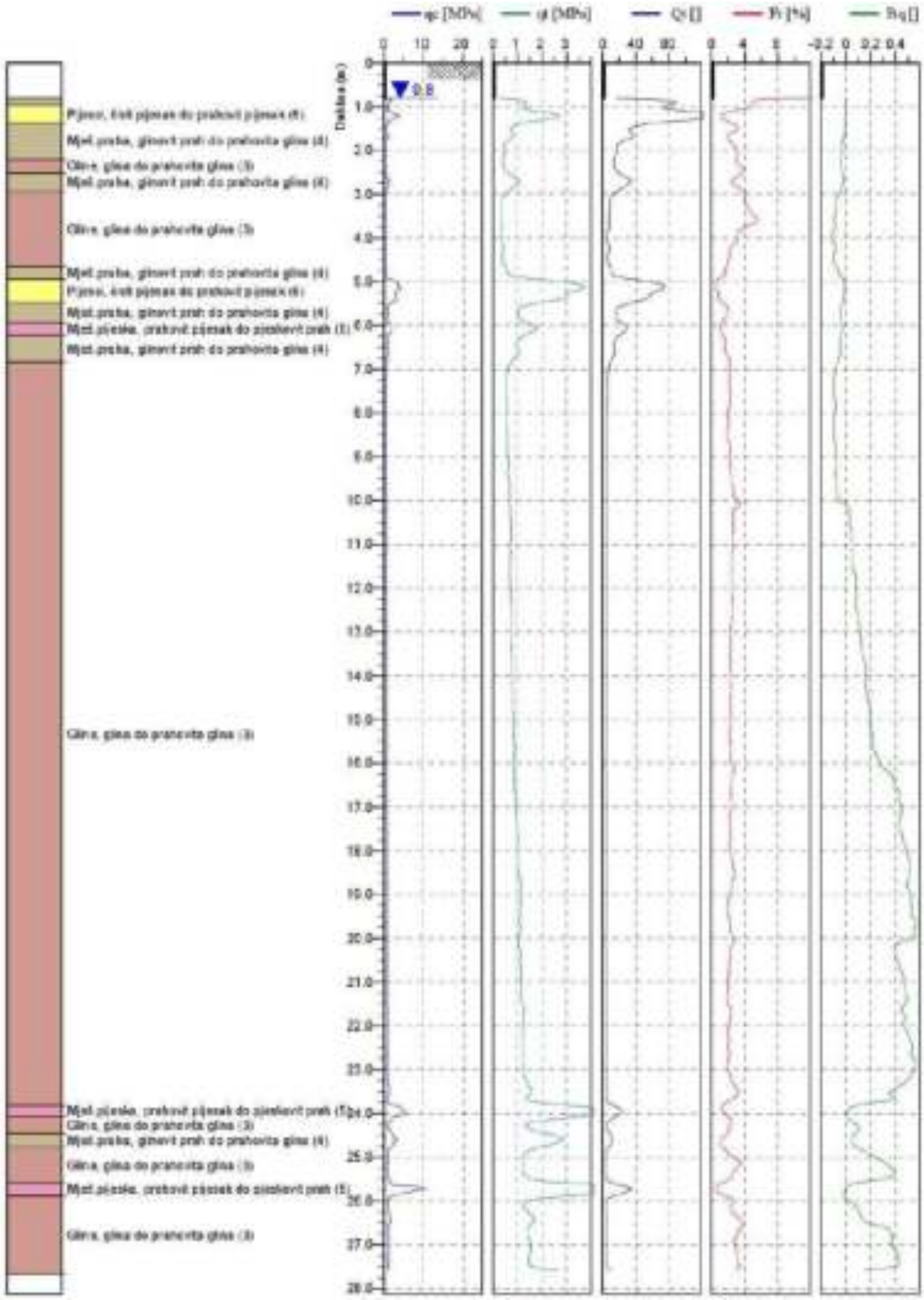


Figure 3.98 Classification of soil type according to the method of Robertson (1990)

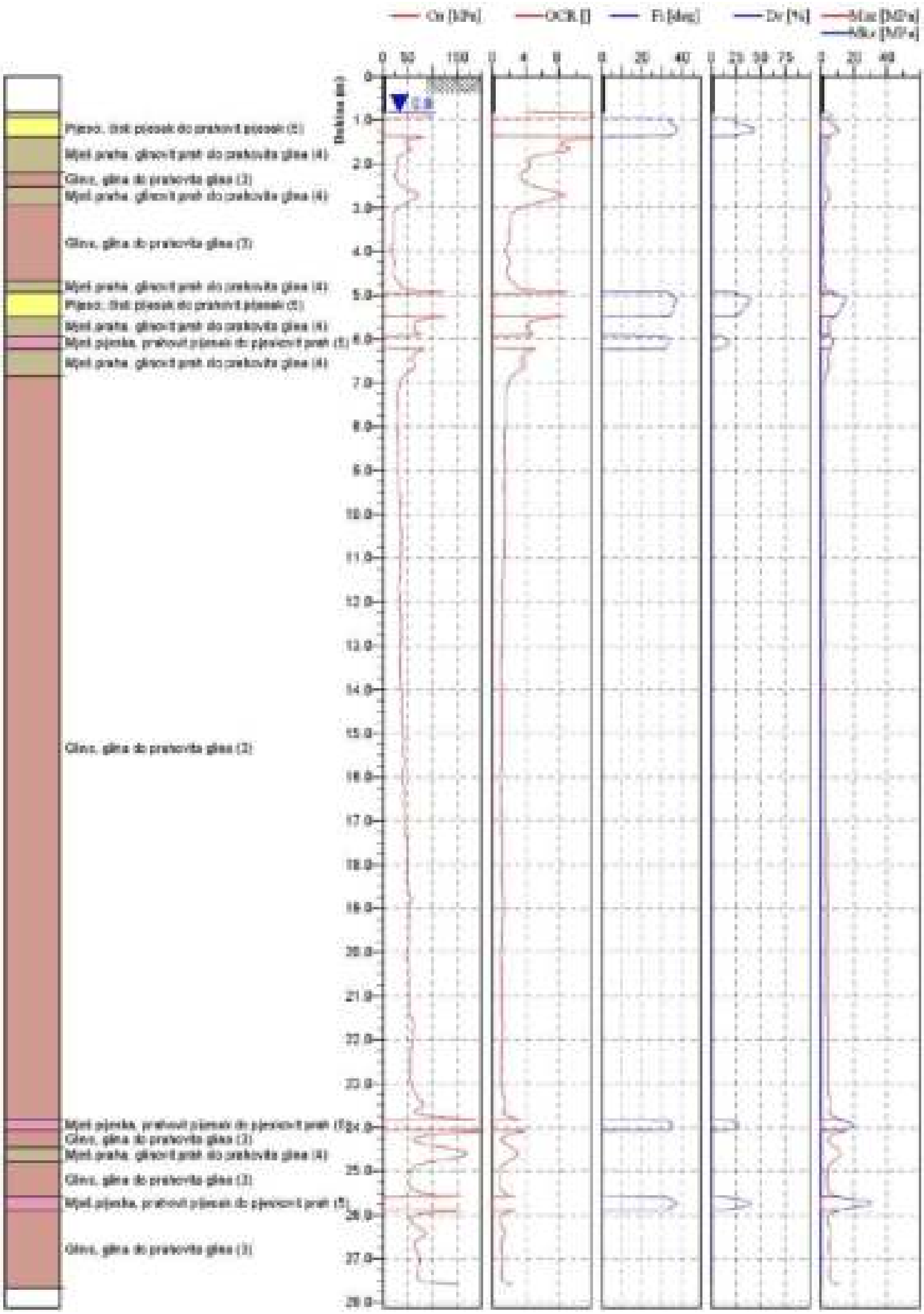
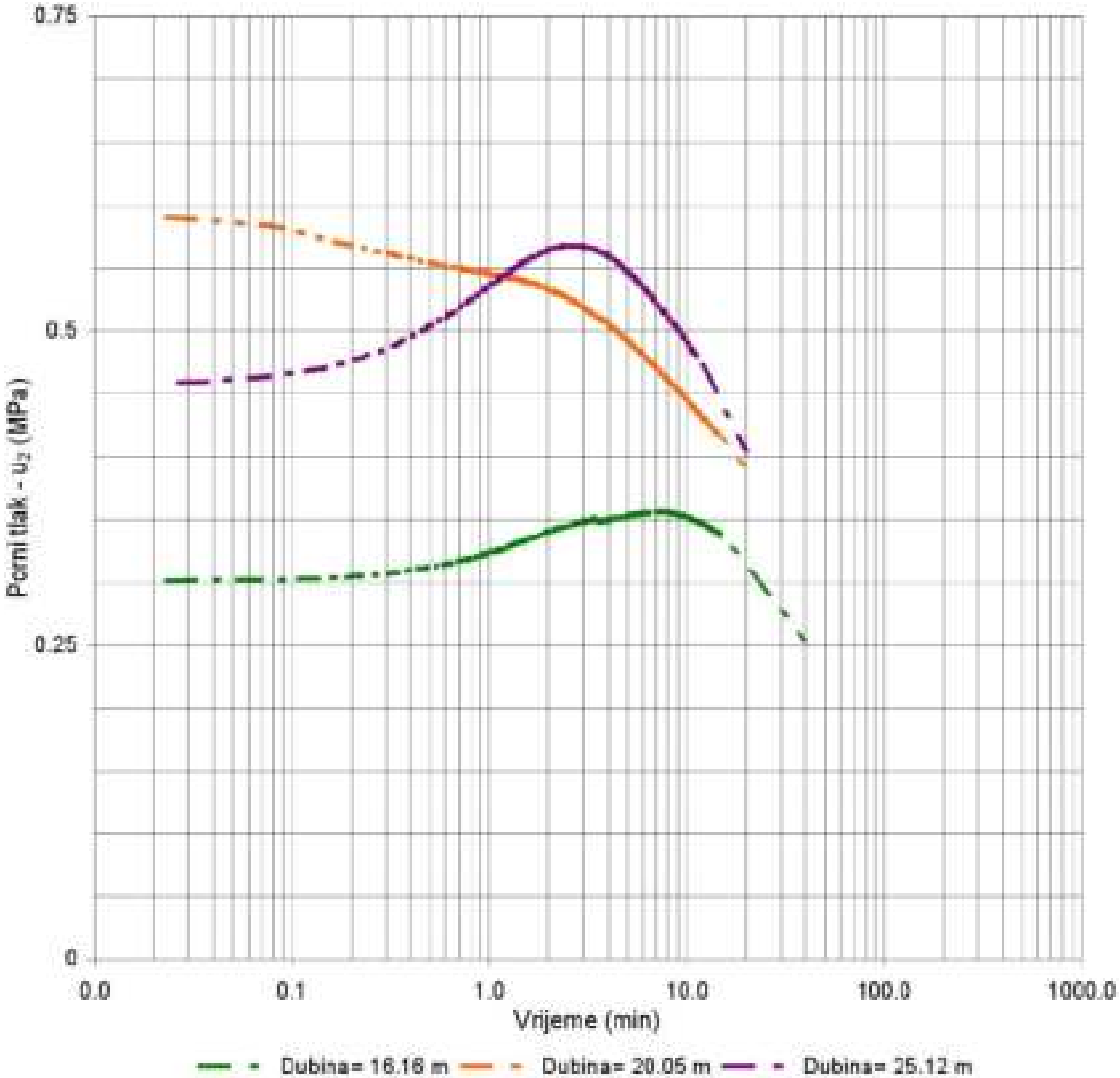


Figure 3.99 Interpreted geotechnical parameters



Dubina pokusa disipacije (m)	Horizontalni koeficijent konsolidacije c_h (cm^2/min)	Maksimalni porni tlak u_2 (MPa)	Porni tlak u_2 na 50 % disipacije (MPa)	Procjenjeni hidrostatski tlak (MPa)
16.16	**1.6**	0.356	0.255*	0.154
20.05	**0.4**	0.591	0.392*	0.193
25.12	**2.4**	0.568	0.406*	0.243

Figure 3.100 Static penetration - pore pressure dissipation experiments

RN 77506056 DATUM: 2013-02-22 GRAĐEVINA/LOKACIJA: Sustavi navodnjavanja Opuzen i Koševo-Vrbovci, podsustav Opuzen - Pregrada

Uzorak broj	Bušotina	Dubina	Granulometrijski sadržaj					Specif. težina	Volumna težina		Vlažnost	Atterbergove granice				UC klas.	Modul kompresije	Kohezija	Kut un. trenja	Jednoosna tlačna čvrstoća	Sadržaj org. tvari
			kamen	šljunak	pijesak	prah	glina	γ_s	γ	γ_d	W_0	W_L	W_P	I_P	I_C		M_K	c'	φ'	q_u *	ORG
		(m)	(%)	(%)	(%)	(%)	(%)	(kN/m³)	(kN/m³)	(kN/m³)	(%)	(%)	(%)	(%)	(-)		(MPa)	(kPa)	∠°	(kPa)	(%)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	23
01/13	POP-B-1	1,50-1,70	0	3	82	13	2	26,11			14,83					SM					<0,5
02/13		2,75									34,58										
03/13		3,50-3,70	0	0	13	87	0	25,81			28,42	39,23	25,01	14,22	1,0	ML					0,67
04/13		4,65									40,73										
05/13		4,70-4,95	0	0	16	60	24	26,04			27,50	34,10	24,45	9,65	0,68	ML					<0,5
06/13		5,00-5,50	0	0	85	15	0	26,12	18,54-19,03	14,03-15,00	28,05 (27,38-32,94)					SM	6,68	9,2	37,1		<0,5
07/13		8,50-8,70	0	2	38	53	7	26,03			27,55	38,80	23,49	15,30	0,58	ML/OL					0,97
08/13		10,45									38,58										
09/13		11,45									38,62										
10/13		13,50-13,70	0	18	18	44	20	25,95			36,33	37,96	23,44	14,52	0,11	CL/ML					<0,5
11/13	POP-B-1	15,00-15,75	0	0	1	80	19	26,04	17,26-18,14	11,30-13,63	41,11 (33,29-53,87)	38,67	24,40	14,27	≈0 (do 0,35)	CL/ML	7,87	4,9	30,1	56,78	<0,5
12/13		16,70									39,24										
13/13		20,00-20,70	0	0	1	80	19	26,04	17,16-17,75	11,26-12,65	40,32 (35,39-37,22)	41,90	24,72	17,18	0,08 (do 0,17)	CL/ML	2,50	14,8	21,7	33,71	<0,5
14/13		21,60									37,06										
15/13		24,60									30,36										
16/13		23,90-24,10	0	0	2	82	16	25,99			23,93	37,51	24,95	12,55	≈1	ML/OL					5,24
17/13		26,50-26,70	0	0	0	73	27	26,21			27,44	31,50	26,20	5,30	0,77	ML					<0,5
18/13		27,60									21,58										
19/13		28,70-28,95	0	92	8		0				21,43					GW					

Figure 3.101 Table overview of laboratory results

Figure 3.102 Grain-size diagram

Izvještaj broj: 2130-30-01/13, DODATAK 3, Stranica 4 od 8 — OBUPL-BS 1377-P2-(4.5/5)/03A, Rev.0

GRANICE PLASTIČNOSTI - metoda pomoću Casagrandeovog uređaja

RN:	77506056	UZORAK:	10/13
DATUM:	2013-02-18	BUŠOTINA:	POP-B-1
LOKACIJA/GRAĐEVINA:	Podsustav Opuzen - Pregrada	DUBINA:	13,50-13,70 m

OPIS UZORKA (tip, položaj unutar polaznog uzorka, vizualni opis, poremećenje uočeno ili izazvano uključujući gubitak vlage)

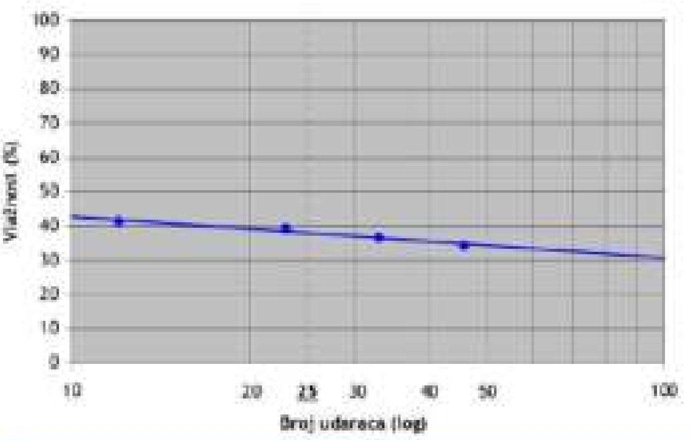
-jarah glinoviti/glina prašinasta sive boje, s pijeskom i sitnim šljunkom

Ispitano prema BS 1377 : Part 2 : 1990 : 4.5/5 — Oprema: Casagrandeova treskalica ELE

POVIJEST UZORKA, PRIPREMA	ULAZNI PODACI	
Kako je donoseno (prirodno stanje)	-masa polaznog uzorka m_s (g)	300,00
-mokro sijanje na situ 0.425 mm	-početna (prirodna) vlažnost w_0 (%)	36,33
-nepoznato	-suha masa čestica krupnijih od 0,425 mm m_r(g)	-
-sušenje na zraku na ______°C	-suha masa polaznog uzorka m_d=100/(100+w_0) * m_s	220,05
-sušenje u sušioniku na ______°C	-postotak čestica sitnijih od 0,425 mm p_a=(m_d-m_r)/m_d * 100	100,0
-ostalo (navesti)	-ekvivalentna vlažnost tla sitnijeg od 0,425 mm w_a=w_0*100/p_a	36,33

GRANICA PLASTIČNOSTI w_P		Pokus br. 1	2	3	4	Prosjek
Posuda br.		39	62			(max. razlika
Masa uzorka i posude vlažno	m_2 (g)	21,22	21,11			dva rezultata
Masa uzorka i posude suho	m_3 (g)	19,29	19,32			izmeđ 0,5%)
Masa posude	m_1 (g)	11,09	11,65			
Vlažnost	w=(m_2-m_3)/(m_3-m_1)*100 (%)	23,54	23,34			23,44

GRANICA TEČENJA w_L		Pokus br. 1	2	3	4	5
Broj udaraca		12	23	33	46	
Posuda br.		69	109	76	143	
Masa uzorka i posude vlažno	m_2 (g)	15,67	14,87	15,89	17,06	
Masa uzorka i posude suho	m_3 (g)	14,50	13,88	14,69	15,57	
Masa posude	m_1 (g)	11,67	11,36	11,41	11,22	
Vlažnost	w=(m_2-m_3)/(m_3-m_1)*100 (%)	41,34	39,29	36,59	34,25	



Granica tečenja (metodom najmanjih kvadrata)

w_L(%) = 37,96

Granica plastičnosti

w_P(%) = 23,44

Indeks plastičnosti $I_P = w_L - w_P$

I_P (%) = 14,52

Indeks tečenja $I_L = (w_0 - w_P) / I_P$

I_L = 0,89

Indeks konzistencije $I_C = (w_L - w_0) / I_P = 1 - I_L$

I_C = 0,11

UC klasifikacija

CL/ML

Figure 3.103 The limits of plasticity - method using the Casagrande device

Izvještaj broj: 2130-30-01/13, DODATAK 4, Stranica 2 od 3 — OBUPL-BS 1377-P5-3/04, Rev.0

JEDNODIMENZIONALNA KONSOLIDACIJA - dijagram i moduli kompresije

RN:	77506056	UZORAK:	11/13
DATUM:	2013-02-21	BUŠOTINA:	POP-B-1
LOKACIJA/GRAĐEVINA:	Podsustav Opuzen - Pregrada	DUBINA:	15,00-15,75 m

Ispitano prema BS 1377 : Part 5 : 1990 : 3 — METODA PRIPREME 3.3.3 (utiskivanjem prstena u blok-uzorak ili nabušenu jezgru)

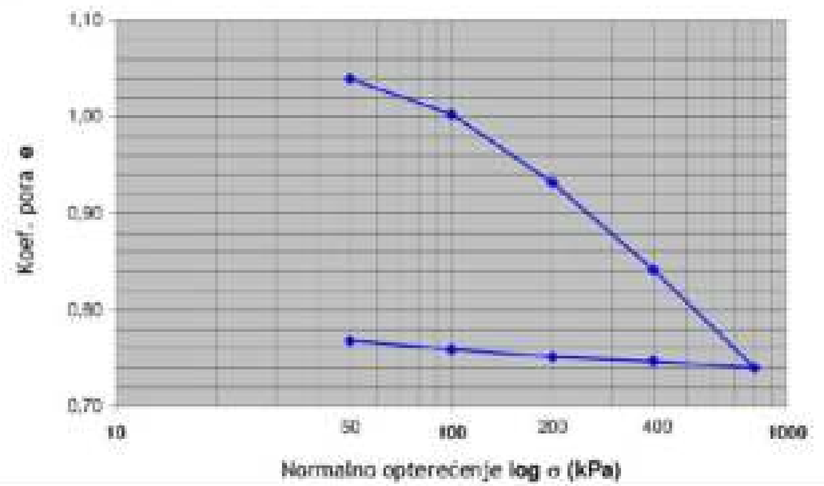
OPIS UZORKA (tip, položaj/orijentacija u položenom uzorku, vizualni opis)
-prah glinovit/glina prašinasta sive boje

UVJETI ISPITIVANJA - POTOPLJENOST
- potopljeno (standardno) - suho
- potopljeno pri opterećenju od ____ kPa

UZORAK PODACI (POČETAK ISPITIVANJA, t=0)

Promjer D (mm)	75,22	Vlažnost w_0 (%)	43,08	Podaci bubrenja po potrebi
Visina H_0 (mm)	19,59	Gustoća ρ (Mg/m³)	1,77	kPa
Koef. pora e_0	1,14	Suha gustoća ρ_d (Mg/m³)	1,24	mm
Stupanj saturacije S_0 (%)	100	Gustoća čv. čestica ρ_s (Mg/m³)	2,65	ispitana / pretpostavljena

DIJAGRAM OPTEREĆENJE-RASTEREĆENJE



Temperatura laboratorija (°C)
20,0-20,6

IZRAČUN PARAMETARA

KOEFICIJENT PORA					MODUL KOMPRESIJE			KOEF. KONSOLIDACIJE			Koef. sek. slijeganja C_{sec} = -δH,/H,
Inkrement broj	Pritisak σ = p (kPa)	Kumulativno slijeganje ΔH-y (mm)	Konsolidirana visina uzorka H=H₀-(ΔH-y) (mm)	Koef. pora na kraju inkrementa e=(H-H_s)/H_s	Inkrementalna promjena visine δH (mm)	Inkrementalna promjena pritiska δp (kPa)	M_v = 1/m_v = δp/(δH/H₀)* 1/1000 (MPa)	t_{50} (min)	H_a = 0,5(H₁+H₂) (mm)	c_v = 0,026H_a^2/t_{50} (m²/god)	
0	0	0,000	19,590	1,14	0,000	0	-	-	-	-	
1	50	0,943	18,647	1,04	0,943	50	1,04	1,40	19,119	6,79	
2	100	1,275	18,315	1,00	0,332	50	2,81	3,02	18,481	2,94	
3	200	1,925	17,665	0,93	0,650	100	2,82	5,87	17,990	1,43	
4	400	2,752	16,838	0,84	0,827	200	4,27	3,15	17,251	2,46	
5	800	3,679	15,911	0,74	0,927	400	7,27	1,70	16,374	4,10	

Figure 3.104 One-dimensional consolidation - diagram and compression modules

Izvještaj broj: 2130-30-01/13, DODATAK 5, Stranica 1 od 2 | OBL-BS 1377-P7-7.2, str.1

JEDNOOSNA TLAČNA ČVRSTOĆA TLA

RN:	77506056	UZORAK:	11/13
DATUM:	2013-02-21	BUŠOTINA:	POP-B-1
LOKACIJA/GRAĐEVINA:	Podsustav Opuzen - Pregrada	DUBINA (m):	15,00-15,75

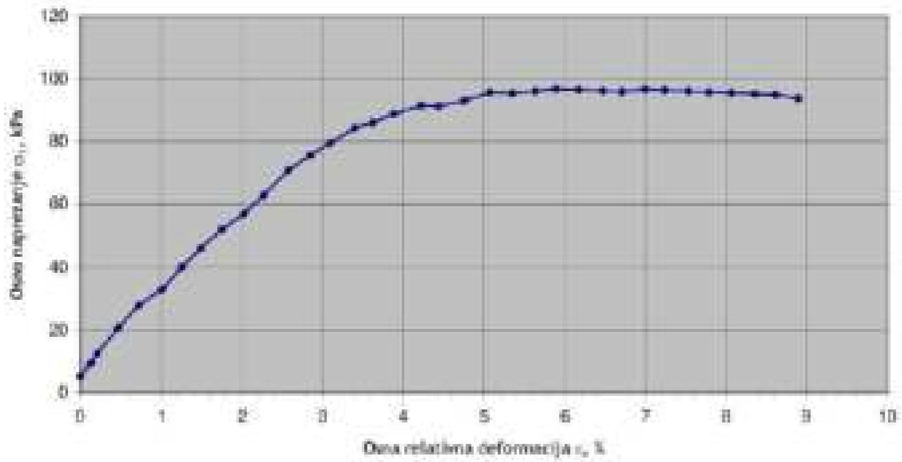
Ispitano prema BS 1377 : Part 7 : 1990 : 7.2 (metoda tlačenjem u preši)

OPIS UZORAKA I UVJETA PRIPREME / ISPITIVANJA

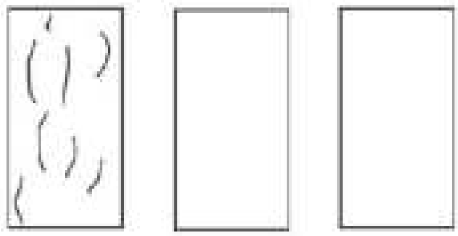
- tip uzorka: neporemećeni, iz cilindra
- metoda pripreme: BS 1377 : Part 1 : 1990 : 8, istiskivanje iz cijevi s uzorkom
- opis uzorka: prah glinovit/glina prašinasta sive boje

Ispitni uzorak	Visina (mm)	Promjer (mm)	Vlažnost (%)	Gustoća, vlažna (Mg/m^3)	Gustoća, suha (Mg/m^3)	Dubina i orijentacija ispitnog uzorka, druga zapažanja po potrebi
A	140,0	70,0	33,3	1,85	1,39	Vertikalna orijentacija, središnji dio uzorka

DIJAGRAM σ/ε



SKICE SLOMA



A

JEDNOOSNA TLAČNA ČVRSTOĆA

Ispitni uzorak	Prirast vertikalnog pomaka (mm/min)	Jednoosna tlačna čvrstoća q_u (kPa)	Deformacija pri slomu (%)
A	2,0	96,78	5,90

Figure 3.105 Uniaxial compressive strength of soil

Izvještaj broj: 2130-30-01/13, DODATAK 6, Stranica 1 od 6 — OBUPL-BS 1377-F7-4/03, Rev.0

IZRAVNI POSMIK - zbirni podaci i dijagrami

RN:	77506056	UZORAK:	06/13
DATUM:	2013-02-21	BUŠOTINA:	POP-B-1
LOKACIJA/GRAĐEVINA	Podsustav Opuzen - Pregrada	DUBINA:	5,00-5,50 m

Ispitano prema BS 1377 : Part 7 : 1990 : 4 postupkom 4.5.4 / 4.5.5
Pokus je proveden: u jednoj fazi / ciklički (višestruki reverzibilni)

PRIPREMA UZORAKA: 4.4 (utiskivanjem prstena)

Povratni hod: (a) strojno (b) ručno (c) naprijed-nazad

OPIS UZORAKA (tip, položaj/orijentacija, vizualni opis):
pijesak sive boje, s učešćem praha

Uzorci su ispitani: potopljeni / nepotopljeni

Prirodna vlažnost: w_0 = 28,05 %

Uzorci su ugrađeni: neporemećeni / poremećeni / zbijeni / suhi / zasićeni

Gustoća čvrstih čestica: ispitana / pretpostavljeno ρ_s = 2,68 Mg/m³

ostalo:

SUMARNI PODACI UZORAKA

Ispitni uzorak, označen normalnim naprezanjem σ_n		kPa	50	100	200			
Prsten ili dodatna oznaka			-	-	-			
Podaci ispitnih uzoraka na početku ispitivanja	Stranice L_1, L_2 (nazivna mjera)	mm	60,0	60,0	60,0			
	Visina H_0	mm	19,3	19,3	19,3			
	Vlažnost w	%	32,94	27,38	29,16			
	Gustoća ρ	Mg/m³	1,90	1,94	1,89			
	Suha gustoća ρ_d	Mg/m³	1,43	1,53	1,46			
	Koef. pora e_0		0,88	0,76	0,83			
	Stupanj saturacije S_r	%	100,0	97,1	93,7			

DIJAGRAMI

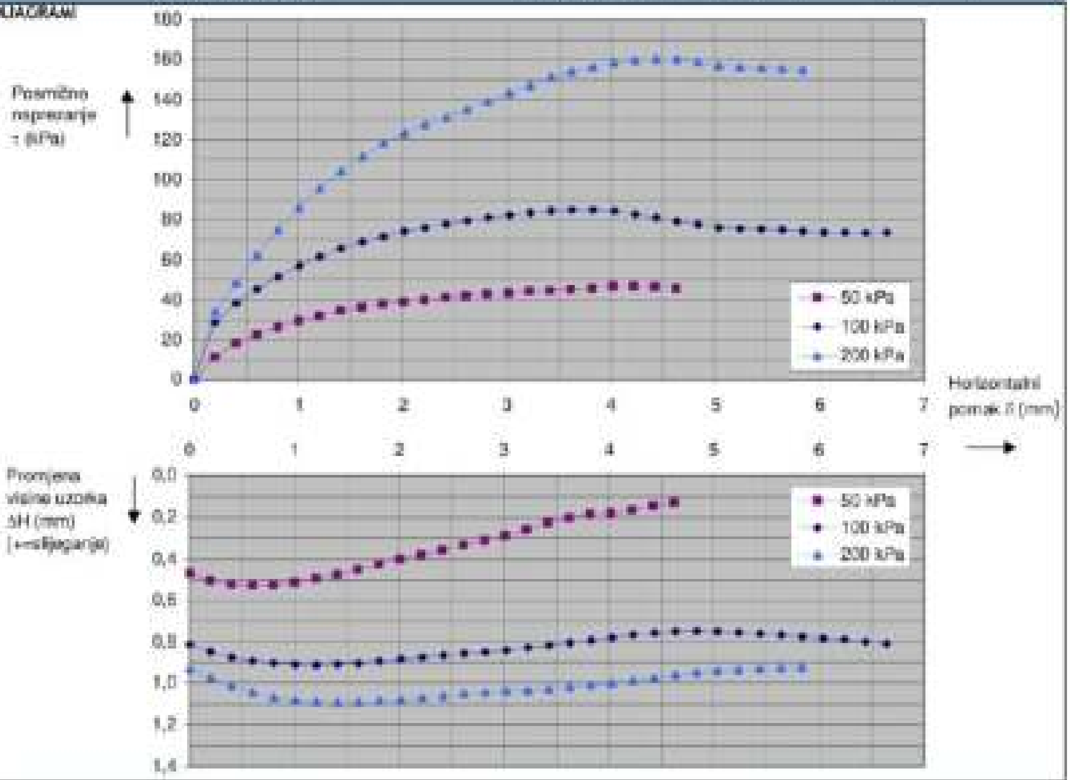


Figure 3.106 Direct shear - summary data and diagrams

Izvještaj broj: 2130-30-01/13, DODATAK 6, Stranica 2 od 6 OBUPL-BS 1377-P7-4/04, Rev.0

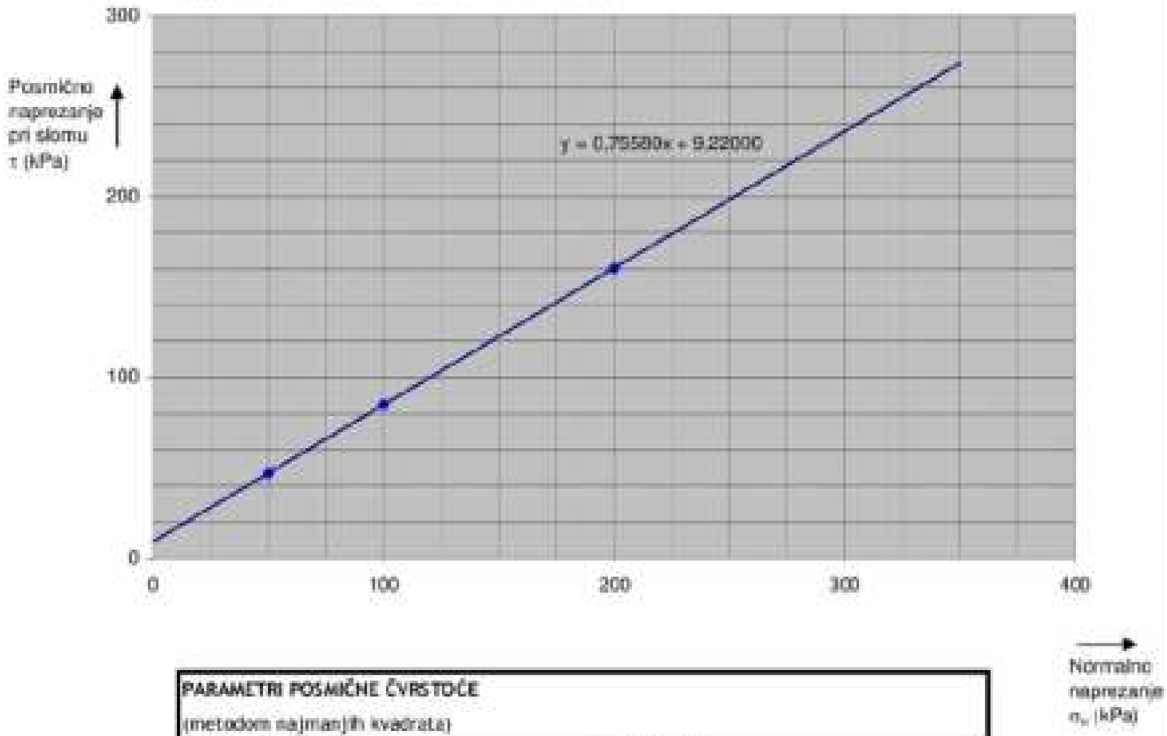
IZRAVNI POSMIK - parametri posmične čvrstoće

RN:	77506056	UZORAK:	06/13
DATUM:	2013-02-21	BUŠOTINA:	POP-B-1
LOKACIJA/GRAĐEVINA:	Podsustav Opuzen - Pregrada	DUBINA:	5,00-5,50 m

SUMARNI PRIKAZ REZULTATA

Normalno naprezanje σ_n		kPa	50	100	200			
Brzina posmika		mm/min	0,0019	0,0500	0,0459			
Vršno - maximum	Posmično naprezanje τ	kPa	46,89	84,98	160,32			
	Pripadni horizontalni relativni pomak δ	mm	4,019	3,628	4,432			
	Pripadna promjena visine uzorka ΔH	mm	0,180	0,805	0,974			
Rezidualno	Posmično naprezanje τ_R	kPa						
	Broj prolaza (ciklusa)							
	Kumulativni horizontalni pomak δ_{kum}	mm						
	Kumulativna promjena visine ΔH_{kum}	mm						

COULOMBOVA ANVELOPA ZA ISPITANI SET UZORAKA



PARAMETRI POSMIČNE ČVRSTOĆE (metodom najmanjih kvadrata)					
Vršno (maximum)			Rezidualno		
c' =	9,2	kPa	c_R =		kPa
φ' =	37,1	°	φ'_R =		°

Figure 3.107 Direct shear - shear strength parameters

Figure 3.108 Investigation borehole core

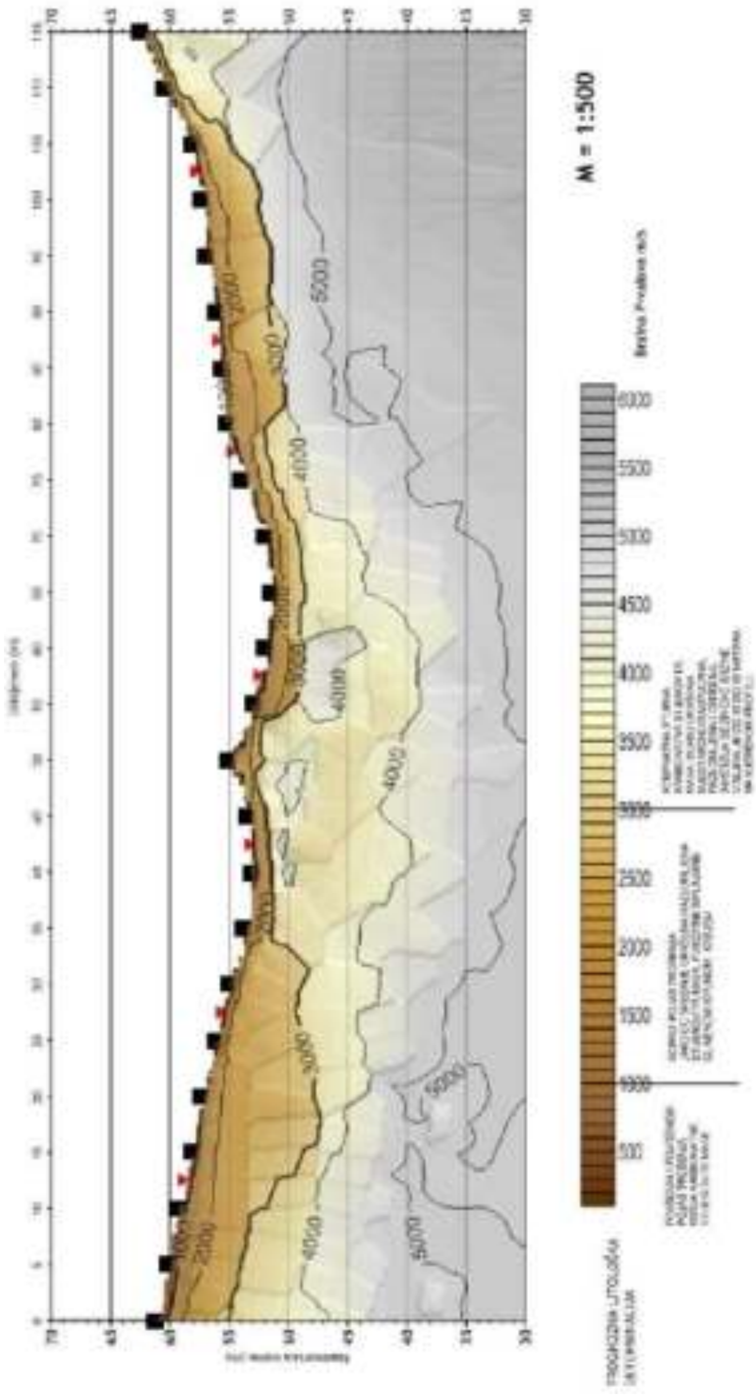


Figure 3.109 Profile of seismic refraction

3.34 Geotechnical investigation works for renovation of the right river bank of the Neretva River in Komin (2014.)

For the purpose of the right river bank renovation of the Neretva River in Komin, geotechnical investigation works were carried out including engineering-geological mapping and determination of drilling core, as well as laboratory tests on disturbed and undisturbed soil samples. Drilling was performed including field identification and classification of drilling core, sampling of undisturbed and disturbed soil samples, testing of relative compression by standard penetration test (SPT), testing with a pocket wing probe, testing of undrained shear strength of the ground with a field wing probe and monitoring of occurrence and level of groundwater in boreholes during investigation works.

The aim of the investigation works was to determine the composition and properties of soil materials and the groundwater level in Komin, identify the causes of instability and make recommendations for renovation project.

Dynamic impact of the Neretva River is one of the reasons of instability; sandy materials that are prone to erosion are registered in the foundation soil, resulting with weakening of the river bank slope and ultimately with displacements in the upper part of the river bank (tensile cracks in asphalt). Uncontrolled embankment and concreting of the river bank results in uneven distribution of additional loads in the soil, leading to uneven subsidence of the underlying soil and finally with collapse of the river bank. Traffic loads and adverse shoreline geometry, where at several locations the slope of the river bank is very steep, also have negative effect on stability of the river bank.

Considering the results of the investigations carried out, the characteristics of the site and the recorded instability, following recommendations and guidelines for renovation were provided: finishing the river bank and ensuring the stability of it and preventing erosion of sandy materials by coating slopes and forming steep slopes. It was mentioned that the method of renovation of the river bank and the foundations of facilities, with the required load and subsidence calculations, should be done in a separate project.

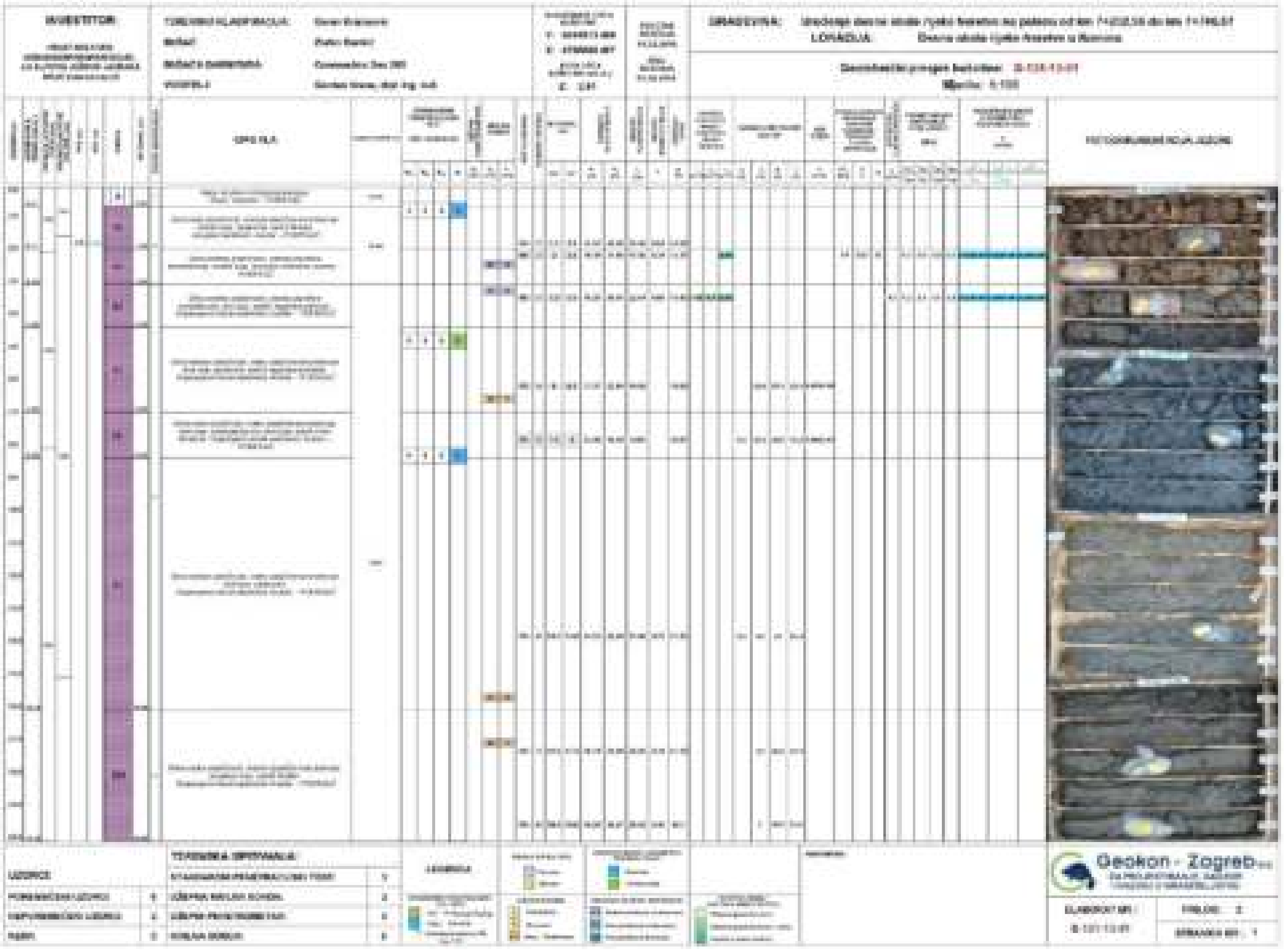


Figure 3.110 An example of borehole results

3.35 Piezometers drilling for groundwater monitoring in the area of Mala Neretva (2014.)

The Neretva River Valley between Metković and the sea consists of Quaternary deposits. Along the perimeter and base of the valley are carbonate deposits of Jurassic, Cretaceous, Paleocene, and Eocene, and a narrow belt of clastic Eocene flysch deposits. Groundwater is saved by the surface water, rainfall, groundwater from the side of the rocky massif and the sea, which is why it is salted.

The surface layer of soil up to a depth of about 3.0 m consists of dusty and organic (peat) clay and loam, and is saturated with water throughout the year or lies under water. Below this layer is a layer of Holocene sandy sediments whose thickness mainly doesn't exceed 10.0 m, except in the narrow zone along the Mala Neretva, where its maximum registered thickness is 20.0 m. This layer represents the first aquifer and is designated as the layer of greatest importance in land melioration sense.

Below the first aquifer there is a layer of average thickness of 20.0 m, consisting of silty clay (loam) with thin layers of dusty sand up to 2 cm thick, but also sand lenses and layers up to 1.5 m thick, without regularity in appearance. This layer is also saturated with water.

The next layer below the silt clay is aquifer, but with less distribution than is the case in the Holocene sands. It is made of gravels with different sand content and clay in places. The lower boundary of this layer is horizontal and is between 40 and 50 m deep.

Below the gravel layer is a thin layer of clay 3.0 to 4.0 m thick, under which a thin layer of limestone conglomerates between 3.0 and 6.0 m thick. Then a layer formed of gravels of the Early Pleistocene up to 60 m thick is deposited on a karstified carbonate massif which forms the bottom and sides of the Valley. This layer has highly mineralized water that is under high pressure.

There are currently four locations in the Neretva Valley where shallow and deep pairs of piezometers (P-1, P-2, P-3 and P-4) and the deepest piezometer reaching 125.0 m (DP) were drilled. The shallow piezometers are about 10.0 m deep, and are performed through the first aquifer from sandy sediments to the beginning of the lower clayey layer. Deep piezometers (depths from 29.0 to 35.0 m) are made through the entire layer of silt clay and enter the lower layer that is formed of gravel with different sand content.

On the surface of the terrain, piezometers are properly protected by a concrete block. The pipe end (top of the pipe) is threaded to allow the plug (cover) to be fitted onto the piezometer. On the piezometer pipes the corresponding height is determined using a network of fixed elevation points of precise leveling in the area of the Lower Neretva. During the pumping tests, groundwater levels in piezometers were continuously measured. Immediately after the step-test and the constant-test, after the pump was switched off, the water level was measured. Logging measurements were taken on the wells P-5, P-6, and P-7 as well as DP.

1,0 – 5,0 m

6,0 – 10,0 m

11,0 – 15,0 m

16,0 – 20

Figure 3.111 Investigation borehole core

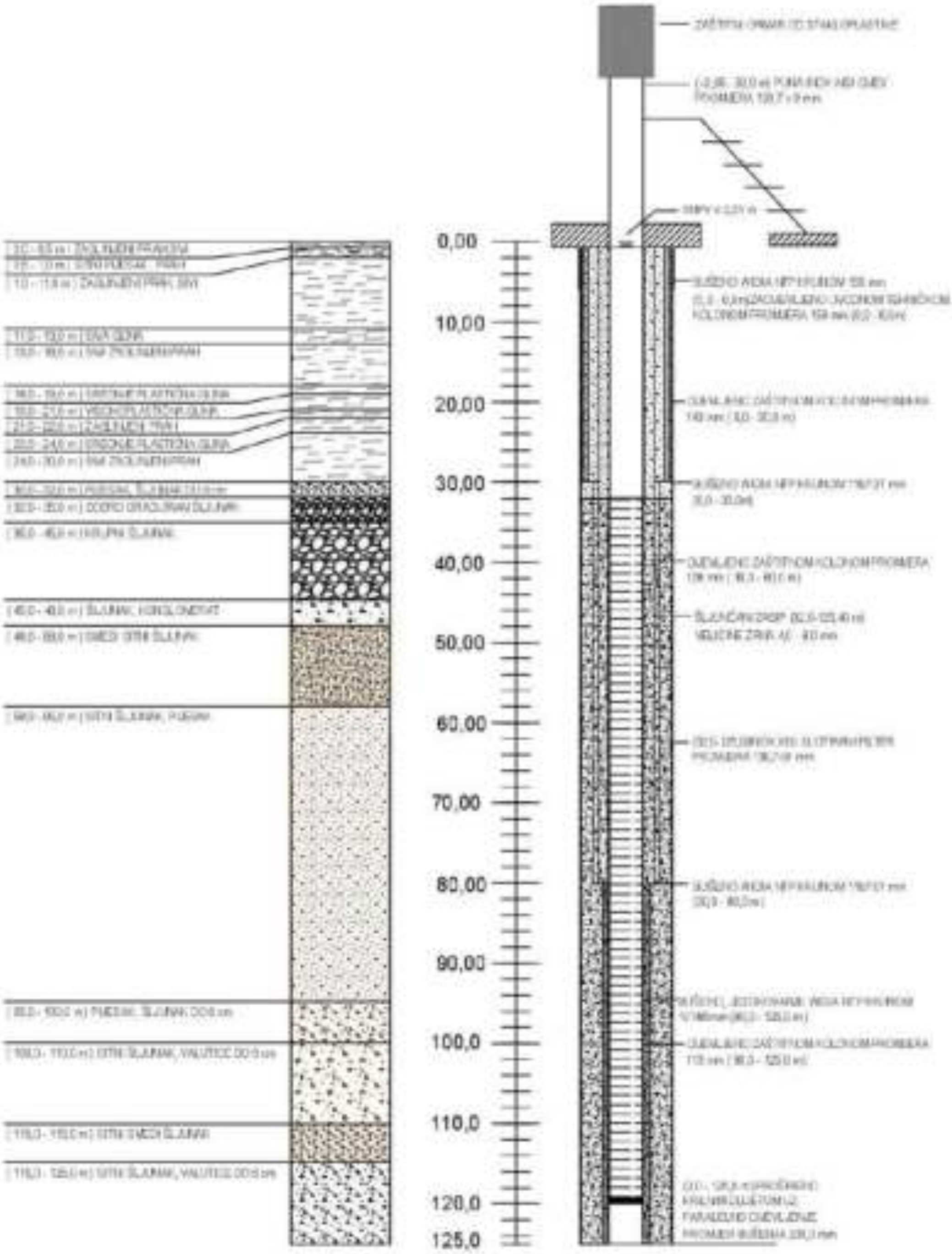


Figure 3.112 Lithological and technical profile of the borehole

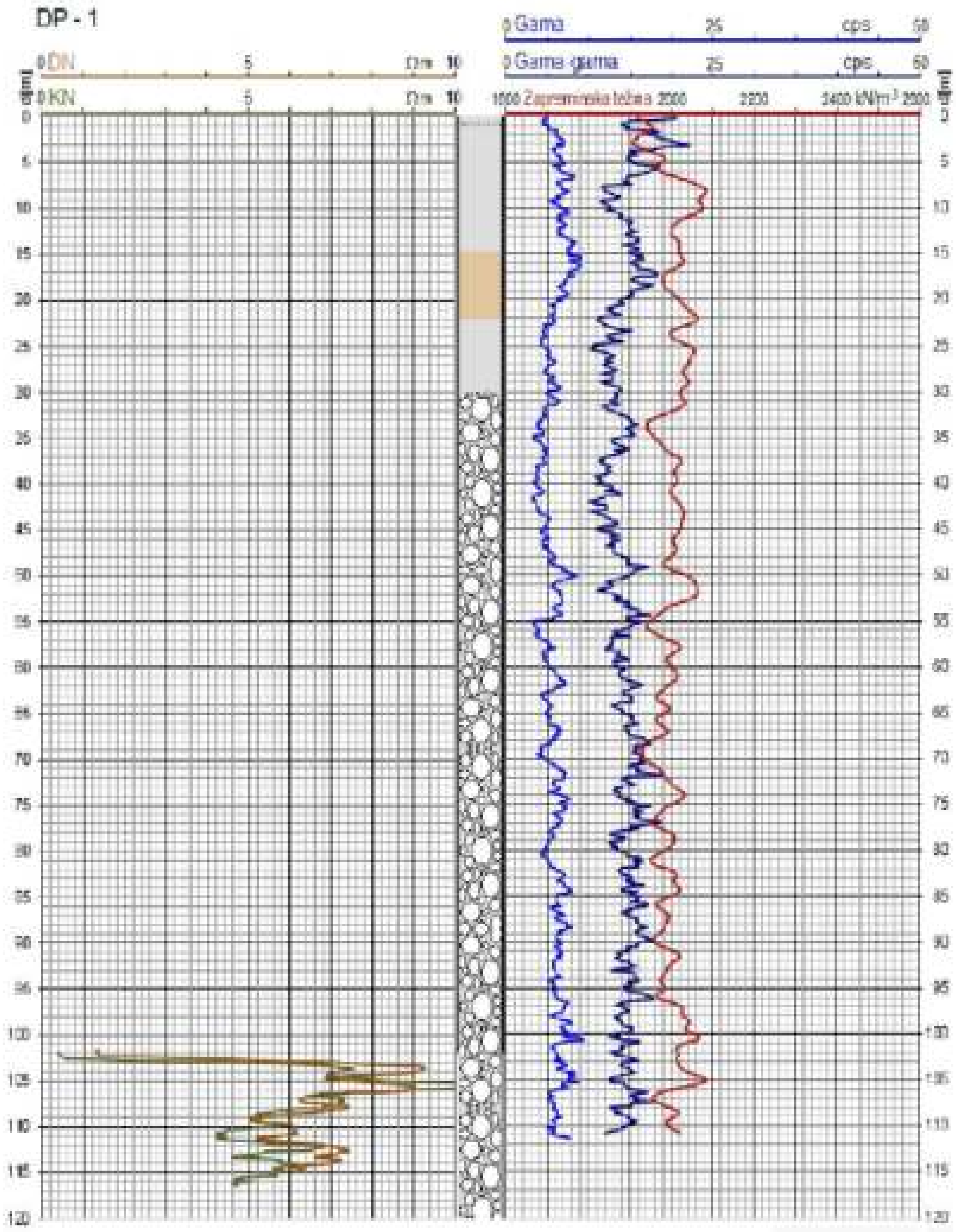


Figure 3.113 Logging measurements

3.36 Geotechnical investigation works for pipelines of Glog irrigation system (2017.)

The aim of geotechnical research was to determine the stratification, composition and properties of the soil, the groundwater level and make recommendations for the implementation project. Geotechnical research included investigative drilling with sampling, standard penetration testing and groundwater levels measurement in the well; in-situ soil Static Penetration Test (CPTU), determination of silt thickness in the channel by manually pressing the bar, laboratory tests and design of a geotechnical study.

Stratification, identification and classification of soil, and interpretation of geotechnical parameters were performed only based on the measured CPTU values: qc - resistance at the tip of the probe, fs - friction at the probe sheath, and u_2 - pore pressure. Interpretation of geotechnical parameters was performed using empirical correlations and its values depend on the suitability of the correlations used and the coefficient values selected.

OZNAKA UZORKA	DUBINA	PRIRODNA VLAGA	GRANULOMETRIJSKI SASTAV					GRANICE PLASTIČNOSTI		INDEKS PLASTIČNOSTI	INDEKS KONZISTENCIJE	SIMBOL
	m	w [%]	G [%]	S [%]	M [%]	C [%]	VDP USER k [cm/s]	wL [%]	wP [%]	IP [%]	Ic	
BUŠOTINA		**B-GL-1(S-040-17-01)**										
S-040-17-01-02	1,80-2,15	34,84		24,20	50,40	25,40		43,64	20,17	23,47	0,37	CI
S-040-17-01-03	2,85-3,15	38,20						35,88	19,84	16,04		CI
S-040-17-01-04	3,80-4,10	43,51		12,40	61,30	26,30		34,98	19,03	15,95		CL
S-040-17-01-05	4,70-5,00	43,52		2,30	55,10	42,50		49,06	20,15	28,91	0,19	CI
S-040-17-01-06	6,50-6,70	43,18						48,13	19,37	28,76	0,17	CI
S-040-17-01-07	9,40-9,60	43,96						34,62	20,45	14,17		CL
BUŠOTINA		**B-GL-2(S-040-17-02)**										
S-040-17-02-01	0,75-1,00	26,09		21,50	51,10	27,40		47,72	23,33	24,39	0,89	CI
S-040-17-02-02	1,25-1,45	39,75						73,18	29,03	44,15	0,76	CH
S-040-17-02-03	1,80-2,00	34,94		46,30	42,60	11,10	1,090E-08	31,83	20,23	11,6		CL
S-040-17-02-04	2,20-2,40	34,43		24,50	51,70	23,80	7,907E-08	36,50	20,32	16,18	0,15	CI
S-040-17-02-05	3,30-3,50			58,00	26,70	15,30	6,082E-07					SC
S-040-17-02-06	5,90-6,10			65,30	22,20	12,50	9,067E-07					SC
S-040-17-02-07	7,30-7,40	34,29						31,60	14,31	17,29		CL

Figure 3.114 Results of physical properties of soil material

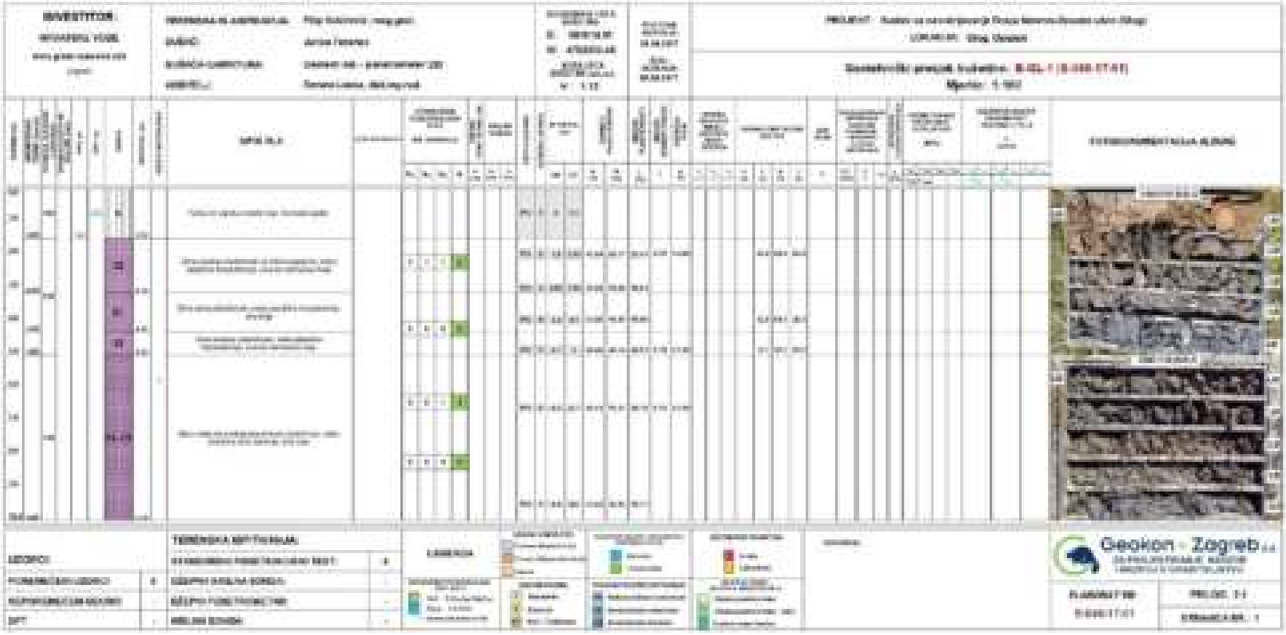


Figure 3.115 An example of borehole results

4 GIS data base

After preliminary overview of available in situ work reports, additional step was necessary to create a digitalised data base which would enable the work with the documentation especially in a way of efficient determination of covered areas, applied methods and arose results. To end this, *GeNera* is created as a GIS base which is assumed to be used as a digital data base solely. Over than 500 local data and more than 30 cross sections have been incorporated and digitally presented in *GeNera* thus representing a unique and crucial data base for further geological characterization of Lower Neretva coastal aquifer.

General overview of *GeNera* interface is presented in Figure 4.1. Figure 4.2. presents an insight to local data base for the sources ranging from 1962. up to date. In total more than 500 locations have been covered by this base. To each of local data one or more information is associated as follows:

- Granulometric curve/s or information on sediment granular features;
- Borehole vertical cross section as derived from the boreholes digging procedure;
- Borehole core photography;
- Pumping test results.

In case of available borehole vertical cross section, core photography or granulometric curve/s, user of Genera can easily draw and use available data as shown in Figure 4.1-4.10.

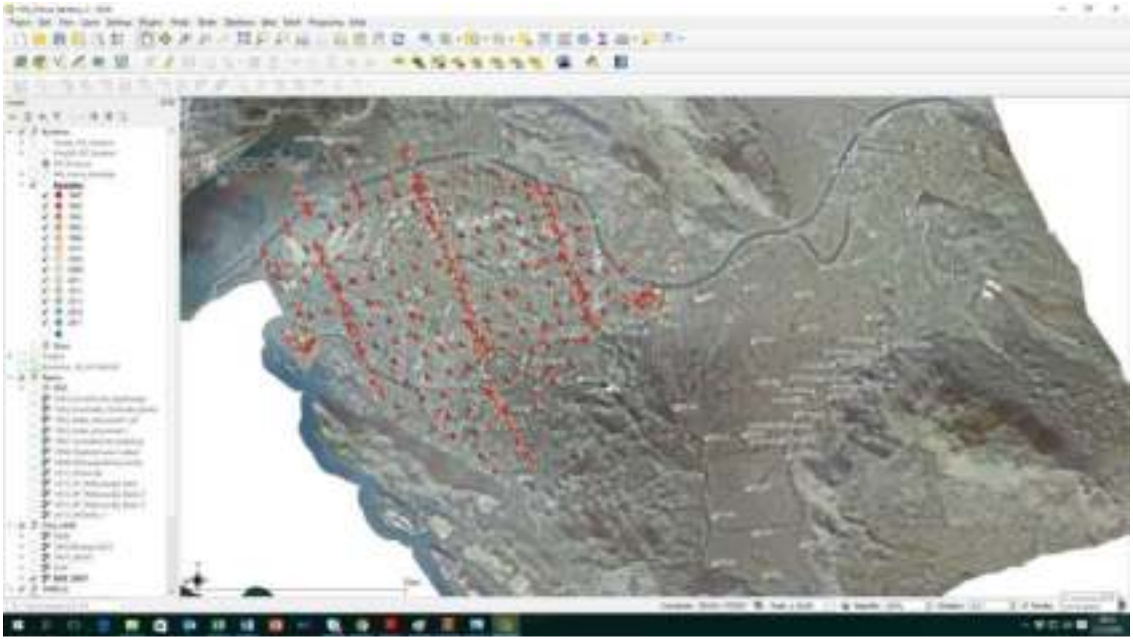


Figure 4.1 Screenshot from GeNera workspace – local data sets

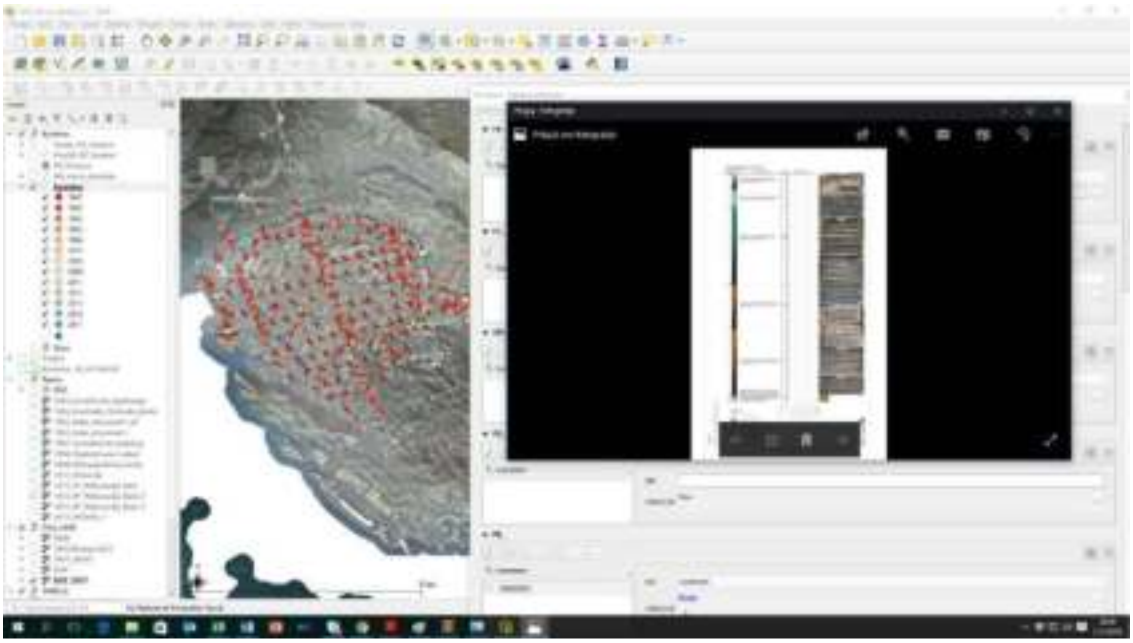


Figure 4.2 Screenshot from GeNera workspace – borehole cross section data

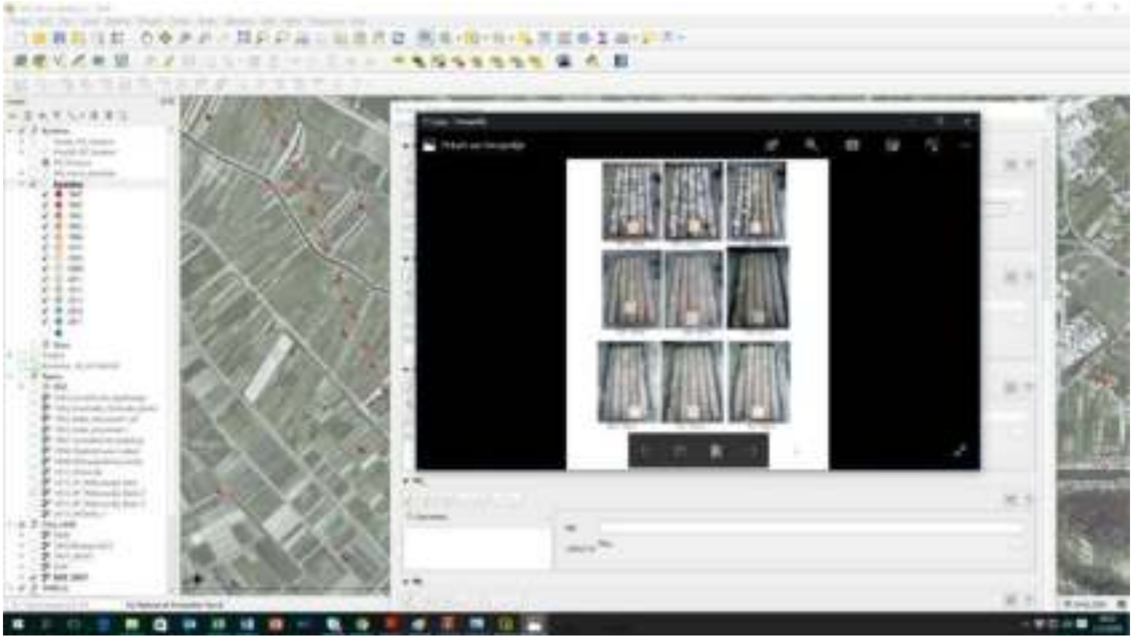


Figure 4.3 Screenshot from GeNera workspace – usage of photo documentation

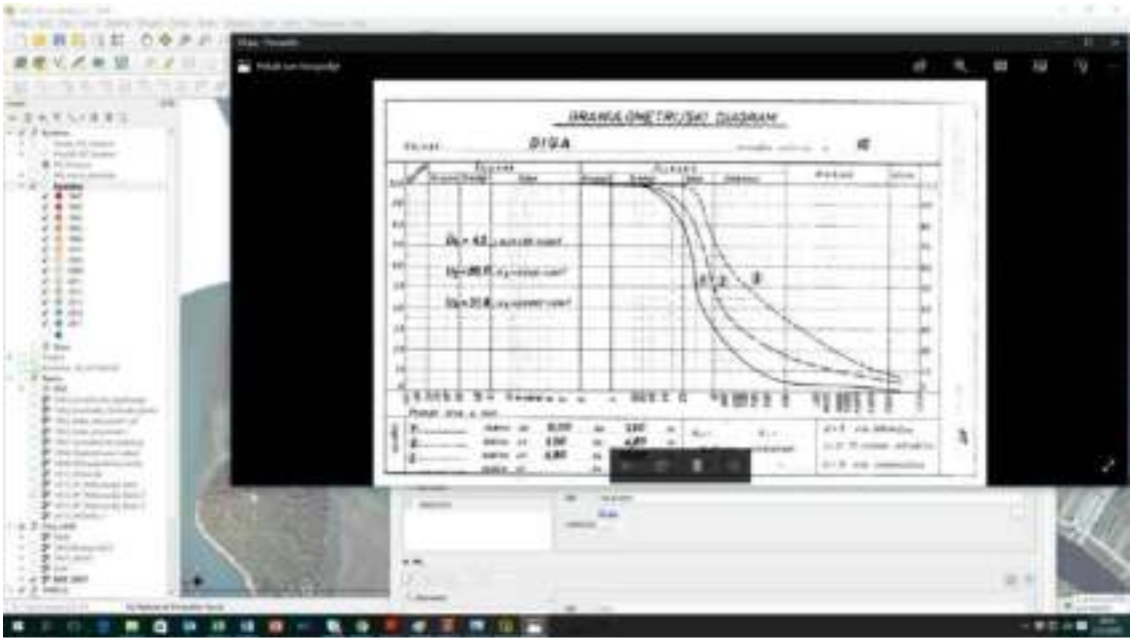


Figure 4.4 Screenshot from GeNera workspace – usage of granulometric features of the samples taken from the borehole

Besides local data sets, *GeNera* is also a source of more than 30 different planar data sets known as cross sections shown in Figure 4.5.-4.10. Those cross sections are characterised by one or more pre assumed data types as:

- Interpretation of geoeletrical sounding values;
- Interpretation of applied geophysical work done;
- Schemes of aquifers layer stratigraphy derived from local data.

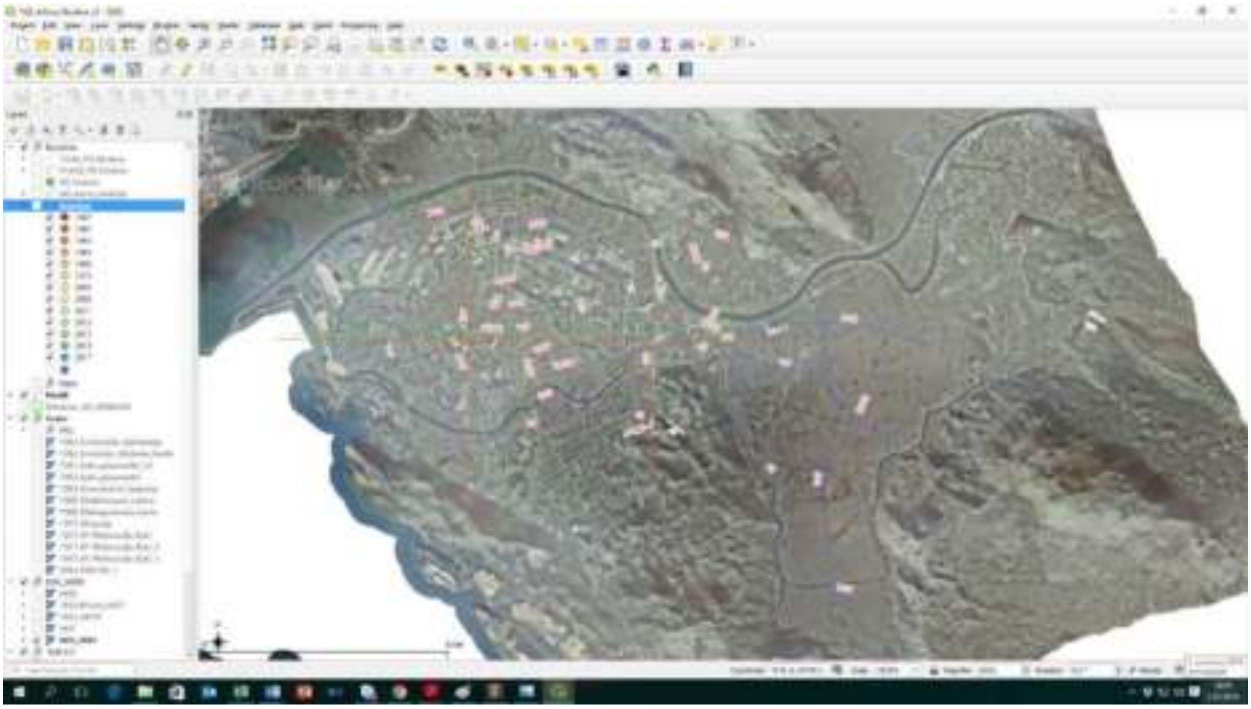


Figure 4.5 Screenshot from GeNera workspace – cross sections

Typical planar info sets available in GeNera are shown in Figure 4.6. to 4.8.

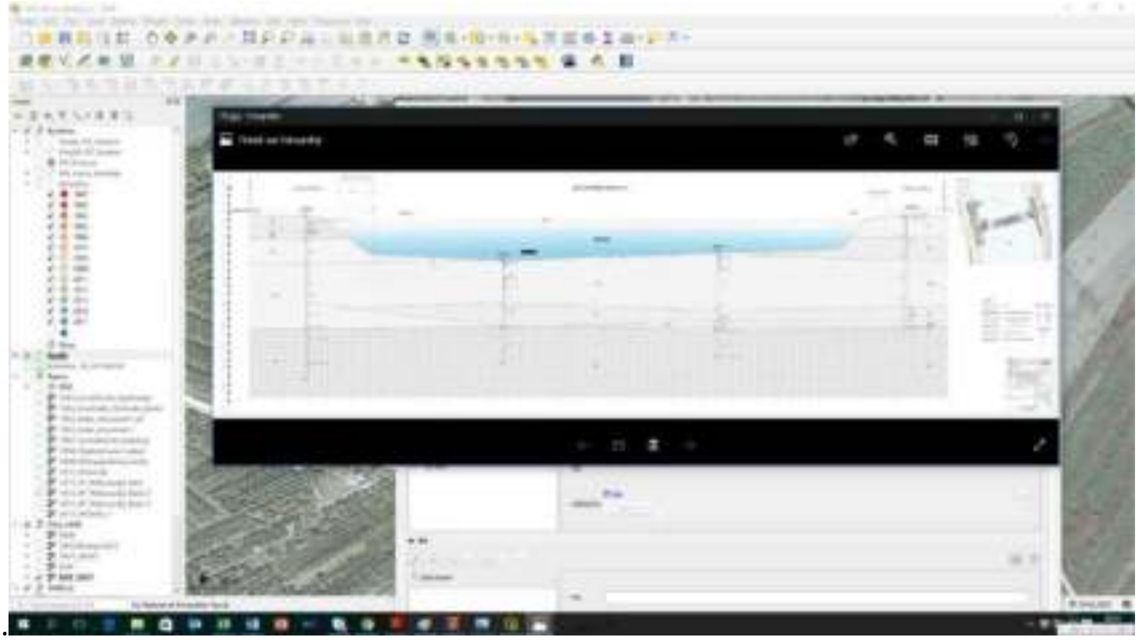


Figure 4.6 Screenshot from GeNera workspace – cross section preview and interpretation

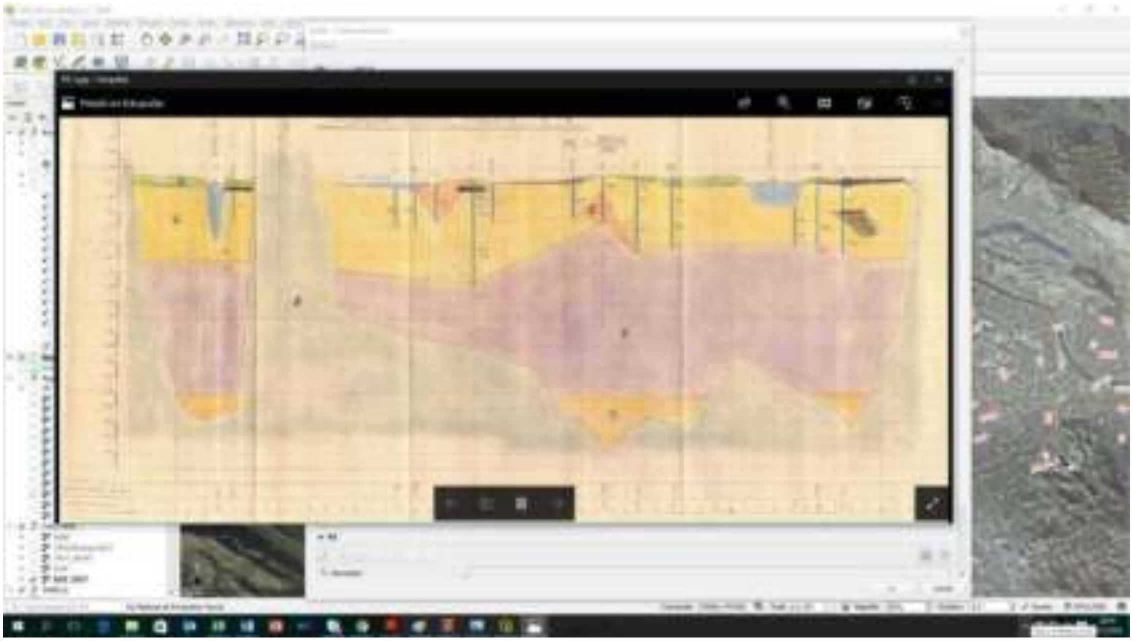


Figure 4.7 Screenshot from GeNera workspace – cross section preview and interpretation (initial versions)

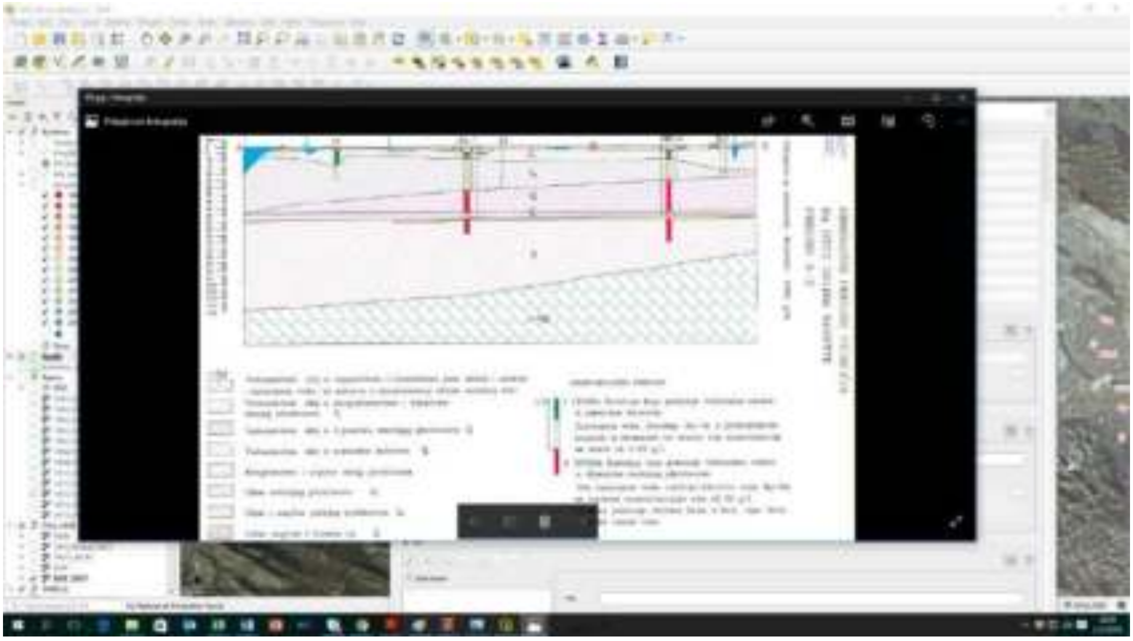


Figure 4.8 Screenshot from GeNera workspace – cross section schemes as a source of information

Once different data sets are incorporated in *GeNera*, additional possibility is enabled to use original situation stems from the reporting document but now geo reprehended. This is especially helpful for matching the data from different period of their origin.

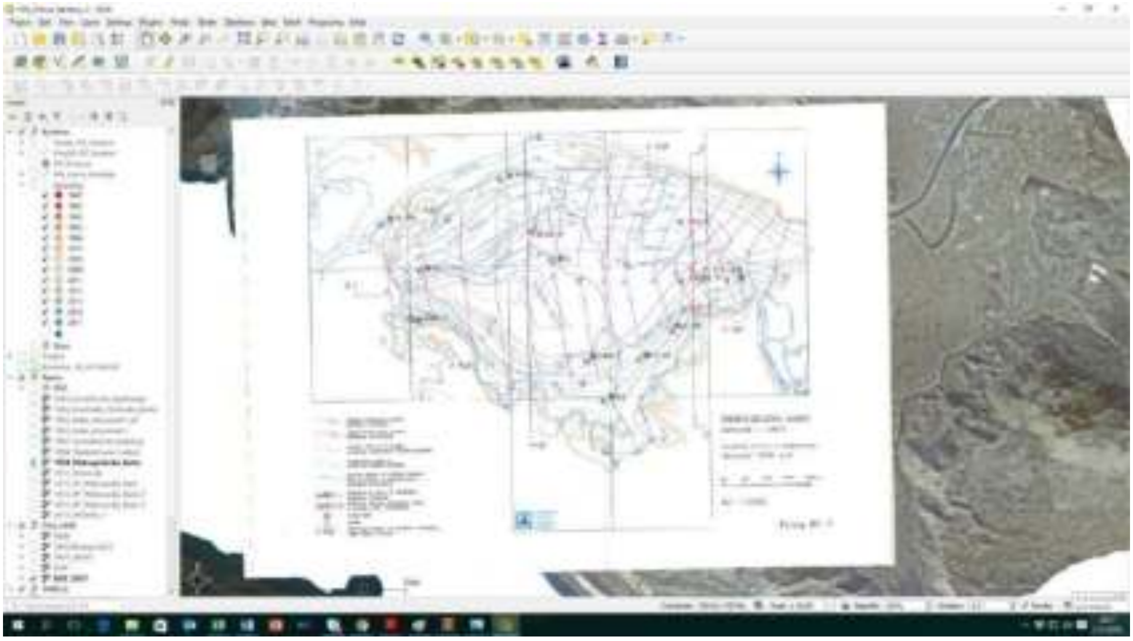


Figure 4.9 Screenshot from GeNera workspace – usage of georeferenced available documentation and reports

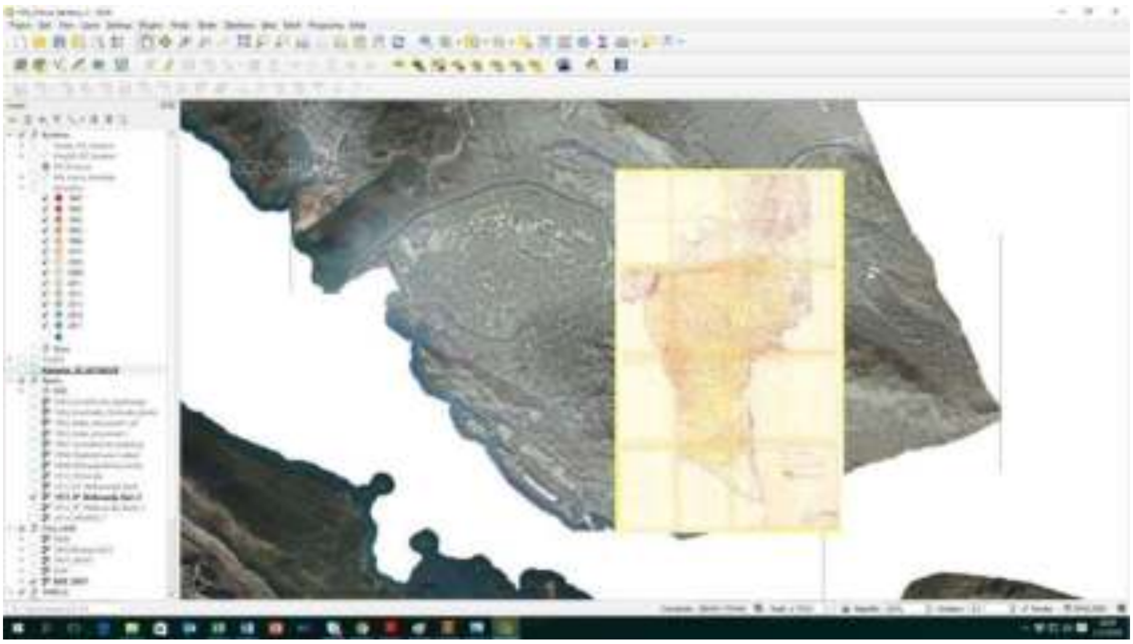


Figure 4.10 Screenshot from GeNera workspace – usage of georeferenced available documentation and reports

5 Agricultural background

The River Neretva springs beneath Gredelj saddle of Zelengora mountain in the Bosnia and Herzegovina, at the height of 1095 m above sea level. The river flows for around 230 km, of which only 22 km run through Croatia, before reaching the Adriatic Sea. The Neretva River catchment area covers around 10,100 km^2 in Bosnia and Herzegovina and 280 km^2 more in Croatia. Upper Neretva, situated in the Dinaric Alps, runs off in Triassic formations with outspread network of surface streams which flow into the main Neretva River body. Middle and Lower Neretva are characterized mainly by Karst limestone-dolomite environment.

In the last 30 km of its flow, river Neretva expands into an alluvial delta. Before soil amelioration works, the area downstream from Metkovic town used to be a vast swamp. From 1950s to 1990s intensive efforts were exerted to reclaim the soil from the sea and to lower the groundwater level. Today, terrain level in the River Neretva delta is barely above or even under the mean sea level (m.s.l.), as the elevations generally range from -1 to 5 m above m.s.l. (Figure 5.1).

The delta is semi-arid area characterised by Mediterranean climate with hot, dry summers and mild, wet winters. The mean annual rainfall (1980-2000) is 1 230 mm, occurring mostly in the period from October to April. The average annual air temperature is 15.7 °C and the annual Penman-Monteith reference evapotranspiration is 1196 mm. The highest values of average monthly air temperature (25.2 °C) and the average monthly Penman-Monteith reference evapotranspiration (191 mm) are noted in July.

The River Neretva delta covers around 12,000 hectares of which 5200 hectares are used for agricultural production. The area that is used for agricultural production can be recognized by dark blue drainage/irrigation canals on Figure 1. There are five distinct agricultural regions: Koševo, Vrbovci, Luke, Opuzen ušće and Vidrice (Figure 5.1). In this report, initial agricultural conditions of the regions Luke, Opuzen ušće and Vidrice are explained.

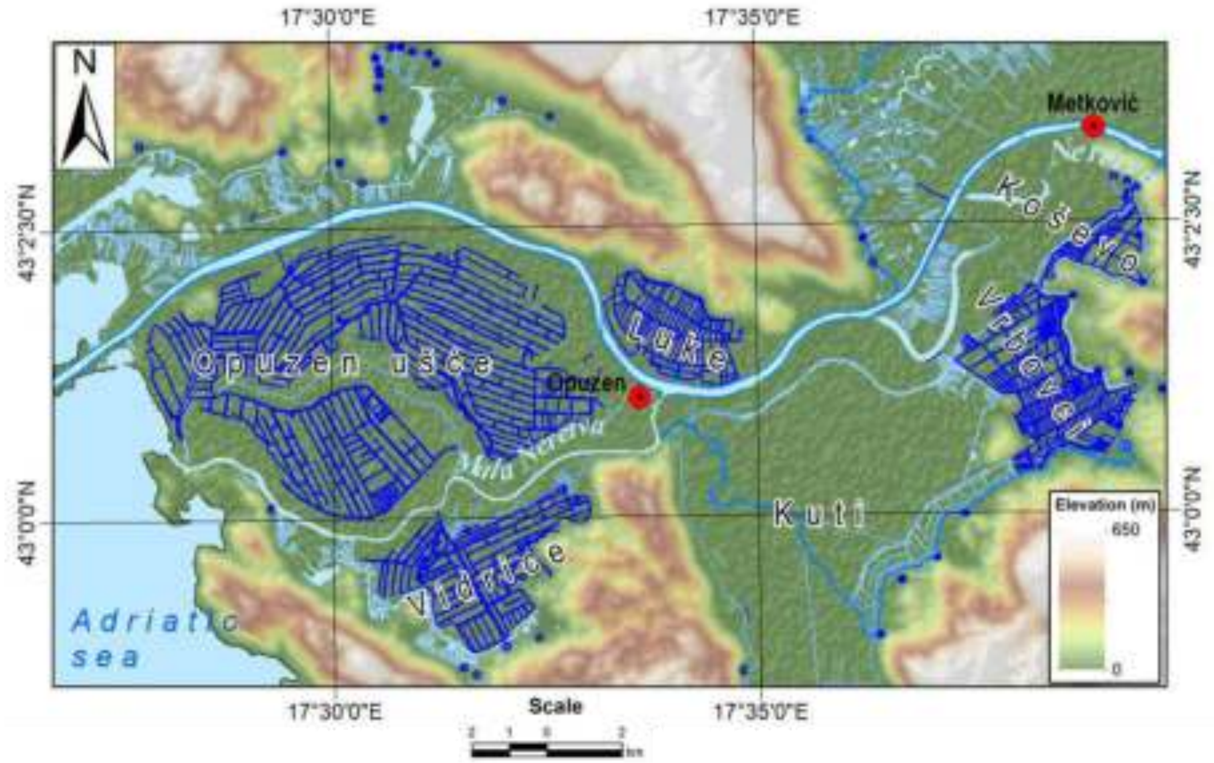


Figure 5.1 Geographical extent of the River Neretva Delta

5.1 Luke

Soil amelioration works in the River Neretva Delta started in the Luke area (Figure 5.1 and Figure 5.2). Due to its small area of roughly 330 ha Luke served as a pilot project. Luke is the only ameliorated area which is situated on the right river Neretva bank.

Figure 5.2 Extent of Luke area and location of soil quality monitoring station P-8

From a historical point of view, agricultural plots in the Luke area were mostly governed by social enterprise PIK "Neretva" (Figure 5.3). Excluding the small fields with permanent crops in the south-western part, Luke area consisted of arable land, meadows, and greenhouses.

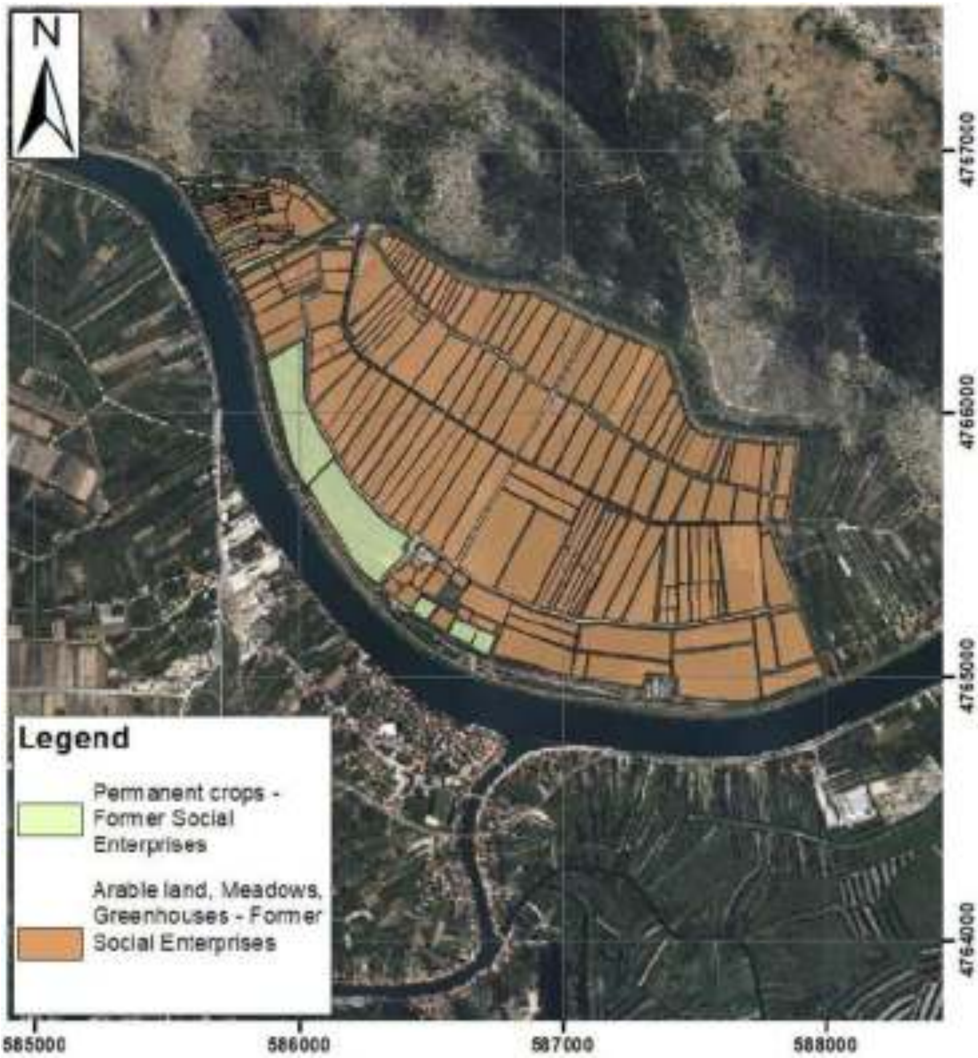


Figure 5.3 Historical land use of Luke area

The CORINE[1] Land Cover (CLC) is inventory which is mostly produced by visual interpretation of high resolution satellite imagery, while in some countries additional processing is implemented: use of national in-situ data, satellite image processing, GIS integration and generalisation.

According to the CLC data from 2018, there are 4 classes in the Luke area (Figure 5.4): permanently irrigated land, complex cultivation patterns, natural grasslands, transitional woodland-shrub. Spatial distribution and areas in hectares are depicted on Figure 5.4 and Figure 5.5.

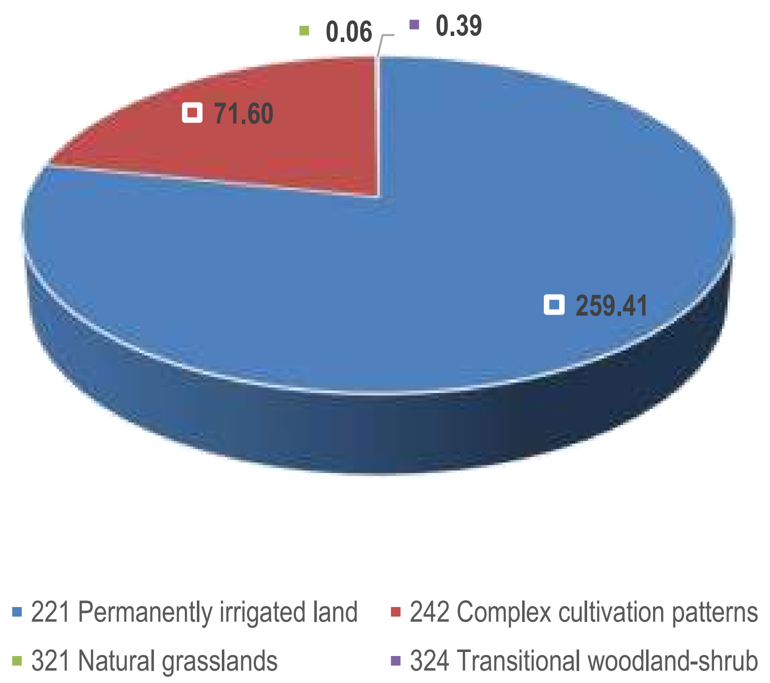


Figure 5.4 Areas (in hectares) of CLC classes for Luke area

[1] https://land.copernicus.eu/pan-european/corine-land-cover

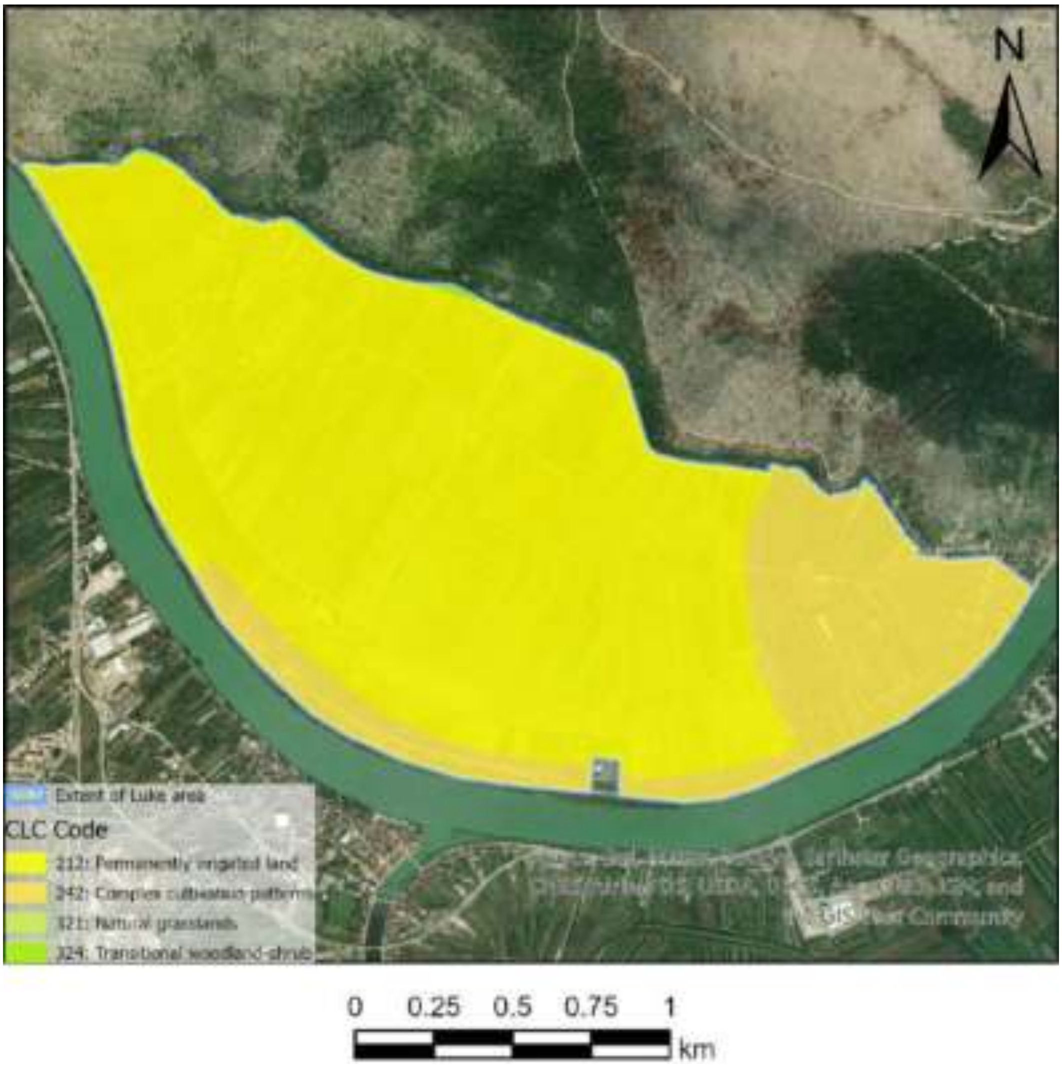


Figure 5.5 CORINE Land Cover for Luke area

Paying Agency for Agriculture, Fisheries and Rural Development (PAAFRD)[2] in Croatia, among other things, keeps track about the agricultural land use through Farmers Register, ARKOD[3] – land parcel identification system, and other accompanying registers (e.g. vineyards register, register of the primary food producers, register of ecological producers). ARKOD data is published

[2] https://www.apprrr.hr/about-us/
[3] https://www.apprrr.hr/arkod/

once a year and it serves for determination of agricultural incentives. Areas in hectares of PAAFRD ARKOD land use classes in 2019 are shown in Figure 5.6. Spatial distribution of agricultural land use in Luke area in 2019, per PAAFRD data, is depicted on Figure 5.7.

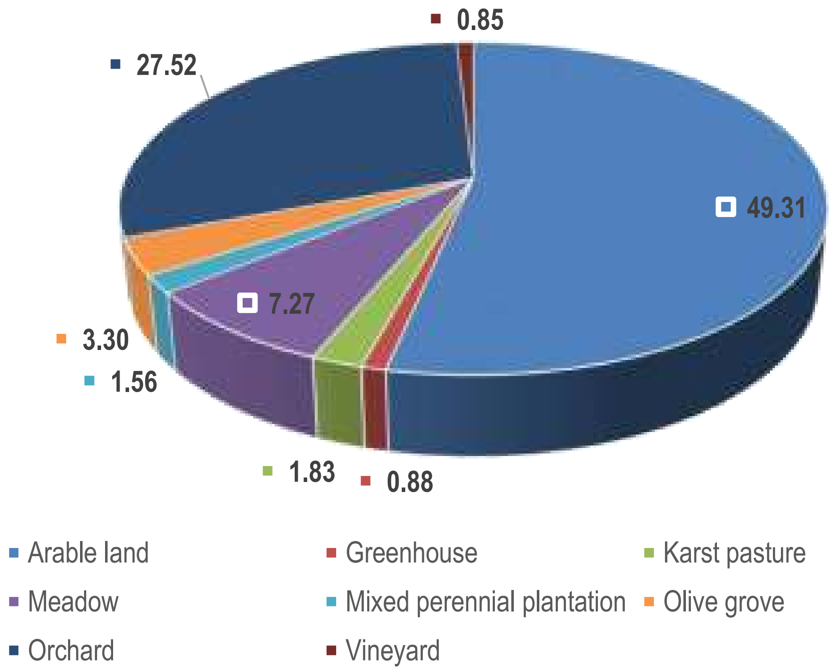


Figure 5.6 Areas in hectares of PAAFRD ARKOD land use in 2019 for Luke region

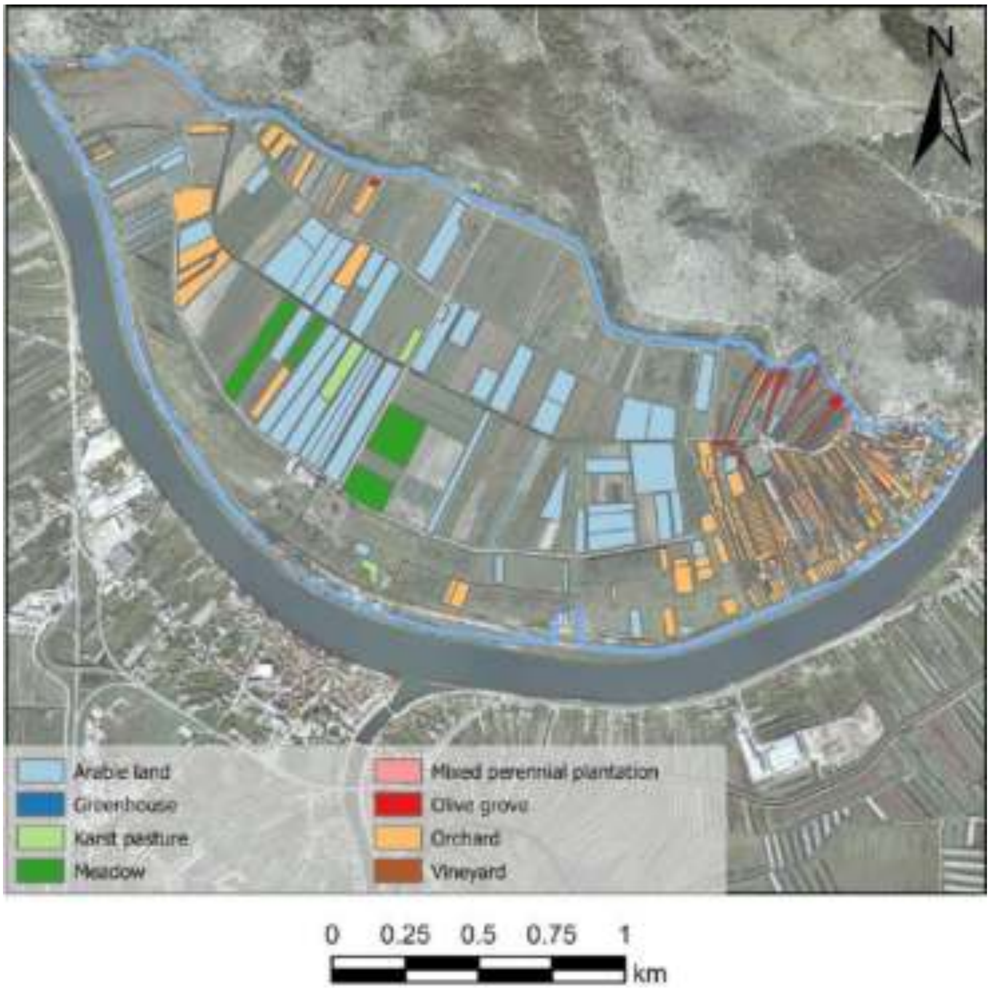


Figure 5.7 Land use in Luke area in 2019 according to the PAAFRD ARKOD data

When the Figure 5.3 and Figure 5.7 are compared, it can be noticed that in recent time significant areas in Luke are abandoned. Precisely, less than a third of the arable land in Luke is cultivated. Arable land occupies 53% of cultivated areas in Luke and it is the most common land use, it is followed by orchards with 30% and meadows with 8%. Overall average area of agricultural plots in 2019 for Luke is 3116 m^2 (Figure 5.8), while the greatest average agricultural plot area had Meadows (18.183 m^2), Arable land (7147 m^2) and Karst pastures (6099 m^2).

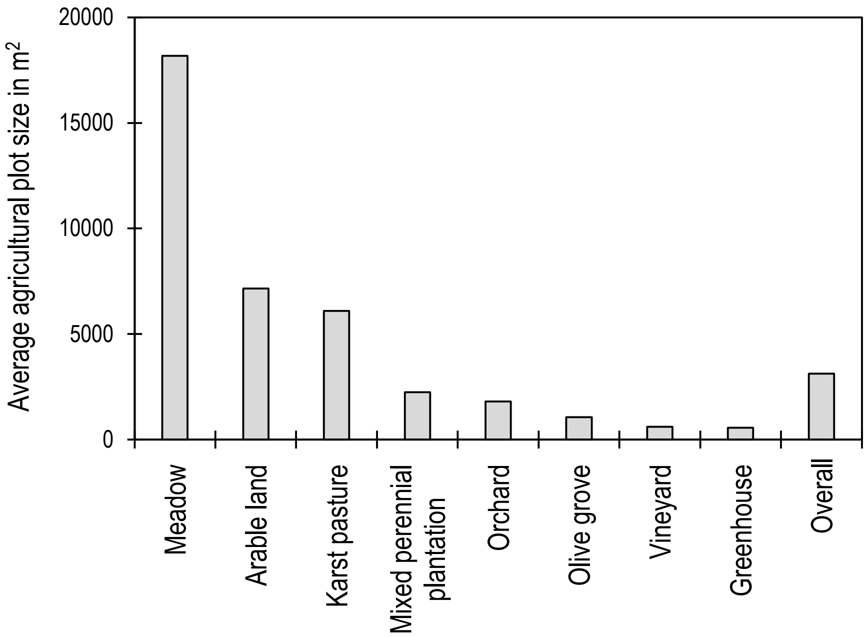


Figure 5.8 Average agricultural plot sizes in m² per PAAFRD ARKOD land use classes in 2019 for Luke area.

Hrvatske Vode[4] (Croatian water), a legal entity for water management in Croatia, funds monitoring of soil and water quality in the River Neretva Delta. In the Luke area one soil quality monitoring station was established, and its location is marked with P-8 on Figure 5.2. Soil quality is monitored twice a year: at the end of the winter season and at the end of the summer season. Sampling and analysis of soil samples is done by Faculty of Agriculture University of Zagreb and the results are published in yearly reports[5].

Pedological profile of the station P-8 is displayed on Figure 5.9 and it can be characterized as eugley, amphigley, mineral, non-carbonate, non-saline, hydromeliorated by channels. Soil salinity can be expressed with several parameters, but electrical conductivity (EC_e) of saturated water extract can be used as overall measure of salinity in a soil profile. For soil quality monitoring station in Luke, for the period 2014-2018, it can be seen that salinity is generally higher after the

[4] https://www.voda.hr/en/node/44

[5] Romić, D., Romić, M., Zovko, M., Bubalo Kovačić, M., Ondrašek, G., Vranješ, M. and Srzić, V. (2014-2018). Monitoring of soil and water salinity in the Neretva River valley-five-year (2004-2018) report.

summer season compared to the measurements after the winter season (Figure 5.10). Statistical parameters of soil quality parameters for station P-8 in period from 2014 to 2018 are listed in Table 5.1.

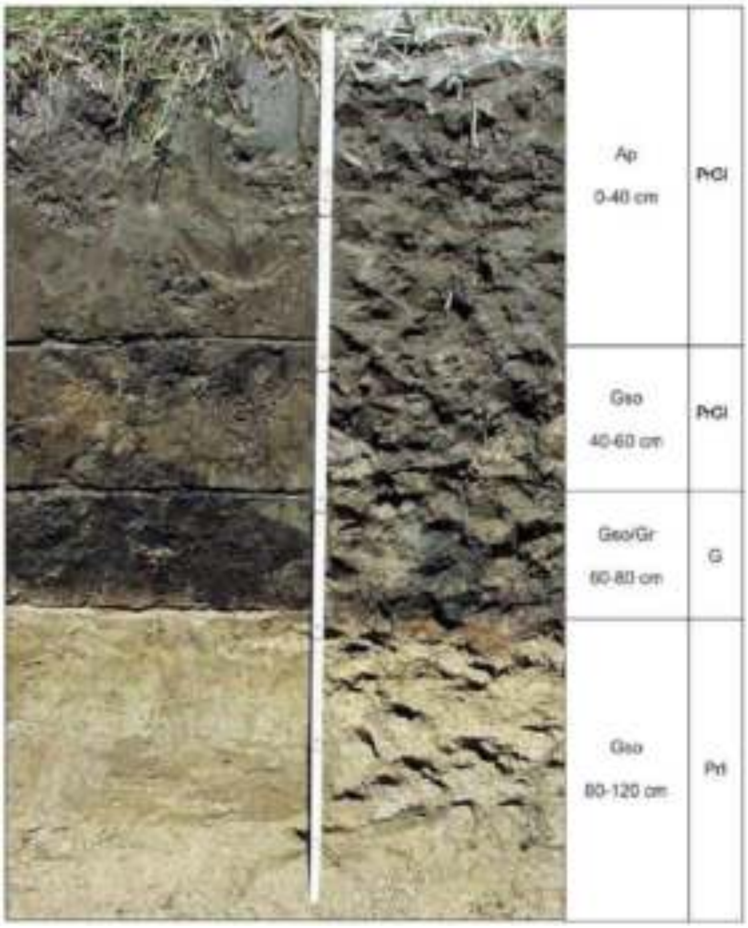


Figure 5.9 Pedological profile P-8 in Luke area (Figure 2)[5]

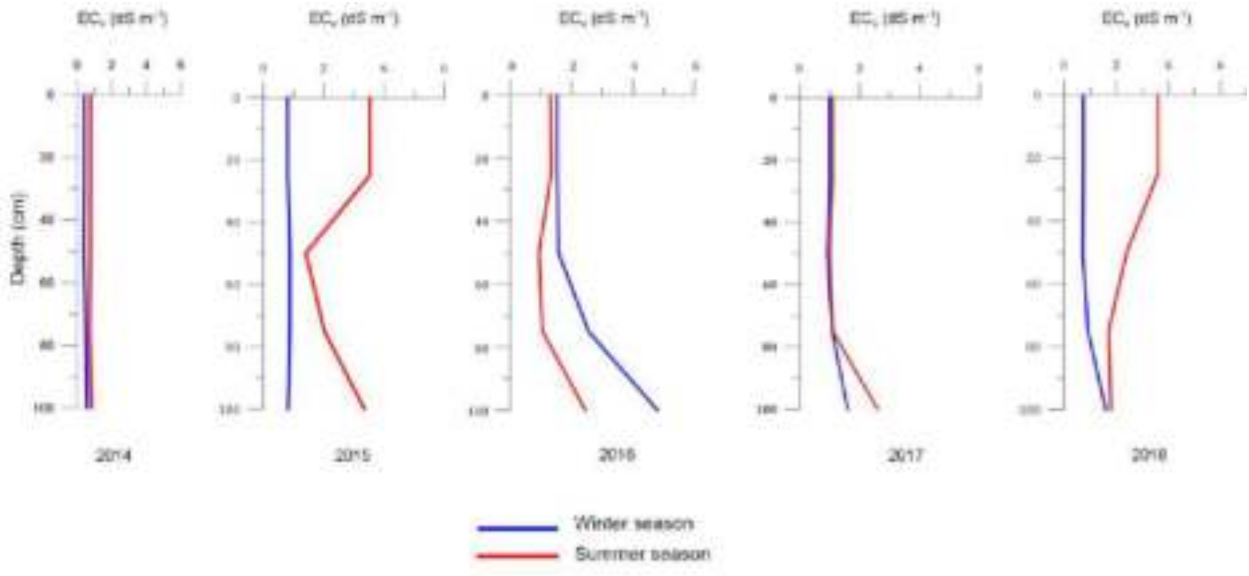


Figure 5.10 Vertical profile of Electrical Conductivity (EC_e) in dSm^{-1} in saturated water extract in winter and summer season from 2014 to 2018 for soil monitoring station P-8. Analysis executed by Faculty of Agriculture University of Zagreb[5].

Table 5.1 Basic statistics of soil quality parameters (ECe,pH, major ion concentrations in saturated water extract) for soil monitoring station P-8 in Luke for period from 2014 to 2018. SD stands for standard deviation and C.V. stands for coefficient of variation. Analysis executed by Faculty of Agriculture University of Zagreb[5].

Parameter	Average	SD	Min	Max	C. V. (%)
EC_e [dS m^{-1}]	1.5	1.0	0.38	4.8	68
pH [mg l^{-1}]	8.2	0.17	7.8	8.5	2.1
Cl^- [mg l^{-1}]	201	207	2.7	823	103
Na^+ [mg l^{-1}]	115	75	7.8	367	65
SO_4^{2-} [mg l^{-1}]	289	318	87	1527	110
Mg^{2+} [mg l^{-1}]	25	18	9.7	103	73
Ca^{2+} [mg l^{-1}]	195	168	67	763	86
HCO_{3-} [mg l^{-1}]	242	64	110	354	27
NO_3-N [mg l^{-1}]	15	36	0.05	206	233
NH_4-N [mg l^{-1}]	2.1	3.8	0.05	18	177
K^+ [mg l^{-1}]	17	15	4.9	81	87
P [mg l^{-1}]	0.1	0.10	0.01	0.38	102

5.2 Vidrice

Soil amelioration works in Vidrice area (Figure 5.1 and Figure 5.11) started in 1970s and they were finished in 1980s. The works covered more than 400 hectares of agricultural fields. Vidrice is the southernmost region in the River Neretva Delta, and it is a pocket encompassed by Mala Neretva effluent from the North and limestone hills from remaining sides.

Figure 5.11 Extent of Vidrice area and location of soil quality monitoring station P-10

Historically, agricultural plots in the Vidrice area were governed social enterprise PIK "Neretva" (Figure 5.12). Private owners cultivated much smaller fields around the perimeter of fields shown on Figure 5.12. In north-western part of the Vidrice region arable land, meadows, and greenhouses were more common land use, while the other parts were populated with permanent crops.

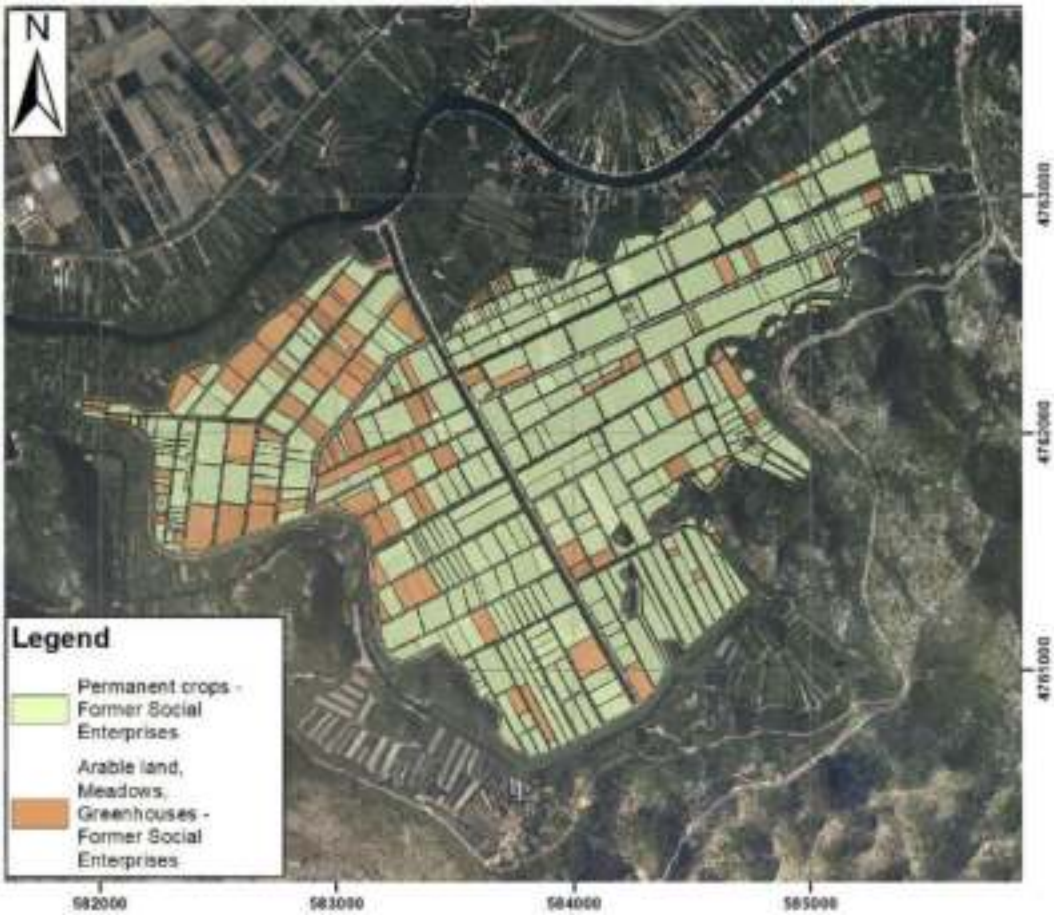


Figure 5.12 Historical land use of Vidrice area

According to the CLC data from 2018 the whole Vidrice area is classified with one code 222 which stands for fruit trees and berry plantations.

Today, agricultural production in Vidrice is mainly oriented on orchards (Figure 5.13 - Figure 5.15), dominated by mandarins. According to the PAAFRD ARKOD data from 2019, orchards occupied 92.13% of the agricultural areas in the Vidrice area. Orchards were followed by mixed perennial plantations (3.54%) and arable land (3.49%).

Figure 5.13 Land use in Vidrice area in 2019 according to the PAAFRD ARKOD data

Figure 5.14 Aerial oblique photo of Vidrice area from the southernmost part of the primary amelioration channel.

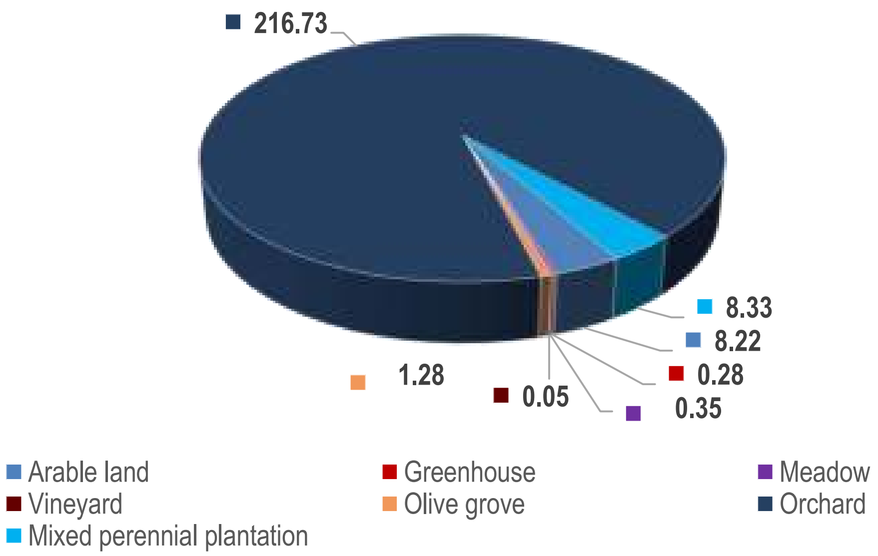


Figure 5.15 Areas in hectares of PAAFRD ARKOD land use in 2019 for Vidrice region

Compared to the Luke area, average agricultural plot areas, per PAAFRD ARKOD classes, showed less variance (Figure 5.16). The most common agricultural plots, orchards and mixed perennial plantations had average size of about 5400 m^2 while arable land had average area of 3915 m^2. Overall average area of all agricultural plots was 5059 m^2.

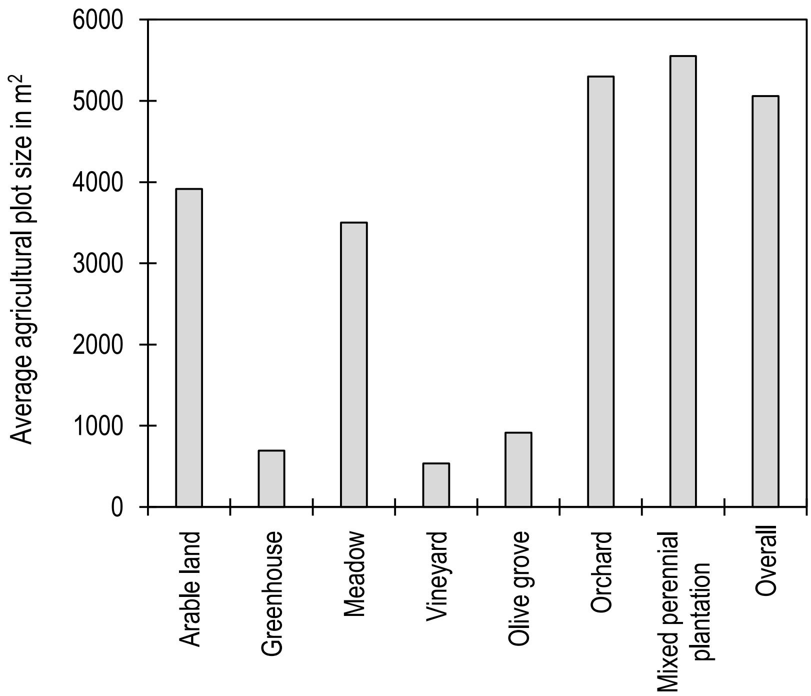


Figure 5.16 Average agricultural plot sizes in m^2 per PAAFRD ARKOD land use classes in 2019 for Vidrice area.

Soil quality monitoring station P-10 is established at land parcel that is being used for intensive production of mandarins with application of irrigation. Pedological profile is displayed in Figure 17 and it can be characterized as eugley, hipogley, mineral, non-carbonate, saline, anthropogenic, hydromeliorated by channels.

In the period 2014-2018, EC_e at station P-10 ranged from 0.97 to 5.0 dSm^{-1} with average value of 3.3 dSm^{-1} (Figure 5.19 and Table 5.2)[5], thus 2.0 dSm^{-1} can be taken as threshold for discrimination of saline and non-saline soils. Statistical parameters of soil quality parameters for station P-10 in period from 2014 to 2018 are listed in Table 5.2.

Figure 5.17 Pedological profile P-10 in Vidrice area (Figure 11) [5]

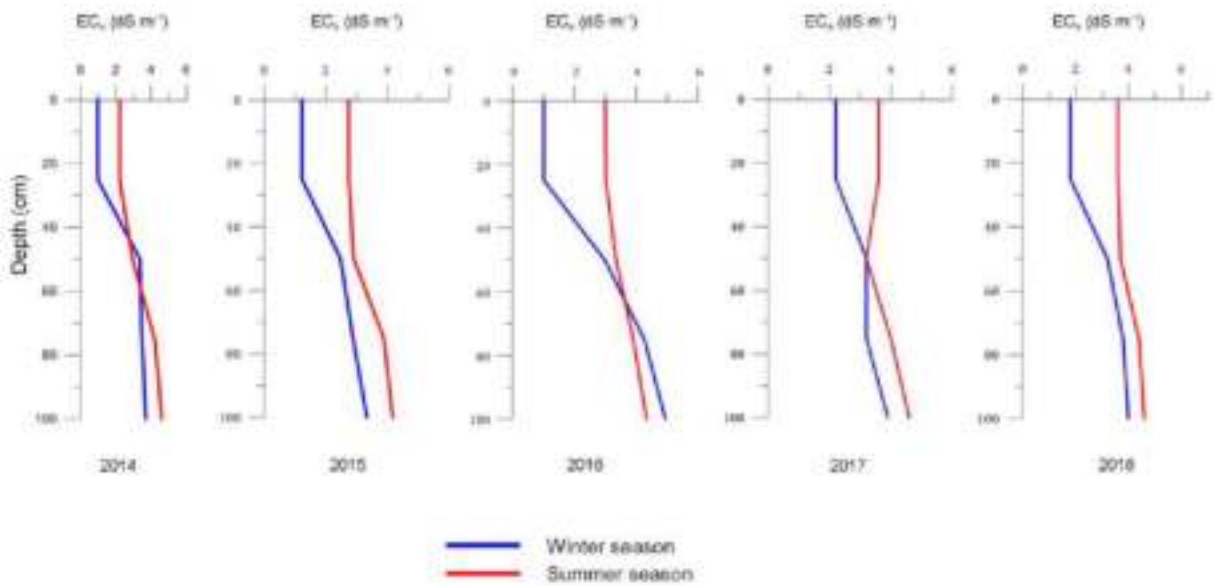


Figure 5.18 Vertical profile of Electrical Conductivity (EC_e) in dSm^{-1} in saturated water extract in winter and summer season from 2014 to 2018 for soil monitoring station P-10 in Vidrice. Analysis executed by Faculty of Agriculture University of Zagreb[5].

Table 5.2 Basic statistics of soil quality parameters (ECe,pH, major ion concentrations in saturated water extract) for soil monitoring station P-10 in Vidrice for period from 2014 to 2018. SD stands for standard deviation and C.V. stands for coefficient of variation. Analysis executed by Faculty of Agriculture University of Zagreb5.

Parameter	Average	SD	Min	Max	C. V. (%)
EC_e [dS m^{-1}]	3.3	0.97	0.97	5.0	29
pH [mg l^{-1}]	8.0	0.13	7.7	8.2	1.7
Cl^- [mg l^{-1}]	254	185	19	634	73
Na^+ [mg l^{-1}]	197	93	33	344	47
SO_4^{2-} [mg l^{-1}]	1808	544	209	3179	30
Mg^{2+} [mg l^{-1}]	107	69	21	399	65
Ca^{2+} [mg l^{-1}]	597	150	106	737	25
HCO_{3^-} [mg l^{-1}]	175	59	85	336	34
NO_3-N [mg l^{-1}]	11	28	0.03	148	259
NH_4-N [mg l^{-1}]	2.8	1.7	0.84	11	62
K^+ [mg l^{-1}]	34	14	17	93	42
P [mg l^{-1}]	0.05	0.06	0.01	0.27	110

5.3 Opuzen ušće

Opuzen ušće (Figure 5.1 and Figure 5.19) is the single largest area in the River Neretva Delta, covering an overall area of almost 3000 hectares. It is encompassed by the river Neretva, the river effluent Mala Neretva, and the Adriatic Sea. Soil amelioration works in Opuzen ušće area started in 1960s.

Figure 5.19 Extent of Opuzen ušće area and location of soil quality monitoring station P-9 and P-11.

As in other regions in the River Neretva Delta, agricultural plots in the Opuzen ušće area were mostly governed social enterprise PIK "Neretva" (Figure 5.20). Private owners owned smaller plots which are placed near the water bodies of Neretva and Mala Neretva, around the fields shown on Figure 5.20. Permanent crops were mostly cultivated in the southern parts, while the northern parts were cultivated with arable land, meadows and greenhouses.

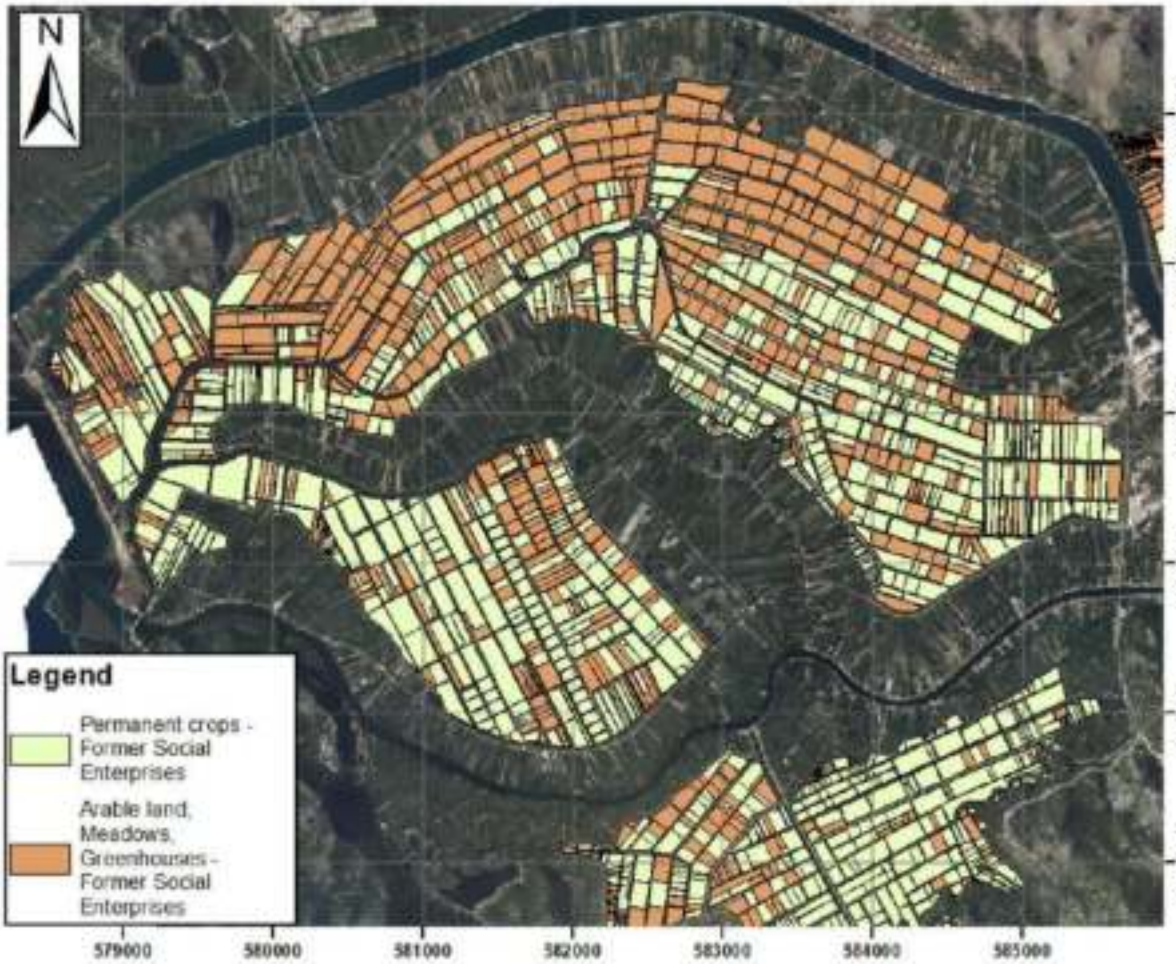


Figure 5.20 Historical land use of Opuzen ušće area

CLC data from 2018 identified seven classes: fruit trees and berry plantations; complex cultivation patterns; discontinuous urban fabric; land principally occupied by agriculture, with significant areas of natural vegetation; sclerophyllous vegetation; salt marshes and water courses. Spatial distribution and areas in hectares are depicted on Figure 5.21 and Figure 5.22.

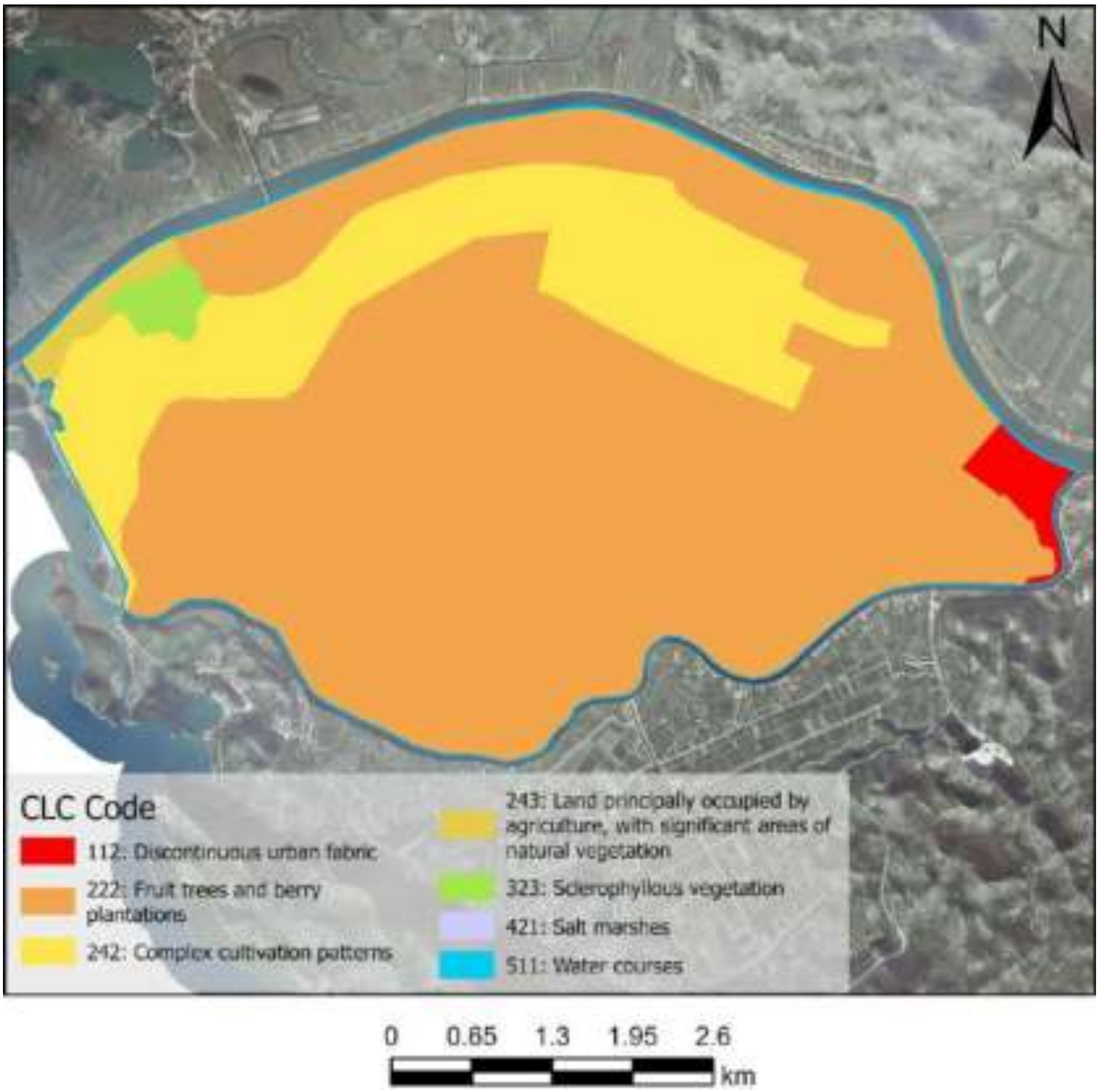


Figure 5.21 Spatial distribution of CORINE Land Cover classes for Opuzen ušće area

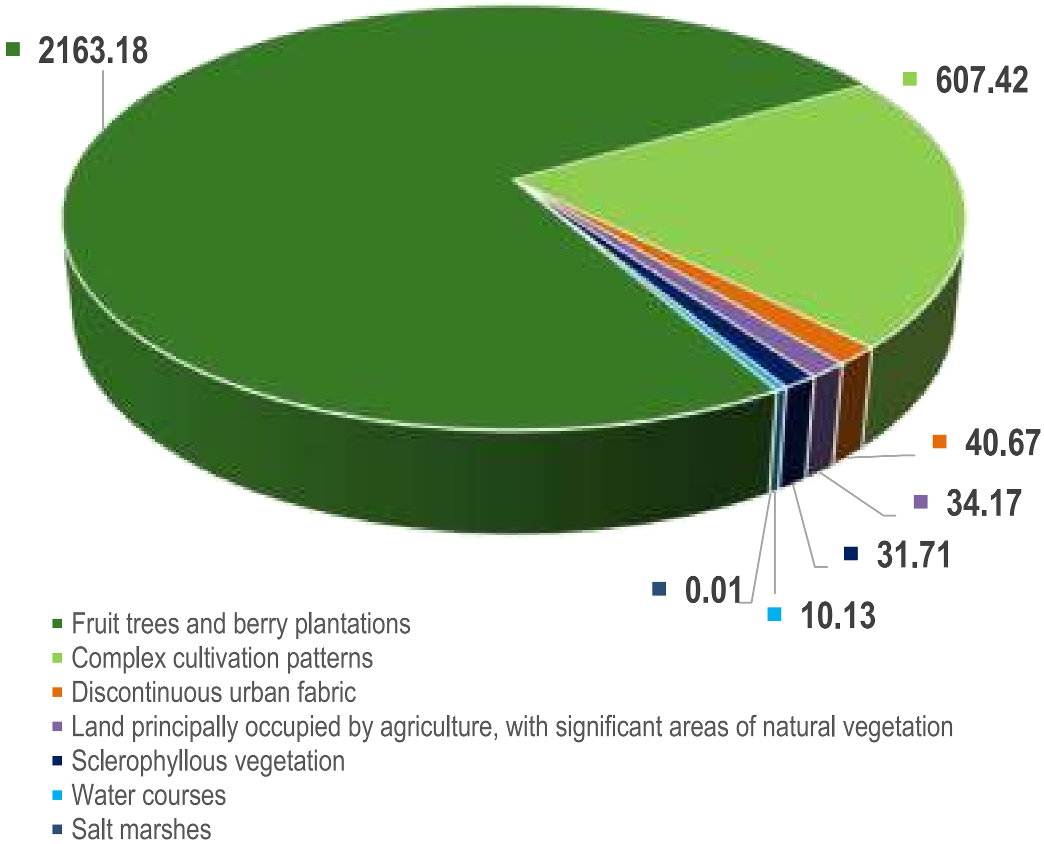


Figure 5.22 Areas (in hectares) of CLC classes for Opuzen ušće area

PAAFRD ARKOD data for 2019 showed that orchards occupy more than 75% of cultivated surfaces in Opuzen ušće and they are followed by arable land (17%) and mixed perennial plantations (1.7%) (Figure 5.23 -Figure 5.25). Orchards are mainly populated with citrus and mandarins are the most frequent culture (Figure 5.24). Arable land is more concentrated in the northern part of the Opuzen ušće, near the river Neretva. The highest average agricultural plot areas in Opuzen ušće are for karst pastures and meadows with average area around one hectare (Figure 5.26). Orchards and overall average area of agricultural plots in Opuzen ušće is around 3700 m^2.

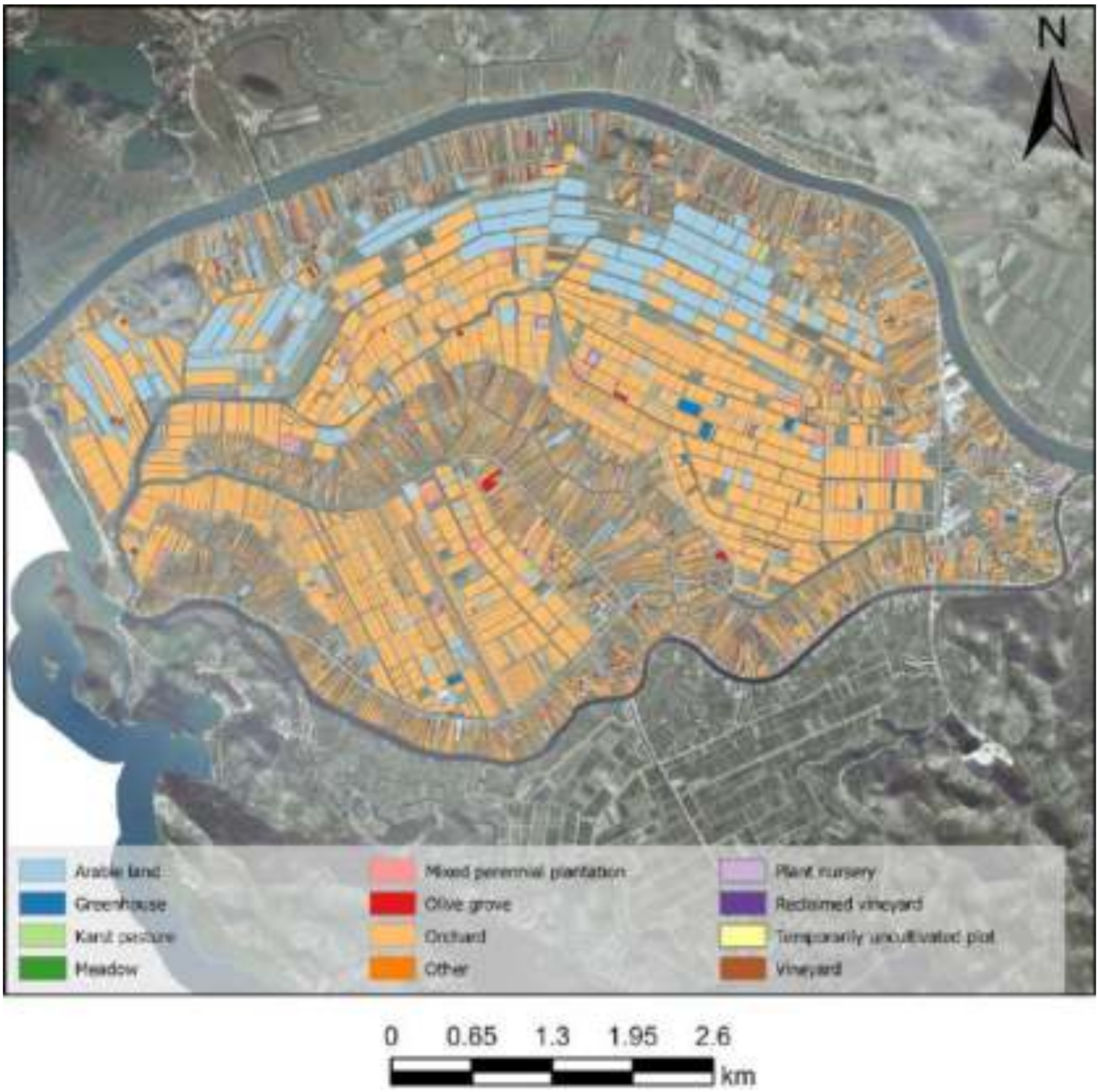


Figure 5.23 Land use in Opuzen ušće area in 2019 according to the PAAFRD ARKOD data

Figure 5.24 Aerial oblique photo of Opuzen ušće area, view from the sea.

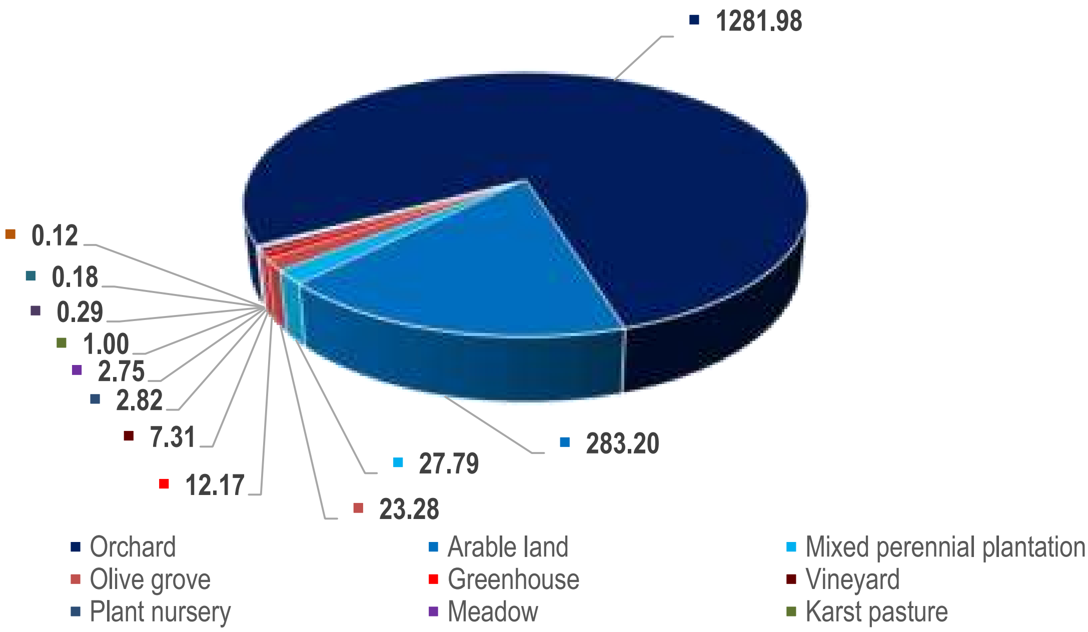


Figure 5.25 Areas in hectares of PAAFRD ARKOD land use in 2019 for Opuzen usce region

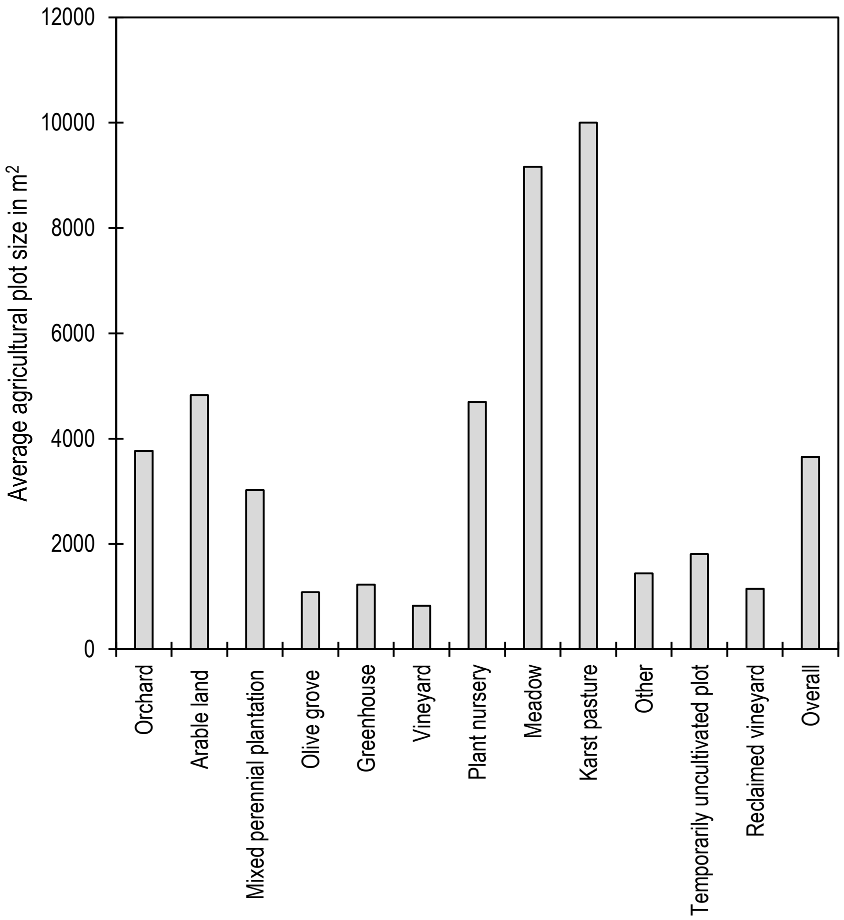


Figure 5.26 Average agricultural plot sizes in m² per PAAFRD ARKOD land use classes in 2019 for Opuzen ušće area.

Soil quality monitoring station P-9 is established at land parcel that is being used conventional production of vegetables with established crop rotation: cabbage in spring or winter with melon or watermelon. Pedological profile is displayed in Figure 5.27 and it can be characterized as humofluvisol. Humofluvisol is dominantly present in areas where hydromelioration systems with open channel drainage are built. These soils are so anthropogenised and hydromeliorated.

In the period 2014-2018, EC_e at station P-9 ranged from 0.41 to 6.0 dSm^{-1} with average value of 2.8 dSm^{-1} (Figure 5.28 and Table 5.3)[5]. Statistical parameters of soil quality parameters for station P-9 in period from 2014 to 2018 are listed in Table 5.3.

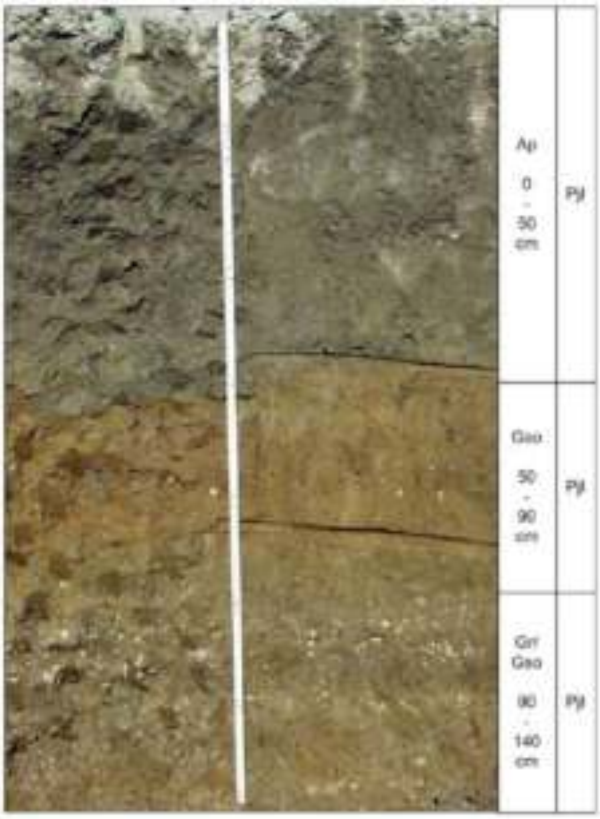


Figure 5.27 Pedological profile P-9 in Opuzen ušće area (Figure 1) [5]

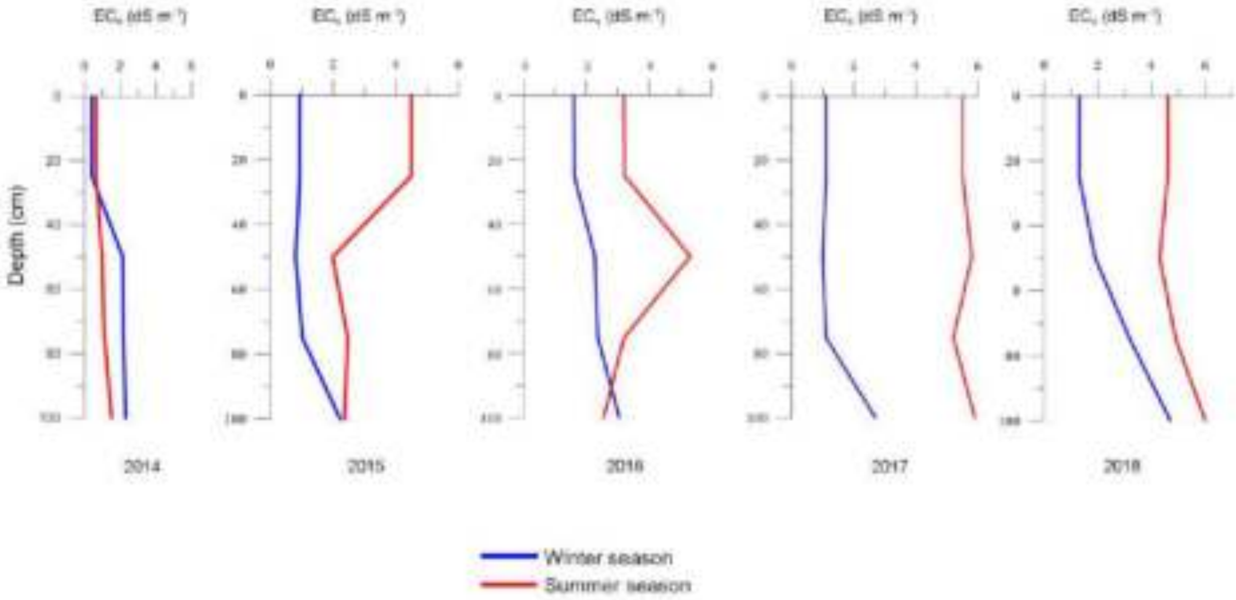


Figure 5.28 Vertical profile of Electrical Conductivity (EC_e) in dSm^{-1} in saturated water extract in winter and summer season from 2014 to 2018 for soil monitoring station P-9 in Opuzen ušće. Analysis executed by Faculty of Agriculture University of Zagreb[5].

Table 5.3 Basic statistics of soil quality parameters (ECe,pH, major ion concentrations in saturated water extract) for soil monitoring station P-9 in Opuzen ušće for period from 2014 to 2018. SD stands for standard deviation and C.V. stands for coefficient of variation. Analysis executed by Faculty of Agriculture University of Zagreb5.

Parameter	Average	SD	Min	Max	C. V. (%)
EC_e [dS m^{-1}]	2.8	1.7	0.41	6.0	61
pH [mg l^{-1}]	8.0	0.21	7.5	8.4	2.7
Cl^- [mg l^{-1}]	330	436	4.9	1361	132
Na^+ [mg l^{-1}]	158	153	4.7	515	97
SO_4^{2-} [mg l^{-1}]	887	709	121	4108	80
Mg^{2+} [mg l^{-1}]	59	43	12	156	74
Ca^{2+} [mg l^{-1}]	442	240	74	954	54
HCO_3^- [mg l^{-1}]	153	83	67	415	54
NO_3-N [mg l^{-1}]	55	107	0.04	571	192
NH_4-N [mg l^{-1}]	1.3	0.80	0.10	3.3	63
K^+ [mg l^{-1}]	40	36	11	148	90
P [mg l^{-1}]	0.07	0.11	0.01	0.56	154

Soil quality monitoring station P-11 is established at land parcel that is being used intensive production of mandarins. Pedological profile is displayed in Figure 5.29 and it can be characterized as fluvisol.

In the period 2014-2018, EC_e at station P-9 ranged from 0.53 to 3.7 dSm^{-1} with average value of 2.3 dSm^{-1} (Figure 5.29 and Table 5.4) [5]. Statistical parameters of soil quality parameters for station P-11 in period from 2014 to 2018 are listed in Table 5.4.

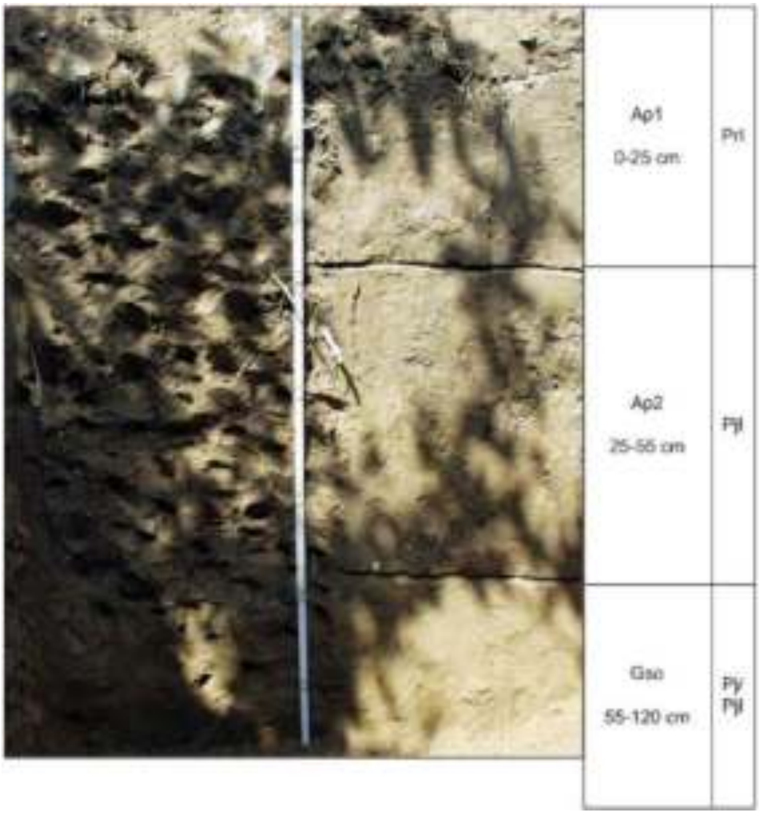


Figure 5.29 Pedological profile P-11 in Opuzen ušće area (Figure 19) [5]

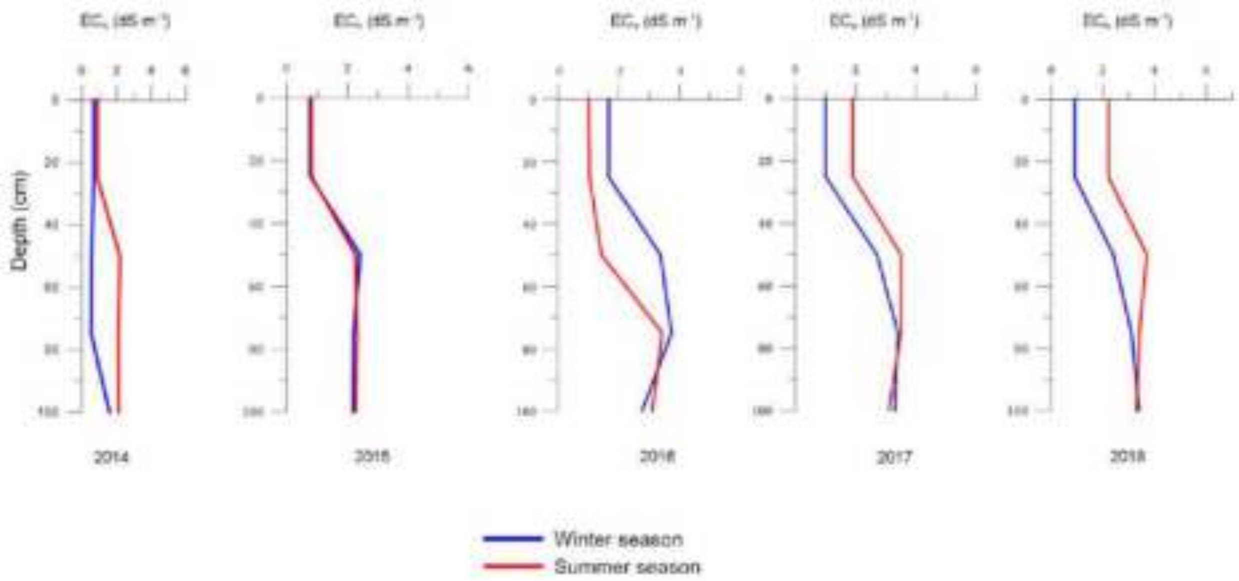


Figure 5.30 Vertical profile of Electrical Conductivity (ECe) in dSm-1 in saturated water extract in winter and summer season from 2014 to 2018 for soil monitoring station P-11 in Opuzen ušće. Analysis executed by Faculty of Agriculture University of Zagreb[5].

Table 5.4 Basic statistics of soil quality parameters (ECe,pH, major ion concentrations in saturated water extract) for soil monitoring station P-11 in Opuzen ušće for period from 2014 to 2018. SD stands for standard deviation and C.V. stands for coefficient of variation. Analysis executed by Faculty of Agriculture University of Zagreb5.

Parameter	Average	SD	Min	Max	C. V. (%)
EC_e [dS m^{-1}]	2.3	1	0.53	3.7	44
pH [mg l^{-1}]	7.9	0.18	7.6	8.3	2.3
Cl^- [mg l^{-1}]	122	118	3.2	459	97
Na^+ [mg l^{-1}]	74	63	5.2	236	86
SO_4^{2-} [mg l^{-1}]	1195	650	180	1903	54
Mg^{2+} [mg l^{-1}]	52	27	9.7	107	51
Ca^{2+} [mg l^{-1}]	479	232	83	750	48
HCO_3^- [mg l^{-1}]	122	57	61	281	46
NO_3-N [mg l^{-1}]	13	26	0.09	113	203
NH_4-N [mg l^{-1}]	1.3	1.3	0.18	8.4	100
K^+ [mg l^{-1}]	28	15	7.2	81	54
P [mg l^{-1}]	0.05	0.06	0.01	0.24	117

[1] CORINE Land Cover:

https://land.copernicus.eu/pan-european/corine-land-cover

[2] Paying Agency for Agriculture, Fisheries and Rural Development (PAAFRD):

https://www.apprrr.hr/about-us/

[3] ARKOD – land parcel identification system

https://www.apprrr.hr/arkod/

[4] Croatian Water

https://www.voda.hr/en/node/44

[5] Romić, D., Romić, M., Zovko, M., Bubalo Kovačić, M., Ondrašek, G., Vranješ, M. and Srzić, V. (2014-2018). Monitoring of soil and water salinity in the Neretva River valley-five-year (2004-2018) report.

6 Engineering geological research

The scope of engineering geological research is defined by the project task of the Investor, Faculty of Civil Engineering, Architecture and Geodesy, University of Split, which includes engineering geological mapping of carbonate base rock outcrops, as follows:

- along the Diga profile, Opuzen road profile, Vidrice – Crepina profile,

- in the zones of elevations, hills within the Neretva valley.

Engineering geological research included mapping the boundary of carbonate rock and alluvial deposits in these zones, determining the lithostratigraphic characteristics of the bedrock and determining the basic structure of the rock mass.

Engineering geological works were carried out during February 2022.

6.1 Engineering geological research

The aim of engineering geological mapping was to define the boundary of carbonate rock and alluvial deposits along Diga, Opuzen road and Vidrice - Crepina profiles, and in the zones of hills within the Neretva Valley, to determine lithostratigraphic characteristics of the bedrock and to determine the basic structure of the rock mass.

The 1700 m long Diga profile is located in the western part of the exploration area and follows the coastal embankment from the Neretva estuary to the Mala Neretva estuary. The profile of the Opuzen road, 2300 m long, extends in the eastern part of the exploration area in a north-south direction. It passes through the state road from the Neretva near Opuzen to the Mala Neretva bridge in the south. The 2300-meter-long Vidrica profile is located in the southern part of the exploration area, east of the Prag pumping station. Profile Crepina is 2000 m long and it is located in the central part of the valley. Within the valley there are several hills, mostly in the southern part, along the edge of the valley. Several hills are located north and northwest of the Diga profile, and also in the northern part of the exploration area, along the state road.

6.1.1 Morphological characteristics of the research area

The research area is defined by the project task of the Investor, and includes the part of the LowerNeretva from Opuzen to the estuary. The research area is bounded by the river Neretva on the north side, the state road Opuzen on the east side, the embankment Diga on the west side, while on the south and southeast side the valley is bordered by hills extending southward.

The part of the Lower Neretva which has been researched is an agricultural area that covers an area of approximately 35 km2. The area is flattened, stretches at an altitude close to sea level, intersected by several bayou and numerous canals dug for irrigation. At Opuzen, the Mala Neretva separates from the main stream, and represents the most prominent watercourse that flows through the central part of the valley and flows into the sea near Blace. The valley is mainly a cultivated area where citrus fruits are primarily grown, but also other crops such as olives, cabbages, watermelons and others. A small part of the area is covered with underbrush and reeds.

In the area of the Neretva Valley, near to the town of Opuzen, there are several smaller places. Along the course of the Mala Neretva near Opuzen, on the east side of the bridge Buk Vlaka is located, while west of the bridge is the settlement of Podgradina. On the south side of the valley, along the local road, there are several smaller places - Pižinovac, Lovorje, Tuštevac, Mihalj, Otok and Trn. At the delta of Neretva, between the hills Kozjak and Galičak, there are a small number of buildings that administratively belong to Komin.

Within the valley rises hills, outcrops of the basic rock of carbonate composition, especially in its southern part. In the southern part of the valley, going from east to west rises Babica školj (18,5 m above sea level), Gubavac (12,9 m above sea level), Veliki školj (14.2 m above sea level), Srednji školj (8,7 m above sea level), Mali školj (9,7 m above sea level), Veliki obalac (26 m above sea level), Mali obalac (28 m above sea level) and Tuštovska glavica (77,8 m above sea level). Slightly north of the Veliki školj there are rock outcrops of carbonate composition that are not shown on the base map M 1:5 000. On the northern edge of the Diga embankment, there is the Galičak hill (33 m above sea level) on which a bird observatory was built, and it belongs to the ornithological reserve of the Neretva estuary. On the eastern side of the Diga profile, there are two smaller hills called Kučice (3,7 and 4,2 m above sea level). Northeast of the estuary is the hill Kozjak (highest peak 80,5 m above sea level). In the northern part of the research area, near the state road D8, which stretches along the Neretva, there are Dobruške glavice (36 m above sea level). East of Dobruške glavice there is a smaller mound Gubava glavica (6,6 m above sea level), and to the west there is a mound without a toponymic mark (8,6 m above sea level).

An overview of the points of observation of engineering geological mapping is given on a topographic basis M 1: 25 000, Figure 7.1.

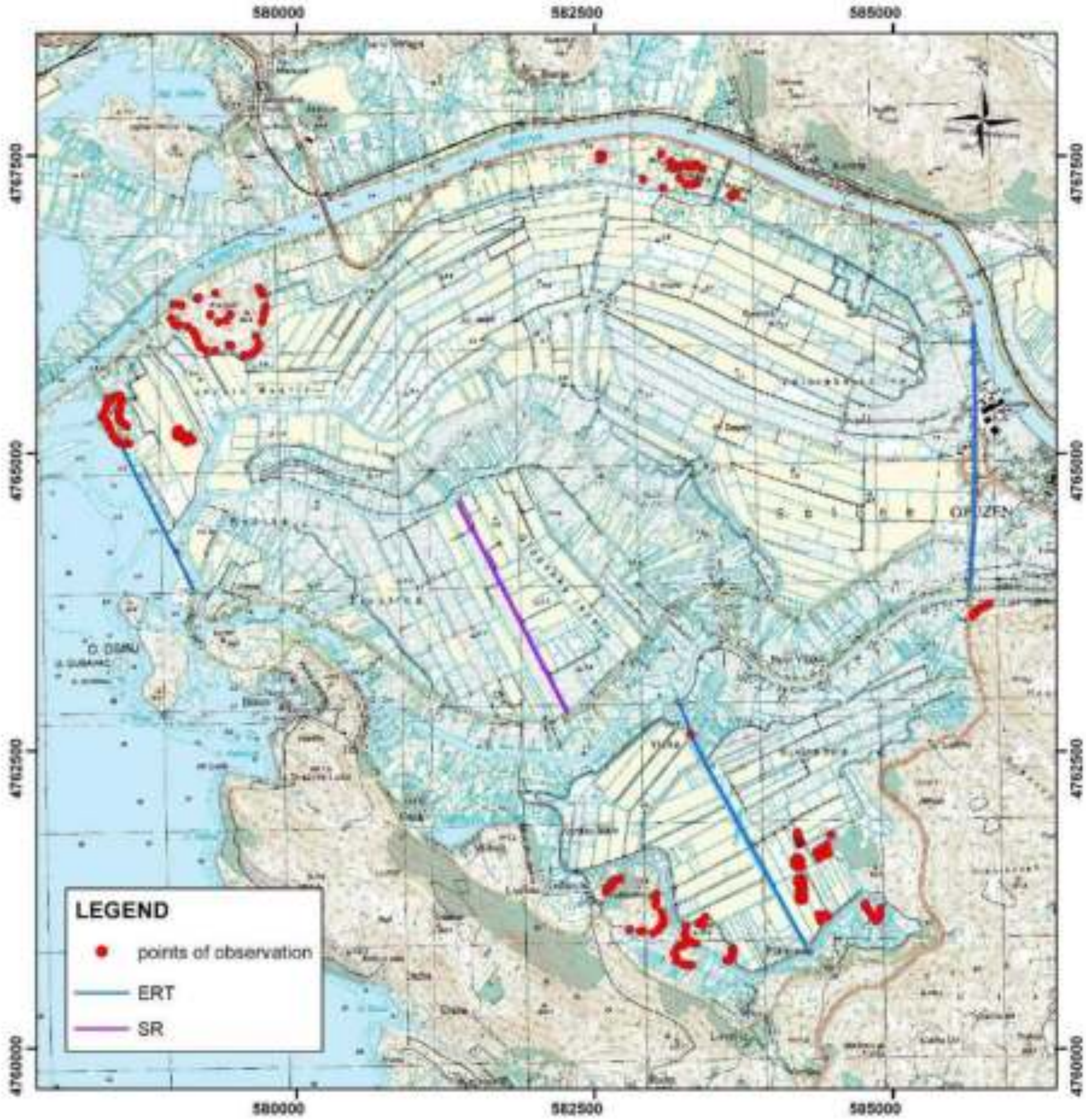


Figure 6.1Overview map of the research area with observation points on topographic map M 1:25 000

6.1.2 Geological characteristics of the wider space

The knowledge about the geological structure of the researched area is contained in the Basic Geological Map of SFRY 1: 100 000 and the corresponding interpreters. The research area stretches on four sheets - Ploče, Metković, Ston and Korčula. The largest part of the Neretva Valley is covered by Metković sheet (Rajić V. et al., 1975), and covers the area approximately between the Neretva and Mala Neretva, from Opuzen to the west in the length of 5,5 km, or the northeastern part of the area. This sheet contains the profile of the Opuzen state road, the profile of Crepina and several carbonate outcrops within the valley. The southern part of the Neretva Valley is covered by the Ston sheet (Rajić V. et al., 1980), and covers the area between the Mala Neretva and the southern edge of the valley. This sheet contains the profile of Vidrica and numerous hills within the valley. The south-western part of the study area nearby Otok is covered by the Korčula sheet (Korolija B., 1976). The north-western part of the study area is covered by the Ploče sheet (Marinčić S., 1978) on which the Diga profile is located and several elevations north and northeast of the profile.

According to the Basic Geological Map, in the subject area deposits that have been deposited belong to periods ranging from the Lower Jurassic to the Quaternary. Quaternary deposits (Q) cover almost the entire valley. The following stratigraphic members are represented in the researched area:

- delta sediments (ad) are present in the area of the Neretva estuary and along the Diga embankment,

- organogenic-bog sediments (b) cover almost the entire valley,

- late Cretaceous deposits of the Turonian - Senonian period (K22,3), limestones with rudists are present in the northern, eastern and southeastern part,

- late Cretaceous deposits of the Cenomanian - Turonian period (K21,2), limestones and dolomites with hodrodonts are present in the southeastern part,

- early Cretaceous deposits (1K1), limestones and dolomites with favreins are present in the southern edge of the valley, and limestones and breccias (K1) in the northwestern part of the researched area,

- late Jurassic deposits of the Kimmeridgian - Tithonian period (J32,3), limestones with Clipeyna are present on the southern and western part of the researched area,

- late Jurassic deposits of the Oxfordian - Kimmeridgian period (J31,2), limestones with cladophoropsis are present in the southwestern part of the researched area,

- early - midle Jurassic deposits (J1,2), oolithic and pseudo oolithic limestones are present in the southern part of the researched area.

The lithological description of these deposits will be described in detail in the chapter below. The geological overview of the wider research area with the profiles of Diga, Opuzen road and Vidrice – Crepina is given on the Basic Geological Map in Figure 6.2.

Structurally, the wider research area is characterized by folds and overturned folds of NW-SE strike. In the northeastern part of the area, within the Svitavsko-Ljubuška tectonic unit, along the edge of the valley, there is an anticline built by Upper Cretaceous deposits, limestone with rudists. In the continuation to the northeast there is an overturned syncline built of Paleogene sediments, on wich the Upper Cretaceous deposits further on the northeast are over thrust. In the south-western part, the researched area belongs to the structural - facial unit of the High karst overthrust. Within this unit comes the structural unit Biokovo - Smokovljani, which in the south-western part is overthrust to clastic Eocene deposits, alveolinic numulitic limestones or directly to the Upper Cretaceous limestone. Jurassic carbonate deposits form this unit in the observed area. The unit stretches on the south of the valley. Northeast of Biokovo - Smokovljani unit lies Hutovo structural unit, developed by Cretaceous deposits. This unit stretches on the southeast of the valley.

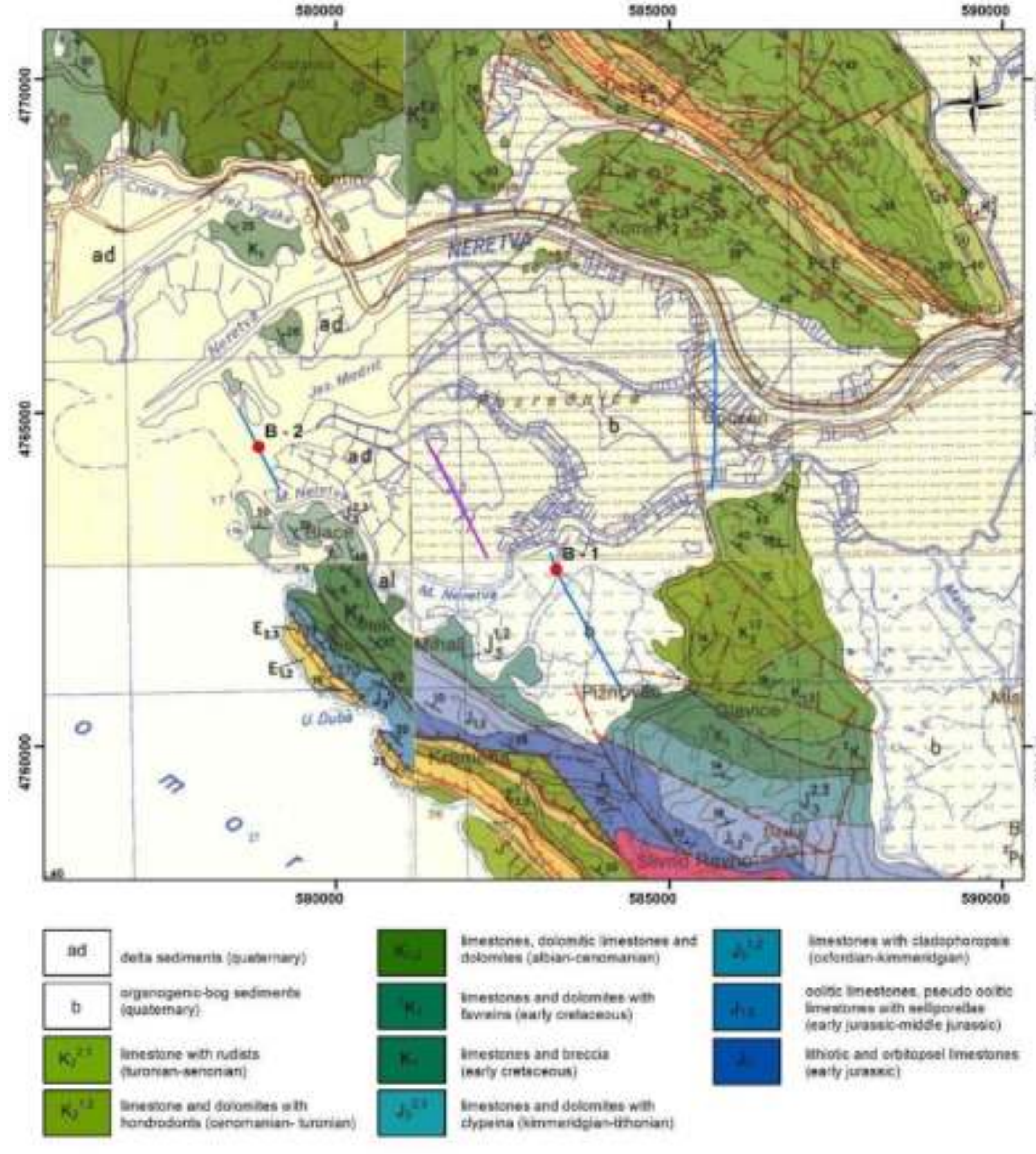


Figure 6.2Research area on Basic geological map M:100 000

6.1.3 Litostratigraphic characteristics of the research area

For reinterpretation of the data of the Basic Geological Map of the researched area, detailed geological mapping works have been made. Geological mapping was performed by processing 200 observation points, which were recorded with a GPS device and photo-documented. As part of field research, rock outcrops were processed with the following data: lithological composition, sedimentological development, fossil content, structural type, stratification, strike and dip of layers, joints, joint sets and systems, faults and fault zones, karstification and tectonicity of deposits.

The largest part of the researched area of the Neretva Valley is covered by Quaternary deposits, which according to the Basic geological map are represented by organogenic bogs (b) and delta sediments (ad). Organogenic bog sediments are represented by clays, sands and peat. The delta sediments are located in the area of the widened Neretva estuary, where marine, freshwater - brackish and lagoon deposits alternate. These sediments are made of gravels that lie on sandy clay material.

In the period from 1962 until today, numerous studies have been conducted to obtain data on the thickness of Quaternary sediments. According to the hydrogeological map Opuzen - Ušće (Beljavski, 1968), the thickness of Quaternary deposits in the Neretva Valley varies between 10 and 120 m, with the greatest thickness assumed in the central part of the valley, and extends from Opuzen to the embankment Diga. In the period 2005.-2019. numerous exploration boreholes between 5,0 and 125,0 m deep were drilled, and in some of them the base rock was drilled. Depending on the position of an individual borehole, the depth to the base rock is 1,5 to 35,0 m. The boreholes in which the base rock was drilled are mostly located along the edges of the valley. On the Diga profile, approx. 400 m south of the Galičak hill, the base rock was drilled to a depth of 35,0 m. The deepest borehole, named DP, 125,0 m deep (Geoid Beroš, 2014) was located in the central part of the valley, in which bedrock was not drilled. Within this project, three exploration boreholes were drilled. B-1 (S-104-21-01) is located in the northern part of the Vidrice profile, 40,0 m deep, B-2 (S-104-21-02) in the central part of the Diga profile, 90,0 m deep, and B-3 (S-104-21-03) in the northern part of Diga profile, 20 m deep. The bedrock in B-1 (S-104-21-01) was drilled on a depth of 34,3 m, and in B-2 (S-104-21-02) and B-3 (S-104-21-03) the bedrock was not drilled.

Within the Neretva Valley there are some carbonate outcrops, hills of relatively small height, from a few to a maximum 80 m. In the following, a description of the mapped units will be given separately for each profile.

6.1.3.1 Diga profile

The Diga profile follows the coastline and stretches through the Quaternary deposits. No outcrops along the profile were observed by field mapping. The terrain was covered with Quaternary deposits. On the northern edge of the profile lies the Galičak hill. The hill is elongated, stretching in a north-south direction, measuring approximately 420x150 m.

According to the Basic Geological Map, Ploče sheet, in this area there are stratigraphic strata of the Late Jurassic, Kimmeridgian - Titohonian (J32,3), and in lithological point of view Clypeina limestones with dolomite and breccia lenses are represented. These deposits were deposited continuously on younger Late Jurassic sediment, Oxfordian - Kimmeridgian period. Limestones are massive to thickly layered (150 cm), in which occur sedimentary breccia lenses and dolomite lenses and interlayers. These are micritic and biomicritic limestones that can be fossilized. Sparite rock varieties contain densely packed pellets or intraclasts. The stratigraphic affiliation was determined on the basis of the fossil community. Of the microfossils, algae are represented, of which Clypeina jurassica is the most numerous. The described deposits very rarely contain the remains of larger mollusk.

Field mapping established that only limestones are present on the GALIČAK hill. The deposits are intensively karstificated and tectonised, with numerous joints, joint sets and systems and faults. The appearance of lapies and caverns is common. Limestones are mostly massive, and stratification is rarely observed. The stratified limestones were mapped in the southern part of the hill, where they are slightly laid in the east direction, 4-8 dm thick (Figure 7.3). Limestones are light cream in color, structural type mudstone. Fine-grained to medium-grained varieties are less common, mapped in the northern part of the hill, within the fault zone where limestones have a breccia appearance. Joints and joint systems are varied in orientations and strikes. The joints are mostly open, with aperture 1-5 dm. On the western side of the hill, a stone excavation was carried out. The front of the excavation representing a fault plane, NW-SE strike (Figure .4), with a series of discontinuities visible on the plane. In the northern part of the excavation, the mapped fault has WNW-ESE strike (Figure 7.5). At the northern edge of the hill, a fault zone of

NW-SE strike, about 20 m wide was mapped, with a series of parallel joints (Figure 7.6). The fossil community is represented by microfossils, predominantly algae, while macrofossils are rarely observed, mainly mollusk shells. On the eastern side of the hill, a spring up to 0,2 l/s was recorded, which springs through a set of parallel joints (Figure 7.7).

Figure 6.3 Layered limestones in the southern part of the Galičak hill

Figure 6.4 Fault scarp, NW-SE strike

Figure 6.5 Fault plane, WNW- ESE strike

Figure 6.6 Fault zone of NW-SE in the north of the Galičak hill

Within the valley, approximately 470 m east of the northern edge of the Diga profile, there are two smaller mounds measuring 40x60 m and 40x75 m called KUČICE. These are light cream limestones, structural type mudstone, and in some places there are fine-grained varieties. The deposits are intensively karstic and tectonic, and lapies and caverns are common as karst forms. Limestones are mostly massive or thickly stratified, dm dimenstion (5-9) or m (1-1,2). The layers lie to the southwest at an angle of 33-50° and to the northwest (10-20 °) (Figure 6.8). The joints are subvertical, most often extending NW-SE, or steeply laid to the SW or NE. They are mostly open, with aperture 5-25 cm. The fossil community is represented by microfossils, predominantly algae, while macrofossils are less common, mostly mollusk shells.


Figure 6.7 Spring on the east side of the Galičak hill


Figure 6.8 Layered limestone on the southeastern mound of Kučice

6.1.3.2 Profile Opuzen state road

The profile of the Opuzen state road extends along the state road D8 in the length of 2300 m. On the southern side of the Mala Neretva there is the hill RKALOVAC, at the foot of which the town of Podgradina is located. The field mapping covers the edge of the hill from the state road to the east, in the length of 250 m.

According to the Basic Geological Map, Metković, in this area there are stratigraphic strata of the Late Cretaceous, turon - senon (K22,3), and in the lithological point of view it is limestone with rudists. This part of the Upper Cretaceous is represented by limestone with a high content of $CaCO_3$ (about 99%), and dolomite deposits are of insignificant distribution. Limestones are mostly massive, and come thickly layered, rarely thinly layered. They are darker gray, light gray to white. The most common are micrites, fossil micrites, biomicrites, rudist biomicrites, intramicrites, intrasparites and biosparites. The stratigraphic affiliation is determined on the basis of the fossil community of numerous genera of rudists. Microfossils are represented with foraminifera.

Field mapping established that the southern part of the Opuzen road profile is represented exclusively by limestone. Mudstones, crystalline and fine-grained limestones are represented. The colour of the limestone is light cream, cream to grey cream. The deposits are tectonised, fractured, karstificated, with numerous joints, joint systems and caverns. Joints and smaller cavities are filled with red clay, and often are open. The veins are mostly filled with crystallized calcite, less often with clay. Limestones are mostly massive. Where stratification is observed, they are thickly layered, in dm dimension (4-10). Thinly layered, almost laminated, cm dimensions (1-10) limestones are rarely observed (Figure 7.9). The layers lie toward the north, northeast at an angle of 48-52°. Inside the thinly layered limestones come layers of grey to dark grey limestone. Among macrofossils, rudists are represented (Figure 7.10), and among microfossils foraminifera are rarely observed.

Figure 6.9Thinly layered limestones, Rkalovac

Figure 6.10 Rudist limestones

6.1.3.3 Vidrice-Crepina profile

The Crepina profile is located in the central part of the valley where the terrain is covered with Quaternary deposits.

The Vidrice profile is located in the southern part of the research area, and extends from the Prag pumping station on the Mala Neretva in the southeast direction, to the town of Pižinovac. The profile passes through the terrain on which the Quaternary deposits are deposited. On the eastern side of the profile, several mounds rise within the valley - Veliki školj, Srednji školj, Mali školj and Gubavac, which extend in a north-south direction, and Babica školj in the southeastern edge of the valley. North of the Veliki školj there are outcrops of carbonate composition of smaller extent.

According to the Basic Geological Map, the Ston sheet, the edge of the valley, the hill eastward of the Vidrica profile is built of Late Cretaceous deposits, the Turonian - Senonian period (K22,3), limestones and dolomites with rudists. These deposits are identical to the deposits described on the Opuzen road profile in Chapter 7.1.3.2, which build the hill Rkalovac. Slightly further to the south, along the edge of the valley, there are Late Cretaceous deposits, the Cenomanian - Turonian period (K21,2), and in the lithological sense these are limestones and dolomites with chondrodonates. Well layered limestones often alternate with dolomites and dolomitic limestones. In the higher horizons, only limestones are represented. The thickness of the layers varies from 30 to 60 cm. The structure is microcrystalline and crystalline, and color is brown, brownish gray and gray. Apart from chondrodonts, there are also rudists. These rocks are classified as micrites, fossil micrites, intramicrites, and pelmicrites. Biosparites, intrasparites, pelsparites, biointrasparites also occur. Limestones contain a high content of CaCO3, up to 99,9%.

Along the southern part of the profile, on the edge of the valley come Early Cretaceous deposits (1K1), limestones and dolomites with favreins. The lower parts of the series are built of gray and brown-gray cryptocrystalline limestones with frequent dolomite interlayers. Most parts of the series are built exclusively of limestones with a CaCO3 content of over 99%. Limestones are massive and banked, rarely well layered. The deposits of older Lower Cretaceous are allochem sparitic and allochem micritic limestones. The most common allochems are liotogenic intraclasts and fossils, while pellets and oolites are rarer. Fossil remains include foraminifera and calcareous algae.

BOREHOLE B-1(S-104-21-01) is located in the northern part of the Vidrice profile. The base rock was drilled at depth of 34,3 m, light cream limestone, structural type mudstone. Scarps and numerous longitudinal veins filled with crystallized calcite are visible at the core. The deposits are weakly fossilized, mainly mollusk shells. These sediments are from Cretaceous period, but a more detailed stratigraphic affiliation has not been determined.

On the EDGE OF THE VALLEY, eastward of the Vidrice profile Late Cretaceous limestones are represented. The sediment is light cream in color, structural type mudstone. Limestones are massive, bulky, and in some places there are layers of dm dimensions (3-10) and over 1 m. The layers are laid in the direction of the WSW, but also the NNW. The deposits are highly tectonised, fractured and karstificated (Figure 6.11), with numerous karst forms, lapies and caverns. Joints and joint systems are mostly open. Limestones are fossiliferous, microfossils are represented by algae and less often foraminifera, and macrofossils by rudists and other mollusk (Figure 6.12).

Figure 6.11 Massive limestones on the edge of the valley on SE

Figure 6.12 Cretaceous rudists limestones on the SE of the valley

East of the Vidrice profile come five hills in a row. To the north, inside the olive groves, there are LIMESTONE OUTCROPS of relatively small extent. They cover an area of 70x10 m, almost at the level of the surrounding terrain, so they are not singled out on the basic map M 1:5000. The outcrops are located approximately 370 m east of the Vidrica profile. They extend in a north-south direction, along the water channel. Limestones are light cream in color, structural type mudstone. The sediments are karstificated and fractured. These are probably Late Cretaceous limestones. Stratification is not observed. In the northern part of the described area, a spring approx. 0,1 l/s was registered (Figure 6.13). A limestone outcrop, measuring 3x5 m, is also located in the channel bed (Figure 6.14). The fossils are represented by rudists, shells of snails and other mollusk.

Figure 6.13 Limestone outcrops north of the Veliki školj

Figure 6.14 Limestone outcrops in the channel bed

VELIKI ŠKOLJ covers an area of 85x65 m, 250 m east of the Vidrice profile. Late Cretaceous limestones of light cream colour, structural type mudstone was mapped in the field. Limestones are massive, and in some places stratification of dm dimensions (3-10) is observed, but also over 1 m (Figure 6.15). The layers are oriented to the west at an angle of 25-38°. The deposits are fractured and karstificated. The joints are open, with aperture 1-10 cm and 2-4 dm. The deposits are fossilized, the microfossils are algae and subordinate foraminifera, and the macrofossils shells of mollusk.

SREDNJI ŠKOLJ covers an area of 50x40 m, followed by the MALI ŠKOLJ on an area of 110x50 m. They are 130 to 200 m east of the Vidrica profile. The terrain is built of limestones of Late Cretaceous period, light cream colour, structural type mudstone. Limestones are massive, no stratification is observed. The deposits are tectonised, fractured, karstificated, cavernous. Joints and joint sets are mostly subvertical (Figure 6.16). Along the western edge of the Mali školj springs out a series of ascending springs, approximately 0,1-0,2 l/s each (Figures 6.17 and 6.18). On this point, toward to the Srednji školj the fault zone is assumed, stretching in direction NNE-SSW. The fault zone was also mapped in the central part of the Srednji školj, stretching in direction NW-SE. The deposits are fossiliferous, the most common microfossils are algae, and foraminifera are subordinate. Macrofossils are also observed, shells of mollusks, snails and rarely rudists (Figure 6.19).

Figure 6.15 Cretaceous limestones, Veliki školj

Figure 6.16 Fractured Cretaceous limestones, Srednji škol

Figure 6.17 Spring on the west side of the Mali školj

Figure 6.18 A series of springs along the fault zone between the Srednji and Mali školj

The GUBAVAC mound covers an area of 90x50 m, 200 m east of the southern part of the Vidrice profile. The terrain around the mound is covered with bushes and trees (Figure 6.20). In the lithostratigraphic point of view, Late Cretaceous limestones are represented, light cream to cream color, structural type mudstone. Limestones are massive, no stratification is observed. The deposits are tectonised and fractured. The joints are open, with aperture 2-9 dm, but also some are without aperture. The most common microfossil are algae (algal limestones), subordinate foraminifera, and from macrofossil shells of mollusk.

Figure 6.19 Fossil Cretaceous limestones, Mali školj

Figure 6.20 Gubavac

BABICA ŠKOLJ is located in the southeastern part of the valley, on an area of 175x90 m, where the terrain is covered with vegetation. In the lithostratigraphic point of view, the sediments, limestones belong to Late Cretaceous period. They are light cream to cream color, structural type mudstone. Limestones are massive, no stratification is observed (Figure 6.21). The rock mass is intersected by joints of various orientations. Microfossils are represented by algae and foraminifera, and macrofossils by hondrodontes and shells of other mollusk.

Figure 6.21 Babica školj

6.1.3.4 Hills inside the Neretva valley

Within the Neretva Valley, several hills rise, apart from those described in the previous chapters. In the southern part of the valley rises Veliki and Mali obalac and Tuštovska glavica, in the northwestern part Kozjak, and in the northern part Dobruška glavica, Gubava glavica and a mound without a toponymic mark.

SOUTHERN PART OF THE NERETVA VALLEY

According to the Basic Geological Map, Ston sheet, in the southern part of the Neretva Valley Late Jurassic deposits, the Oxfordian - Kimmeridgan period (J31,2) and the Kimmeridgan - Thitonian period (J32,3) are represented.

The deposits of the lower part of the Late Jurassic (J31,2) stretch along the edge of the valley, from Mihalj to Tuštevac. They are deposited continuously on the Early – Middle Jurassic deposits. In the lithological point of view, these are limestones with cladophoropsis. The deposits are well layered, in some places laminar, 5-15 cm thick, but there are also thickly layered limestones, 0,3-1 m thick. The CaCO3 content is high, over 98%. Limestones are allochem sparitic, allochem micritic and micritic. Stratigraphic affiliation was determined based on the fossil community of cladophoropsis.

The deposits of the upper part of the Late Jurassic (J32,3) extend along the edge of the valley, from Lovorje to the southeast. They are represented by limestones and dolomites with clypeins. Limestones are well stratified, 0,2-0,8 m thick. They are represented by micrites, fossil micrites, biopelmicrites and intramicrudites. From allochem sparitic limestones comes intrasparites, biosparites, intrasparudites. Limestones have a high content of CaCO3, over 99%. Stratigraphic affiliation was determined on the basis of numerous findings of Clypeina and the microfossil community characteristic for this period.

VELIKI OBALAC is located north of the Rečina canal, and covers an area of 440x150 m. Geological mapping has established only limestones at the location. Limestones are light cream in color, structural type mudstone. The deposits are tectonised, fractured, karstificated, with numerous joints and joint systems of various orientations (Figure 6.22). Lapies appear as karst forms. Numerous veins are filled with crystallized calcite. Limestones are massive, no stratification is observed. The joints are mostly open, with aperture in cm dimension (10-15), dm (5-9) but also m (1-1,5). Microfossils are represented by algae, while macrofossils and rare, represented by shells of mollusk. On the eastern side of the hill, a series of springs were registered in a zone about 30 m wide, approximately 0,5 to 1 l/s each (Figure 6.23).

Figure 6.22 Fractured massive limestones, Veliki obalac

Figure 6.23 Spring on the east side of Veliki obalac

MALI OBALAC is located on the southern channel of Rečina, opposite Veliki obalac. It covers an area of 200x130 m. Light cream limestones are present in the area of Mali obalac. Apart from mudsone, there are also fine-grained varieties of a slightly darker color. The deposits are tectonised, fractured and karstificated, cavernous, with numerous joints and joint systems of various orientations (Figure 6.24). Limestones are massive, no stratification is observed. The joints are mostly open, with aperture in various dimension, cm (10-20), dm (5), but also there are joints without aperture. Limestones are slightly fossiliferous, algae and shells of mollusk are very rare (Figure 6.25).

TUŠTOVSKA GLAVICA is located further west to Veliki and Mali obalac, next to Tuštevac. It covers an area of 550x430 m. Limestone it is a light cream, structural type mudstone, but there are also fine-grained and medium-grained varieties. The deposits are tectonised, fractured and karstificated, with developed karst forms, lapies and caverns. Numerous joints and joint sets and systems have a various orientation. The joints are opened, with aperture in cm dimensions (3-9), or dm dimension (1-3), and in some places filled with clay and soil. On the eastern side of the hill, the NE-SW fault is assumed. Stratification is very rarely observed in the northwestern part of the hill, where layers are 7-10 dm thick. The layers are laid in a northeast direction, in a very small angle (Figure 6.26). Microfossils are represented by algae and macrofossils by shells of mollusk, very rarely snails. In the northwestern part of the hill limestone with rudists are common, which indicates the stratigraphic affiliation of the deposits to the Cretaceous period (Figure 7.27).

Figure 6.24 Fractured massive limestones, Mali obala

Figure 6.25 Karstificated limestones with rare shells, Mali obalac

Figure 6.26 Layered limestones in the northwestern part of Tuštovske glavice

Figure 6.27 Rudist limestones in the northwestern part of Tuštovske glavice

NORTHWESTERN PART OF THE NERETVA VALLEY

According to the Basic Geological Map, Ploče sheet, in the northwestern part of the Neretva Valley there are Early Cretaceous deposits (K1). The beginning of the series was marked by the appearance of breccia with larger limestone fragments, bound with calcite-clay binder. Then followes limestones 30-150 cm thick, alternating with limestone breccias. The complex is built mostly of allochemical limestones. Breccias are sedimentary origin. They represent different varieties of limestones: oosparites, intraoosparites, biomicrites, pelmicrites, intrasparites, intramicrites, micrites and recrystallized fine-grained limestones. The varieties alternate laterally and vertically very quickly. The stratigraphic affiliation was determined on the basis of the macrofossil community of mollusks and the microfossil foraminiferal community from the Cuneolina camposaurii cenozone and species of Salpingoporella dinarica.

The KOZJAK hill stretches along the Neretva River in the northwestern part of the research area. It covers an area of 770x520 m. Based on geological mapping limestones were determinate, structural type mudstone, light cream to whitish cream color. The deposits are tectonised, fractured, karstificated, cavernous, with numerous lapies (Figure 6.28). Limestones are usually massive, stratification is very rarely observed, with a layer thickness of dm dimension (3-10). The layers are laid in a southwest direction, by angle of 34-52° (Figure 6.29). The rock mass is intersected by joints and joint sets, which are either subvertical or relatively steeply laid, over 50°. The joints are streching in the Dinaric direction, NW-SE, but also NE-SW. The joint aperture varies, from cm to m dimensions. The fossil community is represented by microfossils, algae and less common foraminifera, and macrofossils, shells of mollusk.

Figure 6.28 Massive Cretaceous limestones, Kozjak

Figure 6.29 Layered Cretaceous limestones, Kozjak

NORTHERN PART OF THE NERETVA VALLEY

According to the Basic Geological Map, Metković sheet, in the northern part of the Neretva Valley there are stratigraphic strata of the Late Cretaceous, Turonian - Senonian period (K22,3), and in the lithological point of view thiese are limestones with rudists. These deposits are identical to the deposits described on the Opuzen road profile.

The DOBRUŠKE GLAVICE elevation is located near the D8 state road, in the northern part of the research area. These are three connected hills that cover an area of 420x250 m. The terrain around the hill is mostly inaccessible, especially on the south side, overgrown with dense vegetation, and along the very edge of the mound is a canal. Late Cretaceous limestones were determined by field mapping. Structural type is musdstone, and in some places fine-grained varieties appear. Their color is light cream, whitish cream to gray cream. They are mostly massive, rarely thicker layered, dm dimension (2-9), but also m dimension (1-1,2). Where stratification is observed, the layers are laid in a northeast direction at an angle of 15-25° (Figure 6.30). The deposits are tectonised, fractured and karstificated. Joints and joint systems have a various orientation. The joints are vertical or relatively steep (Figure 6.31). A fault between the eastern and western hill is assumed, stretching in direction NNW-SSE. The deposits are weakly fossiliferous, foraminifera are rarely observed, same as shells of mollusk and rudists.

Figure 6.30 Layered Cretaceous limestones, Dobruške glavice

Figure 6.31 A set of joint parallel to the assumed fault, Dobruške glavice

GUBAVA GLAVICA extends east of Dobruške glavice, on an area of 100x50 m. Late Cretaceous limestones, structural type musdstone, light cream colored has been determined by field mapping. On the northern side, medium-grained brownish-gray limestones have been identified. The deposits are fractured and karstificated. Limestones are stratified in dm dimension (2-8), laid in the direction ESE (Figure 6.32). Set of vertical joints are stretching in direction NNW-SSE. The fossil community has not been spotted.

Figure 6.32 Layered limestones, Gubava glavica

Figure 6.33 Massive limestones, western head without toponymic mark

HILL WITHOUT TOPONYMIC MARK is located west of Dobruške glavice, and covers an area of 50x35 m. Cretaceous limestones, light cream to cream color, structural type mudstone has been determined. The deposits are massive, fractured and karstificated (Figure 6.33). The deposits are weakly fossiliferous, shells of mollusk, rudists, and subordinate algae can be seen in some places.

6.2 Literature

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7 Geophysical research works

As part of the research work for Neretva Valley, Croatia, geophysical explorations were conducted. The exploration included the following geophysical methods: seismic reflection, geoelectrical tomography and geoelectrical sounding. The purpose of the survey was to use non-destructive methods in order to characterize the conditions, constitution and depth of the rock mass, determine the locations of possible faults and joints and to determine the electrical resistivity of soil.

In this report, the basis of the applied geophysical methodology, acquisition procedure, data processing and the interpretation of the processed data are provided. Field survey, processing and interpretation have been carried out from January to May 2022. by Terra Compacta d.o.o. from Croatia.

Figure 7.1 Area of investigation (image downloaded from Google Earth)

7.1 About applied geophysical methods

7.1.1 Seismic reflection method

The basic principles of the seismic reflection method are given in Figure 7.2.a. An idealized two-layer model with a horizontal boundary is presented. The elastic properties of these two media are characterized by their P-wave velocities V1 and V2 and densities ρ1 and ρ2.

If the wave source is initially at point S1 and the receiver at point R2, then the wave at the midpoint of M1 and M2 will be reflected at point A. If the wave source and receiver move relative to the centre point A' by the same length d, only on opposite sides (at points S2 or R2), the point of reflection remains again in position A, but the path that the wave travels is now longer. Ignoring certain restrictions at this point, we see that the reflection point A remains in the same place for an arbitrary number of equal displacements of the source and receiver with respect to the central point A'. If n such displacements are performed, it is said that the point A is covered by n × 100% or that the overlap is n.

The described multiple overlap of the depth point A is applied in order to increase the ratio of the useful signal (which provides information about the underground) to the ever-present interference.

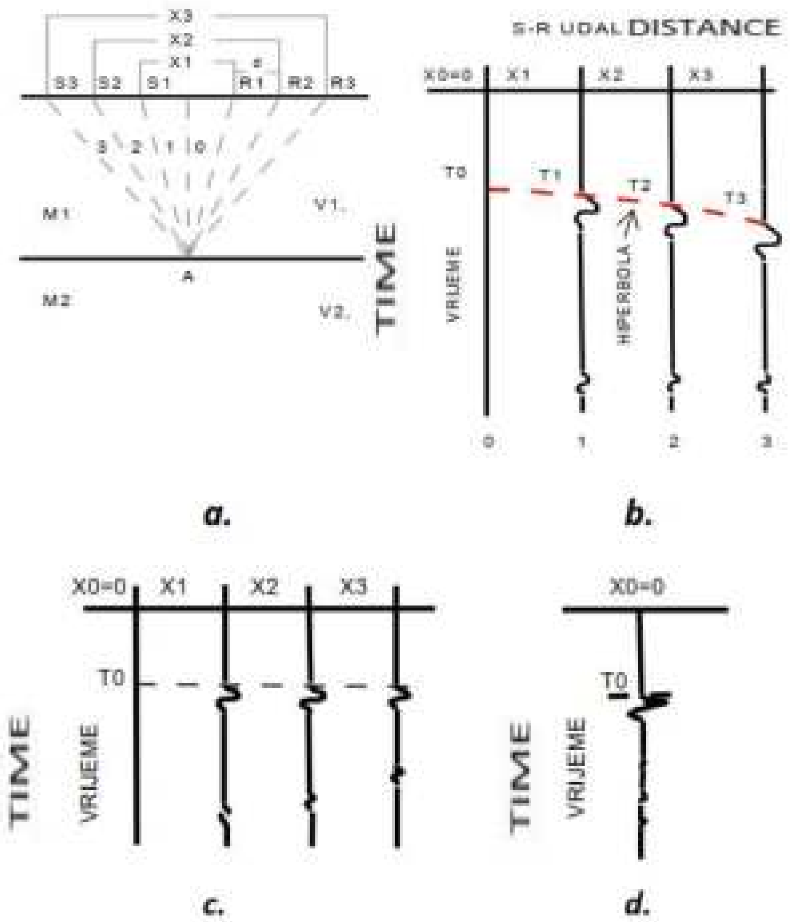

Figure 7.2 Seismic reflection method.

Figure 7.2b shows the curve of the time of occurrence of the signal in relation to the distance source receiver, for some speed V1 wave in the first medium. For the case of the horizontal boundary, the curve has the form of a hyperbola whose vertex is at 0, which is the case when both the wave source and the receiver (geophone) are at the same point. The equation of this hyperbole is:

$$T_X^2 = T_0^2 + \frac{X^2}{V^2}, \tag{1.1}$$

T_X - time of arrival of the reflected wave at a distance X from the source,

T_0 - time of arrival of the reflected wave for the distance X = 0,

X - source-receiver distance,

V - P-wave velocity

If each trace in Figure 7.2b were time-corrected for the value of $\Delta T_X = T_X - T_0$ the signal would be said to be "in phase" while the interference (shown at the bottom of the traces) would remain out of phase as shown in Figure 7.2c.

If the arithmetic mean of the seismic amplitudes of the traces from Figure 7.2c is calculated, which refer to the same time, ie.

$$A_T = \frac{(\sum A_i)_T}{n}, \tag{1.2}$$

A_T - mean amplitude over time T,

A_i - the amplitude of the i-th trace in time T,

n - total number of traces.

If this is shown graphically, one trace is obtained as in Figure 7.2d relating to the midpoint A 'for the distance X = 0. The amplitude of the interference (in relation to the signal) was significantly removed on this track.

The described time corrections of the tracks are of a dynamic nature because they are different for each trace, so they are called dynamic corrections or NMO corrections (Normal Move Out).

It is clear that the situation in nature is not nearly as simple as shown in Figure 7.2a. First, when working on land, the terrain surface is never completely horizontal or flat, but there is usually a height difference between individual points of the profile. Furthermore, there is always, starting from the surface to some depth, the first dilapidated zone of low-speed material, which changes laterally in thickness along the profile. This zone acts by moving the seismic signal over time by a certain amount, depending on its thickness and the rate of propagation of the P-wave.

The described adverse circumstances impose the need for another type of temporal trace corrections called “static corrections” and consist of two parts. The first part refers to the removal of the influence of the surface wear zone of the material, and the second to the reduction of measurements to the direction, either horizontal or oblique, depending on the terrain. There are no described static corrections if the works are performed on the sea or lakes.

7.1.2 Geoelectrical tomography

Geoelectrical methods are based on measurement of surface effects and anomalies that arise from current flow in the ground. The resistivity survey method is the most commonly used geoelectrical method.

The data acquired by resistivity measurement is used for prediction of lithological structure of subsurface, determination of fault or fracture zones, determination of the character of fractures and fillings in fractures and determining differences in layer conductivity.

In a homogenous ground the current flows radially out of the source as is shown in figure 8.3. The arising equipotential surfaces run perpendicular to the current flow lines and form half spheres. If the subsurface was indeed homogenous, the measured resistivity would be real resistivity. However, subsurface is never homogenous, so the measured resistivity is termed apparent resistivity.

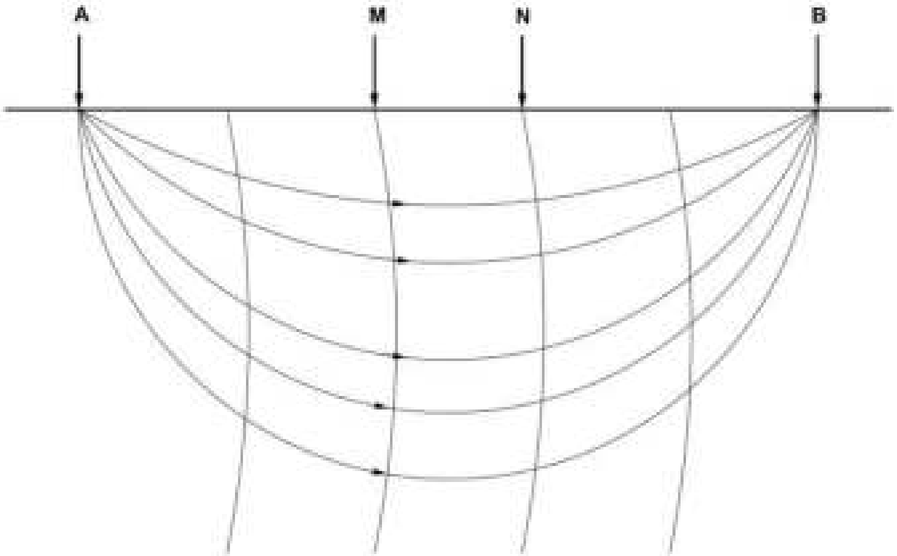

Figure 7.3 Current flow in homogenous medium.

The ratio of the measured receiver voltage to the current input by the transmitter is referred to as the impedance:

$$Z = \frac{V}{I}. \tag{1.3}$$

The value of impedance depends on the path through which the current flows and its cross-section. That is why the electric resistivity is used, which is the measure of volume material resistance to the current flow, normalized to path length and its cross-section. Apparent resistivity is calculated according to the expression:

$$\rho_a = \frac{V}{I}\frac{2\pi}{\left(\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}}\right)} = K\frac{V}{I}. \tag{1.4}$$

where rAM is distance between the current electrode A and potential electrode M, rBM is distance between the current electrode B and potential electrode M, rAN is distance between the current electrode A and potential electrode N, rBN is distance between the current electrode B and potential electrode N. All the parameters that describe the array geometry are joined in the geometrical constant K. General geoelectrical array is shown in Figure 7.4.

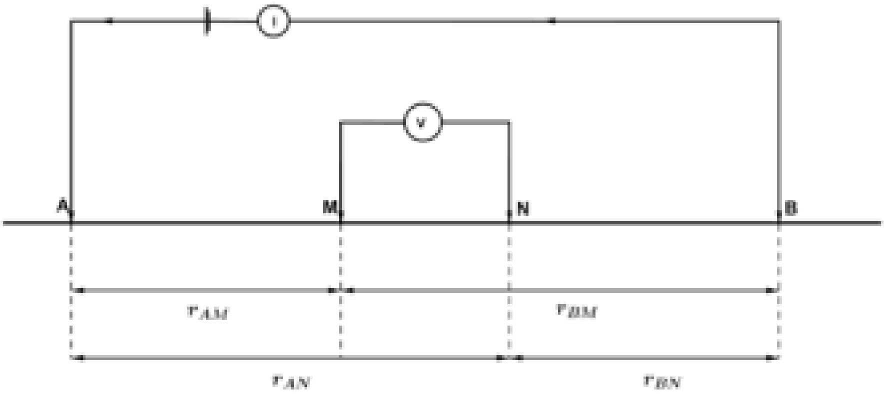

Figure 7.4General geoelectrical array

7.1.2.1 Data acquisition and geometrical arrays

2-D electrical resistivity survey is performed by tomography method. An electric current is injected into the ground through electrodes set on the ground. The measurement is performed for single point on the profile using four active electrodes, two current and two potential electrodes. The measurement process is repeated for all the electrodes with constant spacing between them. After that, the spacing is changed, and with it also the penetration depth. That procedure produces continuous section of apparent resistivity (pseudosection). In a multielectrode system, active electrodes are picked automatically by a computer. Schematic diagram of a multielectrode system (Loke et al., 2011) used for a 2-D geoelectrical survey is shown in figure 7.5.

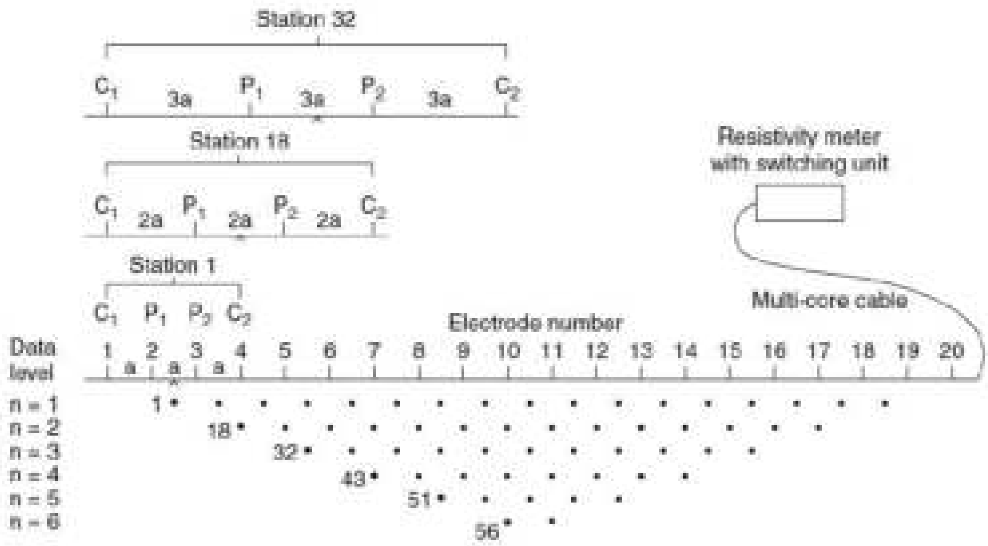

Figure 7.5 Schematic diagram of a multielectrode system used for a 2-D geoelectrical survey

The pseudosection is a useful method to present the data in a pictorial form and as an initial guide for further quantitative interpretation (Loke, 2011). One useful application of the pseudosection is in identifying bad apparent resistivity measurements that usually appear as points with unusually high or low values.

7.1.2.1.1 Geometrical arrays

Data acquisition in geoelectrical survey can be done using different geometrical arrays. Herein three most common are explained: dipole-dipole, Wenner and Schlumberger array.

DIPOLE-DIPOLE ARRAY

In dipole-dipole array, distance between two current and two potential electrodes is equal, here denoted a. Current and potential dipoles are separated by a larger distance, let us assume na. Schematicaly, the array is shown in figure 7.6.

Figure 7.6 Dipole-dipole array.

Geometrical constant for dipole – dipole array, using notations as in figure 7.6, is:

$$K = \pi n(n+1)(n+2). \quad (1.5)$$

Dipole-dipole array is best used for detailed mapping of resistivity response with depth. However, larger distance between the current and potential dipole makes it more sensitive to noise.

WENNER ARRAY

Wenner array is developed primarily for electric profiling. It is characterised by equal spacing between all electrodes. The array is shown schematically in figure 7.7.

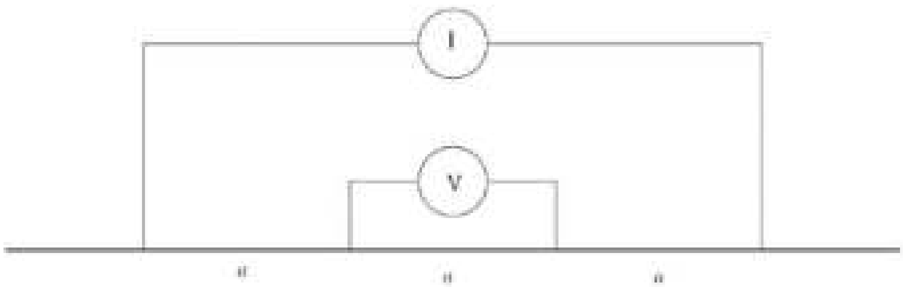

Figure 7.7 Wenner array.

With notations as in figure 7.7, geometrical constant for Wenner array is:

$$K = 2\pi a. \quad (1.6)$$

The array is used mainly for resistivity profiling or for rapidly covering large areas using small electrode spacing.

SCHLUMBERGER ARRAY

Schlumberger array is primarily developed for geoelectrical sounding. Potential electrodes are kept in the same place, and current electrodes are simetrically moved appart, to achieve greater penetration depth. By moving potential electrodes, 2-D image is obtained. The array is shown schematically in figure 7.8.

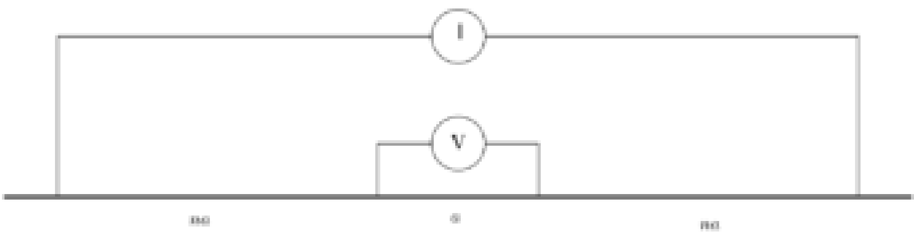

Figure 7.8 Schlumberger array.

With notations as in figure 8.8, geometrical constant for Schlumberger array is:

$$K = \pi n(n + 1)a. \quad (1.7)$$

Schlumberger array provides very good vertical resolution.

7.1.2.2 Data analysis

Pseudosection can be useful for a preliminary qualitative interpretation, but in complex environments it may be difficult to perceive the structure behind the section. In order to obtain more accurate picture of the subsurface, it is necessary to carry out an inversion of the pseudosection.

The approach that can give reasonably accurate models for a variety of geological structures, divides the subsurface into a number of rectangular blocks and uses a nonlinear optimization technique to improve an initial model (Loke, 2011). Least-squares method is usually used to determine the resistivity of the rectangular blocks that will minimize the differences between the calculated and measured apparent resistivity values (Loke & Barker, 1995; Loke & Dahlin, 2002;

Loke et al., 2003). The inversion problem is frequently ill-posed due to incomplete, inconsistent and noisy data. Some constrains are usually incorporated to stabilize the inversion procedure such that numerical artifacts are avoided.

These iterative procedures can reduce the differences between the calculated and measured apparent resistivity values to less than 10%.

7.1.3 Geoelectrical sounding

Geoelectrical methods are based on measurement of surface effects and anomalies that arise from current flow in the ground. Measurement is conducted by using two current electrodes to introduce current into subsurface. Introduction of current into subsurface causes changes in potency which is registered on two potential electrodes (Figure 7.9).

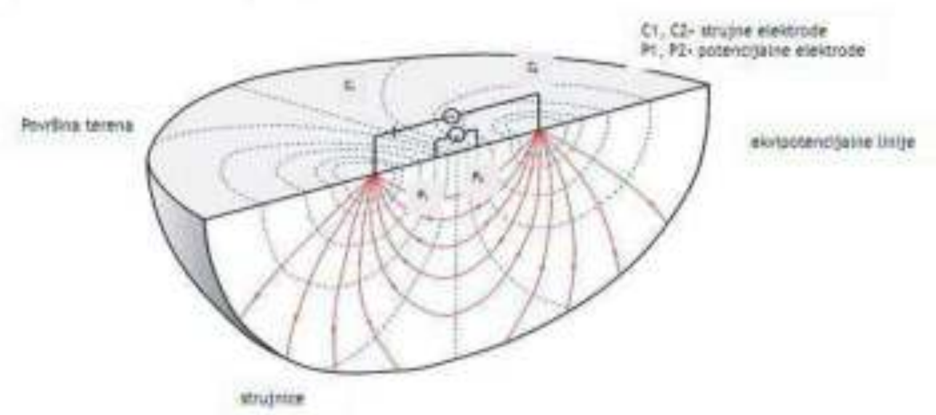

Figure 7.9 Schematic display of method for measuring potency changes.

In basis, geoelectrical sounding method is focused on measuring electrical resistivity in which greater volume of subsurface layers is achieved by constant increase in spacing between current electrodes. Such increase in volume results in greater registered depths. During geoelectrical sounding central point of electrode array is stationary. Final results of geoelectrical sounding are changes in electrical resistivity per depth in central point of electrode array. Initial presumption states that in horizontal direction resistivity is constant but in vertical direction it changes, therefore electrical sounding represents 1D model of measured resistivity.

Electrical sounding most commonly uses Schlumberger or Wenner array type. Wenner array type uses constant spacing between current and potential electrodes and between two potential electrodes. Schlumberger array type has constant spacing between potential electrodes but spacing between current and potential electrodes increases during measurement.

7.2 Description of equipment and quantities of executed work

At the location of the Neretva Valley total amount of measurements is as follows: 1 profile of seismic reflection, 5 geoelectrical tomography profiles and 45 geoelectrical probes (25 probes AB/2=200 m, 20 probes AB/2=600 m).

Lengths of seismic reflection profile is shown in table 7.1. Table 7.2 shows lengths of geoelectrical tomography profiles and Table 7.3 list of geoelectrical sounding measurements. Positions for every geophysical exploration are displayed in appendix 4.

Table 7.1 Name, length and coordinates for seismic reflection profile

Profile name	Lenght (m)	E_coord	N_coord	H_height
RFL-1	2000	582258,82 581369,00	4762837,02 4764601,32	-0,03 -1,25
Total length:	**2000**	-	-	-

Table 7.2Name, length and coordinates for geoelectrical tomography profile.

Profile name	Lenght (m)	E_coord	N_coord	H_height
GE-1	2360	584272,01 583205,60	4760859,24 4762913,81	-1,54 0,94
GE-2	1270	587122,05 586453,66	4766362,38 4765234,50	-1,29 1,19
GE-3	260	586463,89 586290,48	4765526,50 4765326,79	-0,98 1,60
GE-4	630	585663,54 585694,24	4764265,18 4764883,78	1,38 1,75
GE-5	1780	579141,91 578396,95	4763846,35 4765408,65	1,24 2,48
Total length:	**6300**	-	-	-

Table 7.3 Geoelectrical sounding measurements.

Probe name	E_coord	N_coord	H_height
GS - 100 - 1	585708,56	4764911,09	1,90
GS - 100 - 2	583401,34	4762475,56	0,71
GS - 100 - 3	582223,75	4762925,11	-0,32
GS - 100 - 4	585662,53	4764462,26	-0,20
GS - 100 - 5	580498,96	4766349,96	-0,09
GS - 100 - 6	580835,88	4765622,88	-1,78
GS - 100 - 7	581496,16	4767040,01	0,09
GS - 100 -8	581645,54	4766619,38	-1,12
GS - 100 - 9	581796,19	4766087,98	-1,45
GS - 100 - 10	581863,29	4765917,53	-0,39
GS - 100 - 11	583034,99	4766773,03	-0,67
GS - 100 - 12	583351,83	4766244,86	-0,39
GS - 100 - 13	584540,43	4766636,73	1,11
GS - 100 - 14	584537,33	4766284,49	-0,64
GS - 100 - 15	584667,61	4763899,27	0,67
GS - 100 - 16	585040,60	4763186,75	-1,09
GS - 100 - 17	582581,28	4762153,25	-0,25
GS - 100 - 18	583797,41	4761709,02	-1,09
GS - 100 - 19	579399,86	4765542,08	-1,07
GS - 100 - 20	579673,10	4765019,18	-0,52
GS - 100 - 21	580754,69	4763696,41	-0,71
GS - 100 - 22	587122,05	4766362,38	-1,29
GS - 100 - 23	580184,65	4767098,84	1,97
GS - 100 - 24	588671,09	4764684,30	0,77
GS - 100 - 25	587498,68	4765198,24	-0,80
GS - 200 - 1	581529,89	4764276,38	-0,90
GS - 200 - 2	581645,90	4764013,87	-1,41
GS - 200 - 3	581892,13	4763536,07	-0,73
GS - 200 -4	586970,64	4766067,07	-1,13
GS - 200 - 5	586605,70	4765416,35	-0,53
GS - 200 - 6	578894,52	4764350,45	1,37
GS - 200 - 7	581076,66	4765157,33	0,58
GS - 200 - 8	582340,75	4764600,87	0,41
GS - 200 - 9	582675,62	4764229,86	0,44
GS - 200 - 10	583165,74	4763695,01	-0,70
GS - 200 - 11	583137,88	4765607,05	0,41
GS - 200 - 12	583854,60	4765255,26	-1,30
GS - 200 - 13	581380,84	4765114,11	0,59
GS - 200 - 14	583350,52	4764376,46	0,72
GS - 200 - 15	582516,55	4764905,56	0,44
GS - 200 - 16	584559,02	4765651,47	-0,48
GS - 200 - 17	580389,71	4764781,85	0,26
GS - 200 - 18	580859,66	4764486,70	0,40
GS - 200 - 19	584154,73	4764738,71	-1,17
GS - 200 - 20	584613,33	4764981,31	-1,05

Measurements were performed by using the following equipment:

SEISMIC SURVEY:

- Seismograph: PASI GEA-24, s.b. 16077, 24 channels,
- 40 Hz geophones (reflection),
- Seismic cables with 12 takeouts,
- Seismic source: 12 kg hammer and steel plate, seismic gun

Figure 7.10 Equipment for seismic surveys.

Figure 7.11 Seismic reflection measurement on RFL-1 profile position.

GEOELECTRICAL TOMOGRAPHY:

- Instrument: PASI Polares, s.n. 13008,
- Cables with 16 takouts,
- Steel stakes (electrodes).

Figure 7.12 Equipment for geoelectrical surveys.

Figure 7.13 Geoelectrical tomography on GE-5 profile position.

GEOELECTRICAL SOUNDING:

- Instrument: AGI Sting R-1
- Geoelectrical cables
- Current and potential electrodes

Figure 7.14 Equipment for geoelectrical sounding AGI Sting R-1

Figure 7.15 Electrical sounding on GS-100-24 position.

The following data processing software was used:

- VisualSUNT 24,
- ParkSeis,
- Res2din,
- Surfer,
- ProgeCAD.

7.2.1 Survey parameters

Parameters of geoelectrical tomography, geoelectrical sounding and seismic survey (tables 7.4, 7.5, 7.6) were chosen according to theoretical estimations of the methods and conducted tests in the field, with an objective of obtaining the final results which will be in accordance with the demanded penetration depth and of satisfactory resolution.

Table 7.4Seismic survey parameters

	Reflection
Number of activechannels	12
Receiver spacing	10 m
Source offset	10 m
Method	Roll along
Record length	1256 ms
Sampling time	0.125 ms
Seismic source	Hamer and steel plateseismic gun

Table 7.5Geoelectrical tomography survey parameters.

	Geoelectrical tomography
Electrode spacing	10 m
Number of electrodes	32/64
Geometry	Wenner array

Table 7.6Geoelectrical sounding survey parameters.

	Geoelectrical sounding
Maximum halfdistance AB/2=200 m	GS-100-1 – GS-100-25
Maximum halfdistance AB/2=600 m	GS-200-1 – GS-200-20
Geometry	Schlumberger array

7.3 Data processing and interpretation

7.3.1 Seismic reflection

7.3.1.1 General

The processing of the recorded data was performed in the software package Visual SUNT 24 (CWP / SU Seismic Unix). The following steps in the processing sequence were applied:

- loading and converting SEG2 to SU format,
- editing raw recordings,
- amplitude gain (AGC),
- delete refracted occurrences (MUTE),
- geometry editing (input of actual X, Y, Z coordinates),
- sorting traces according to CDP points,
- dynamic corrections (NMO),
- band-pass filtering,
- addition (stacking) of traces by CDP groups,
- conversion to depth scale.

7.3.1.2 Description of profile

INTERPRETED SEISMIC REFLECTION PROFILE RFL-1 (CREPINE)

The seismic reflection profile RFL-1 has a total length of 2000 meters.

The results are presented in the form of an interpreted depth profile with the corresponding latitudes. Visible layered surfaces, significant fault contacts and a possible depth of bedrock are marked on the profile (Appendix 4, Figure 7.16).

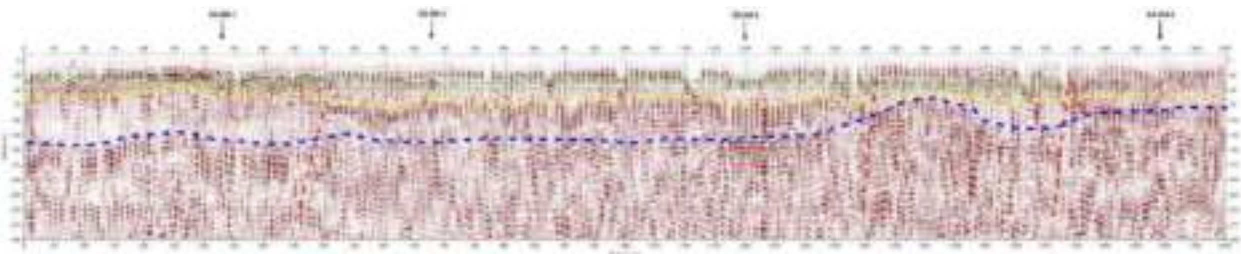

Figure 7.16 Interpreted seismic reflection profile RFL-1

As it can be seen in the figure 7.16 and appendix 4, a green dashed line highlights a possible layer of coarse gravel to conglomerate. Above green dashed line the layers of sand (near surface) and clay are present. Yellow dashed line highlights layer of small grain gravel. Blue dashed line highlights the possible contact of gravel deposits with the bedrock at depths of about 80 meters up to about 150 meters. The crack fault zones are marked with vertical red dashed lines and can be seen at distances of 500, 1400 and 1750 meters from the beginning of the profile.

7.3.2 Geoelectrical tomography

7.3.2.1 General

The processed results are shown in appendix 4, in the form of 2-D sections of resistivity variation with depth. According to resistivity values, the conditional classification of soil was made (Table 7.7 to 7.11).

7.3.2.2 Description of profiles

INTERPRETED GEOELECTRICAL TOMOGRAPHY PROFILE GE-1 (VIDRICE)

The geoelectrical tomography profile GE-1 (Appendix 4) has a total length of 2340 meters. Based on the measured values of electrical resistances, it can be concluded that dry zone near surface with sand, clayey (resistance values >10 Ohm m) is possible along the entire profile (especially in the first 600 meters of the profile) to an average depth of 3.0-4.0 meters.

Below this layer a layer of clay (resistance values <1 Ohm m) or sandy clay (resistance values 1-10 Ohm m) saturated with salt water appears up to an average depth of 35.0-50.0 meters.

Weathered and fractured limestone, saturated with salt water and bedrock appears at depths greater than 40-50 meters.

Table 7.7Conditional classification of soil and rock mass according to electrical resistivity.

Electrical resistivity (Ωm)	Type and state of rock
< 1	CLAY, SATURATED WITH SALT WATER
1-10	CLAY SANDY, SATURATED WITH SALT WATER
>10	WHEATERED AND FRACTURED LIMESTONE (SATURATED WITH SALT WATER), BEDROCK
>10	SAND, CLAYEY (DRY ZONE NEAR SURFACE)

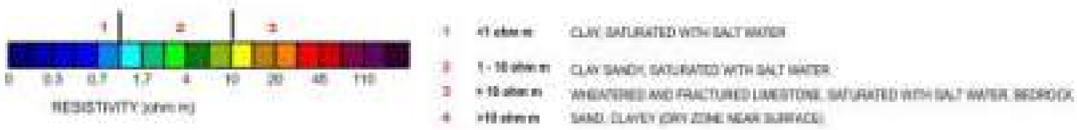

Figure 7.17 Legend with interpreted profile of geoelectrical tomography – GE-1

INTERPRETED GEOELECTRICAL TOMOGRAPHY PROFILE GE-2 (OPUZEN)

The geoelectrical tomography profile GE-2 (Appendix 4) has a total length of 1260 meters. Based on the measured values of electrical resistances, it can be concluded that a layer of clay (resistance values <1 Ohm m) or sandy clay (resistance values 1-10 Ohm m) saturated with salt water is possible along the entire profile and appears up to an average depth of 50.0 meters or deeper (in central parts of the profile, up to an average depth of 100-110 meters).

Wheatered and fractured limestone, saturated with salt water and clayey gravel (resistance values 10-90 Ohm m) or bedrock (resistance values >90 Ohm m) appears at depths greater than 50 meters or deeper (in central parts of the profile, greater than 100-110 meters).

Table 7.8Conditional classification of soil and rock mass according to electrical resistivity.

Electrical resistivity (Ωm)	Type and state of rock
< 1	CLAY, SATURATED WITH SALT WATER
1-10	CLAY SANDY, SATURATED WITH SALT WATER
10-90	GRAVEL CLAYEY, WHEATERED AND FRACTURED LIMESTONE (SATURATED WITH SALT WATER)
>90	BEDROCK - LIMESTONE

Figure 7.18Legend with interpreted profile of geoelectrical tomography – GE-2

INTERPRETED GEOELECTRICAL TOMOGRAPHY PROFILE GE-3 (OPUZEN)

The geoelectrical tomography profile GE-3 (Appendix 4) has a total length of 260 meters. Based on the measured values of electrical resistances, it can be concluded that a layer of clay (resistance values <1 Ohm m) or sandy clay (resistance values 1-10 Ohm m) saturated with salt water is possible along the entire profile and appears up to an average depth of 20.0 meters.

Wheatered and fractured limestone, saturated with salt water and clayey gravel (resistance values 10-90 Ohm m) or bedrock (resistance values >90 Ohm m) appears at depths greater than 20 meters.

Table 7.9 Conditional classification of soil and rock mass according to electrical resistivity.

Electrical resistivity (Ωm)	Type and state of rock
< 1	CLAY, SATURATED WITH SALT WATER
1-10	CLAY SANDY, SATURATED WITH SALT WATER
10-90	GRAVEL CLAYEY, WHEATERED AND FRACTURED LIMESTONE (SATURATED WITH SALT WATER)
>90	BEDROCK - LIMESTONE

Figure 7.19 Legend with interpreted profile of geoelectrical tomography – GE-3

INTERPRETED GEOELECTRICAL TOMOGRAPHY PROFILE GE-4 (OPUZEN-MAGISTRALA)

The geoelectrical tomography profile GE-4 (Appendix 4) has a total length of 630 meters. Based on the measured values of electrical resistances, it can be concluded that dry zone near surface with sand, clayey (resistance values >10 Ohm m) is possible along the entire profile to an average depth of 3.0-5.0 meters.

Below this layer a layer of gravel, clayey (resistance values 10-90 Ohm m) saturated with salt water appears up to an average depth of 30.0 meters.

In some parts of the profile (from distance of 200 to 300 meters and from distance of 330 to 480 meters) a large deposits of clay (resistance values <1 Ohm m) or sandy clay (resistance values 1-10 Ohm m) saturated with salt water appears up to an average depth of 80.0 meters.

Weathered and fractured limestone, saturated with salt water and bedrock appears at depths greater than 75-80 meters.

Table 7.10 Conditional classification of soil and rock mass according to electrical resistivity.

Electrical resistivity (Ωm)	Type and state of rock
< 1	CLAY, SATURATED WITH SALT WATER
1-10	CLAY SANDY, SATURATED WITH SALT WATER
10-90	GRAVEL CLAYEY, WHEATERED AND FRACTURED LIMESTONE (SATURATED WITH SALT WATER)
>90	BEDROCK - LIMESTONE
>10	SAND, GRAVEL (DRY ZONE NEAR SURFACE)

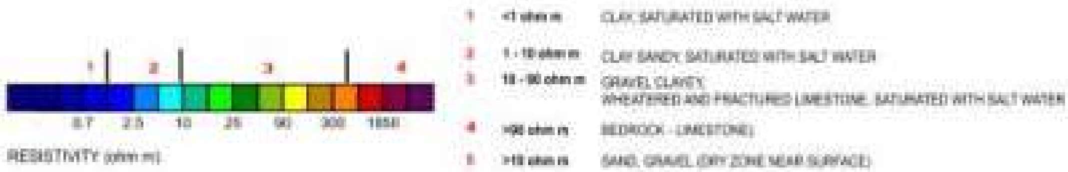

Figure 7.20 Legend with interpreted profile of geoelectrical tomography – GE-4.

INTERPRETED GEOELECTRICAL TOMOGRAPHY PROFILE GE-5 (DIGA)

The geoelectrical tomography profile GE-5 (Appendix 4) has a total length of 1750 meters. Based on the measured values of electrical resistances, it can be concluded that dry zone near surface with sand, clayey, silty (resistance values >10 Ohm m) is possible along the entire profile to an average depth of 2.0-3.0 meters.

Below this layer a layer of clay (resistance values <1 Ohm m) or sandy clay (resistance values 1-10 Ohm m) saturated with salt water appears up to an average depth of 20.0-25.0 meters.

Below this layer a layer of gravel, clayey, conglomerate (resistance values 10-130 Ohm m) saturated with salt water appears up to an average depth of 120.0 meters.

Weathered and fractured limestone, saturated with salt water and bedrock appears at depths greater than 120 meters.

Table 7.11Conditional classification of soil and rock mass according to electrical resistivity.

Electrical resistivity (Ωm)	Type and state of rock
< 1	CLAY, SATURATED WITH SALT WATER
1-10	CLAY SANDY, SATURATED WITH SALT WATER
10-130	GRAVEL CLAYEY, CONGLOMERATE WHEATERED AND FRACTURED LIMESTONE (SATURATED WITH SALT WATER)
>130	BEDROCK - LIMESTONE
>10	SAND, CLAYEY, SILTY (DRY ZONE NEAR SURFACE)

Figure 7.21 Legend with interpreted profile of geoelectrical tomography – GE-5

7.3.3 Geoelectrical sounding

7.3.3.1 General

At the location Neretva Valley total of 45 geoelectrical sounding measurements were taken: 25 measurements with maximum half distance AB/2=200 m (GS-100) and 20 measurements with maximum half distance AB/2=600 m (GS-200). Results of geoelectrical soundings are displayed in appendix 4 (GS-100-1 to GS-100-25) and (GS-200-1 to GS-200-20). Results consists of measured apparent resistivity and derived curves for apparent resistivity layered inversion model.

7.3.3.2 Description

According to model parameters (layer thickness and apparent resistivity), for every probe position, equivalent resistivity of homogenous medium was defined.

Probes GS-100-1 to GS-100-25 were measured to a depth of 100 meters, while probes GS-200-1 to GS-200-20 were measured to a depth of 200 meters.

Each appendix presents the results of geoelectrical sounding in the form of log-log diagrams with derived curves and an interpreted model of the underground.

Every diagram is accompanied by tables with intervals of values of geoelectric resistance by depth and tables of lithological determination of layers.

Considering the results obtained by interpreting the measured data, it is possible to define the basic structure of the terrain in the following way:

- dry materials near surface (sand, clay etc.)
- sandy clay saturated with salt water
- layer of clay saturated with salt water
- coarse gravel to poorly bonded conglomerate saturated with salt water *
- small grain gravel to sand saturated with salt water *
- weathered and fractured limestone saturated with salt water; bedrock

* marked layers are not present south of Little Neretva river and between the geoelectrical probes GS-100-20, GS-100-6, GS-100-10, GS-100-11 and the south bank of Neretva river.

The distribution of lithological units along the Neretva Valley, due to complex sedimentation and tectonic history, is not uniform and cannot be unambiguously interpreted for all probes.

Based on the interpretation of the recorded geoelectric probes GS-100-23, GS-100-5, GS-100-6, GS-200-7, GS-200-13, GS-200-1, GS-200-2, GS-200-3, GS-100-3 and GS-100-17 profile 1-1' was made (Figure 7.22).

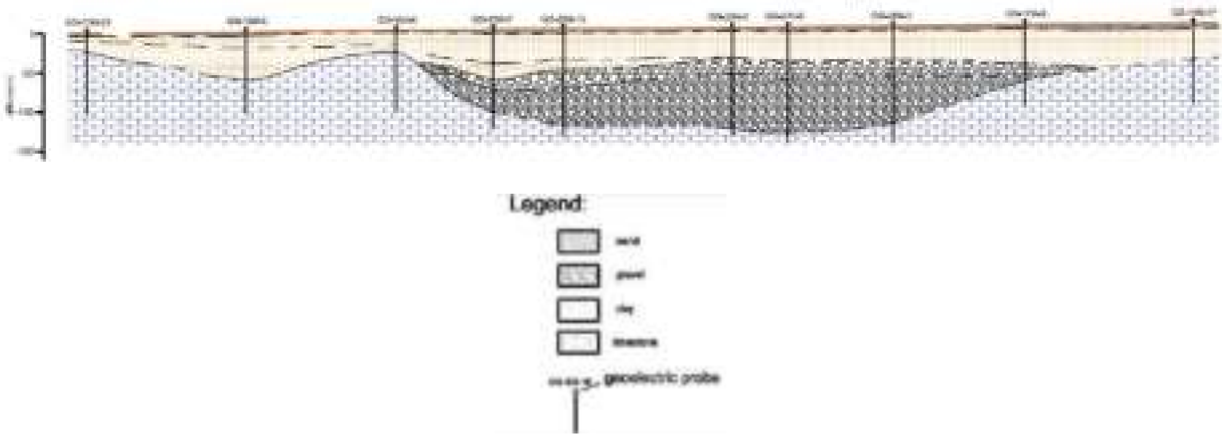

Figure 7.22 Interpreted profile 1-1' with legend.

Based on the interpretation of the recorded geoelectric probes GS-100-13, GS-100-14, GS-200-16, GS-200-20, GS-100-15 and GS-100-16 profile 2-2' was made (Figure 7.23).

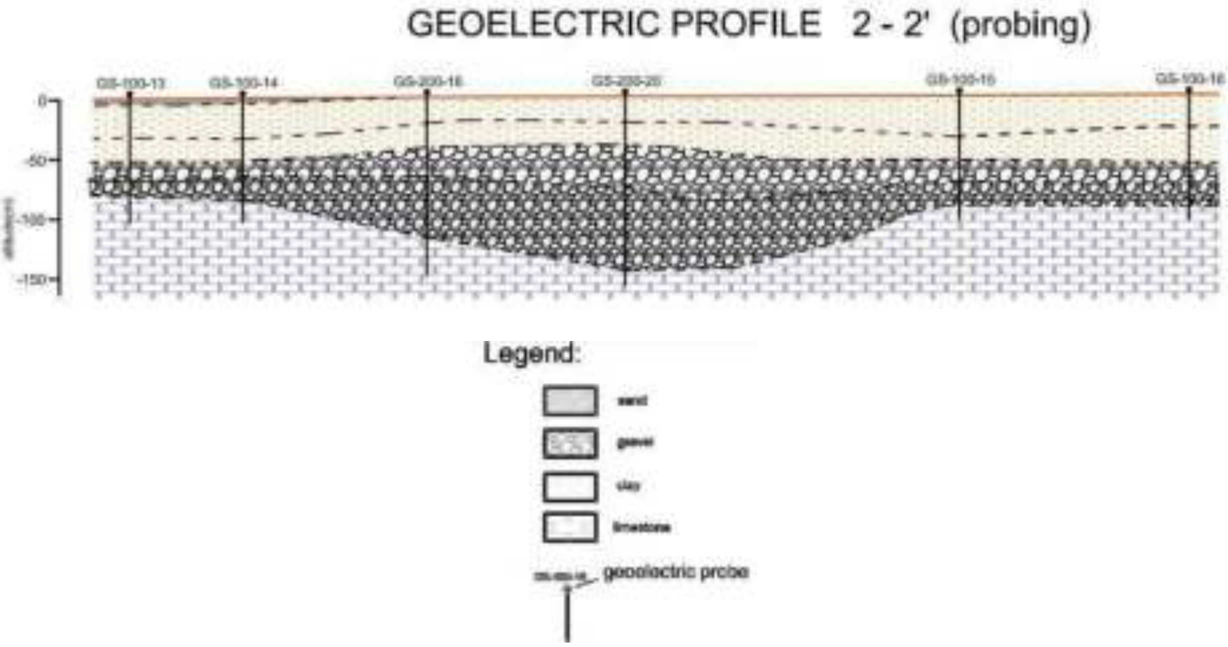

Figure 7.23 Interpreted profile 2-2' with legend

7.4 Conclusion

At the area of Neretva Valley, geophysical explorations were conducted. The exploration included the following geophysical methods: seismic reflection, geoelectrical tomography and geoelectrical sounding. The purpose of the survey was to use non-destructive methods in order to characterize the conditions, constitution and depth of the rock mass, determine the locations of possible faults and joints and to determine the electrical resistivity of soil.

At the location of the Neretva Valley total amount of measurements is as follows: 1 profile of seismic reflection, 5 geoelectrical tomography profiles and 45 geoelectrical probe (25 probe AB/2=200 m, 20 probe AB/2=600 m).

Seismic reflection method resulted in the form of an interpreted depth profile with the corresponding altitudes. Significant reflexes which indicate different layers, significant fault contacts and a possible depth of bedrock are marked.

The processed results of geoelectrical tomography method are shown in the form of 2-D sections of resistivity variation with depth. According to resistivity values, the conditional classification of soil was made.

Based on layers' thickness and resistivity, geoelectric sounding was used to calculate equivalent resistivity of homogenic soil. Through chapter 8.3 the basic interpretation of the terrain was made according to the results obtained by interpreting the measured data.

7.5 Literature

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8 Exploratory drilling with sampling

In order to ensure the quality and coordination of field and laboratory research work and making of geotechnical report, exploratory drilling was performed with continuous guidance by an expert team consisting of research leader and geological engineer. There were 3 exploration boreholes drilled with a total depth of 150,0 m at the site, borehole B-1 (S-104-21-01) was drilled to a depth of 40,0 m, borehole B-2 (S-104-21-02) to a depth of 90,0 m, and borehole B-3 (S-104-21-03) to a depth of 20,0 m. Exploratory drilling was performed in the period from 28.01. to 09.03.2022.

Data on drilled boreholes are provided in the following table (coordinate system HTRS96 / TM, altitude HVRS71).

Borehole ID	Coordinate		Mouth level (m asl)	Depth (m)
	E	N		
B-1 (S-104-21-01)	583304,18	4762640,16	0,46	40,0
B-2 (S-104-21-02)	578928,63	4764297,75	1,26	90,0
B-3 (S-104-21-03)	578606,07	4764959,54	-0,81	20,0

The position of the drilled exploration boreholes is shown in the situation in Appendix 1.

The exploratory boreholes were drilled with the "Nordmeyer DSB 1 / 3,5" drilling machine. In the ground it was drilled rotary, dry drilling, single core pipes with “vidija” drilling crown, profiles 146, 13, 116 and 101 mm. Parallel with drilling, the stability of the borehole wall is ensured with protective steel columns profiles 178 and 116 mm. In the base rock it was drilled rotary, with water, a double core pipe with a diamond drill bit, profile 101 mm.

The drilled core was placed in 1,0 m long crates so that the depth of 1,0 m is equivalent to 1,0 m along the length of the crate. The core was placed in crates from left to right, from top to bottom. After stacking, the core was photographed with the marking of the depth and borehole ID.

As part of the exploratory drilling, the following was performed:

- field identification and classification of drilling core,
- soil sampling - undisturbed and disturbed samples,
- monitoring of appearance and levels of underground water in boreholes and

* remediation of boreholes and surrounding terrain.

The results of field exploration works are presented in borehole logs in Appendix 2 and hydrogeological cross - sections in Appendix 3.

8.1 Field identification and classification of drilling core

Field classification and identification of soil layers of the drilled core was performed by a geological engineer, and helps to select relevant soil samples obtained by exploratory drilling as well as for further detailed testing in the laboratory. Soil identification and description is carried out in a manner adopted in practice, so that according to a certain procedure, all the properties of the material are entered in the forms provided for that purpose.

8.2 Sampling of disturbed and undisturbed soil samples

The purpose of sampling is to obtain samples for soil identification and laboratory tests to determine the geotechnical properties of the underlying soil. In the geotechnical laboratory, physical and mechanical properties were determined on undisturbed and disturbed samples, in accordance with accredited norms.

A sampler was used to take undisturbed soil samples. Once the appropriate depth was reached, the sampler was lowered into the borehole. The depth of sampling was defined by a geological engineer. Samples were wrapped in paraffin after extraction to protect them against disturbance and moisture loss.

Disturbed soil samples for classification tests were taken systematically from each layer, a minimum of one sample and on average every 3 m. Samples were taken from the crates, after photographing the core. Disturbed samples were stored in plastic bags to protect against moisture loss.

During transport, the samples were stored in a suitable crate in which they are protected from possible external influences (heat, cold, vibration and shock). After delivering the samples, they were counted (number of undisturbed and disturbed), inspected and stored in a humid chamber. After the laboratory program was defined, appropriate tests were performed on the test samples.

All samples are marked, the following table shows the method of marking the borehole and test samples according to the work order number.

Work order number	Borehole ID	Sample ID	Description
NA-104-21	S-104-21-01	S-104-21-01-01	Borehole number 01, sample number 01

Disturbed and undisturbed samples are shown on geotechnical cross - sections of exploration boreholes in Appendix 2.

8.3 Underground water

The appearance and level of underground water was monitored during field research works. Observations were made from the borehole mouth. Data of registered levels are shown in the following table.

Borehole	Borehole mouth level (m asl)	Date of measurement (dd.mm.yyyy.)	Appearance of underground water (m)	Underground water level (m)	Absolute underground water level (m asl)
B-1 (S-104-21-01)	0,46	31.01.2022.	-	4.20	-3,74
B-2 (S-104-21-02)	1,26	03.02.2022.	-	1.90	-0,64
B-3 (S-104-21-03)	-0,81	08.03.2022.	-	0.80	-1,61

The measured underground water levels are current because they refer to the period of conducting exploration works. They were measured during drilling and before the installation of protective columns.

More accurate data on the underground water level at the site would be obtained by monitoring the levels via piezometers throughout the whole hydrological season.

8.4 Remediation of boreholes and surrounding terrain

Upon completion of the exploratory drilling, the exploratory boreholes and the surrounding terrain were remediated in agreement with the Investor.

Borehole remediation was carried out by injecting the borehole with the injection mixture, with method from bottom-up. The composition of the injection mixture is cement + water + bentonite suspension.

Injection equipment:

- Electric generator 15 kwh,
- Turbo mixer type Crealius for preparation of bentonite suspension, production of injection mixture and injection up to a pressure of 15 bar,
- Injection flow and pressure meters and
- Pressure hoses.

Figure 8.1 Electric generator 15 kwh

Figure 8.2 Turbo mixer type Crealius

Figure 8.3 Injection flow and pressure meter

Figure 8.4 Pressure hoses

Material for the preparation of the injection mixture:

- Clean water,
- Cement Cemex 42,5 N and
- Bentonite “Bentoplast”, INA Petrokemija, Kutina.

Preparation of the injection mixture:

1. Preparation of bentonite suspension where bentonite is mixed with water in the ratio of 1 kg of bentonite to 9 litters of water,

2. The prepared suspension is placed in a pool to age for 24 hours,

3. In a turbo mixer for 3-5 minutes the injection mixture is made with a composition of: water 63 l + bentonite suspension 37 l + cement 100 kg.

Filling exploration boreholes after drilling with injection mixture with injection method from bottom up:

1. Lowering the drilling rods to the bottom of the borehole,

2. Connecting the turbo mixer and drilling rods with pressure hoses,

3. Preparation of injection mixture for 3-5 minutes, composition: water 63 l + bentonite suspension 37 l + cement 100 kg,

4. Injecting the injection mixture through the drilling rods with constant monitoring of the injection pressure and the amount of used mixture and lifting the drilling rods in accordance with the volume of the borehole and the amount of used mixture,

5. The borehole filling process lasts until the injection mixture appears at the borehole mouth,

6. After the mixture appears at the borehole mouth, the level of the mixture is controlled, and if the level of the mixture decreases, the borehole is filled with a new mixture until the borehole is completely filled,

7. After the level of the mixture at the borehole mouth stabilizes and the mixture begins to set, the remediation of the borehole is completed.

The following photographs show the remediation of the surrounding terrain at the positions of exploration boreholes.


Remediation of the surrounding terrain at the position of the borehole B-1 (S-104-21-01)


Remediation of the surrounding terrain at the position of the borehole B-2 (S-104-21-02)


Remediation of the surrounding terrain at the position of the borehole B-3 (S-104-21-03)

9 List of figures

10 List of tables

11 Appendices

The list of appendices is provided by the following table:

AppendixNo.	Appendix name
1	Map of conducted investigation works
2	Exploratory borehole logs
2.1.	Exploratory borehole log B-1 (S-104-21-01)
2.2.	Exploratory borehole log B-2 (S-104-21-02)
2.3.	Exploratory borehole log B-3 (S-104-21-03)
3	Hydrogeological profile
3.1.	Hydrogeological profile P-1 Diga
3.2.	Hydrogeological profile P-2 Crepina
3.3.	Hydrogeological profile P-3 Vidrice
3.4.	Hydrogeological profile P-4 Opuzen magistrala
3.5.	Hydrogeological profile P-5 Opuzen
3.6.	Hydrogeological profile P-6 Diga - Opuzen
4	Geophysical research
	Locations of geophysical measurements
	Seismic profile RFL-1 (Crepine)
	Geoeletrical profile GE-1 (Vidrice)
	Geoeletrical profile GE-2 (Opuzen)
	Geoeletrical profile GE-3 (Opuzen)
	Geoeletrical profile GE-4 (Opuzen-Magistrala)
	Geoeletrical profile GE-5 (Diga)
	Geoelectrical probes GS-100-1
	Geoelectrical probes GS-100-2
	Geoelectrical probes GS-100-3
	Geoelectrical probes GS-100-4
	Geoelectrical probes GS-100-5
	Geoelectrical probes GS-100-6
	Geoelectrical probes GS-100-7
	Geoelectrical probes GS-100-8
	Geoelectrical probes GS-100-9
	Geoelectrical probes GS-100-10

	Geoelectrical probes GS-100-11
	Geoelectrical probes GS-100-12
	Geoelectrical probes GS-100-13
	Geoelectrical probes GS-100-14
	Geoelectrical probes GS-100-15
	Geoelectrical probes GS-100-16
	Geoelectrical probes GS-100-17
	Geoelectrical probes GS-100-18
	Geoelectrical probes GS-100-19
	Geoelectrical probes GS-100-20
	Geoelectrical probes GS-100-21
	Geoelectrical probes GS-100-22
	Geoelectrical probes GS-100-23
	Geoelectrical probes GS-100-24
	Geoelectrical probes GS-100-25
	Geoelectrical probes GS-200-1
	Geoelectrical probes GS-200-2
	Geoelectrical probes GS-200-3
	Geoelectrical probes GS-200-4
	Geoelectrical probes GS-200-5
	Geoelectrical probes GS-200-6
	Geoelectrical probes GS-200-7
	Geoelectrical probes GS-200-8
	Geoelectrical probes GS-200-9
	Geoelectrical probes GS-200-10
	Geoelectrical probes GS-200-11
	Geoelectrical probes GS-200-12
	Geoelectrical probes GS-200-13
	Geoelectrical probes GS-200-14
	Geoelectrical probes GS-200-15
	Geoelectrical probes GS-200-16
	Geoelectrical probes GS-200-17
	Geoelectrical probes GS-200-18
	Geoelectrical probes GS-200-19
	Geoelectrical probes GS-200-20


MAP OF CONDUCTED INVESTIGATION WORKS
M 1:10 000
E-104-21-01
app. No.: 1
Legend:
Previous exploratory boreholes
Year:
2005
2008
2011
2012
2013
2014
2017
Preliminary geophysical works 2019
Geoelectrical probes
Geoelectrical profiles
Interpretative geophysical profiles
1-1'
2-2'
Hydrogeology / Geophysical profiles
P-1 (Diga)
GE-3
P-5 (Opuzen)
P-2 (Crepina)
P-3 (Vidrice)
P-4 (Opuzen magistrala)
Geoelectrical probes
100m
200m
Hydrogeology profile
P-6 (Diga-Opuzen)
Exploratory boreholes 2022
LEGEND
exploration borehole
spring
bedding plane
joint
vertical joint
geological boundary
fault
fault zone
LITHOSTRATIGRAPHIC UNITS
delta sediments, organic-swamp sediments (Q)
P-6 Diga-Opuzen
P-2 Crepina
P-3 Vidrice
P-4 Opuzen magistrala
P-5 Opuzen
NERETVA
JEZ. PARILA
O. OSINJ

CLIENT: UNIVERSITY OF SPLIT Faculty of Civil Engineering, Architecture and Geodesy Matice hrvatske 15, Split	**FIELD CLASSIFICATION:** Marijana JELIĆ, dipl.ing.geol. **DRILL OPERATOR:** Davor RIBIĆ **DRILLING RIG:** Nordmeyer DSB 1/3,5 **HEAD OF INVSTIGATIONS:** prof.dr.sc. Leo Matešić, dipl.ing.građ.	**BOREHOLE COORDINATES:** E: 583304,18 N: 4762640,16 **GROUND LEVEL (m.a.s.l.):** H: 0,46	**START DATE:** 28.01.2022. **END DATE:** 01.02.2022.

PROJECT: Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation

LOCATION: Lower Neretva

Borehole log: B-1 (S-104-21-01)

Scale: 1:100

DEPTH (m)	GROUND LEVEL (m.a.s.l.)	CORE BARREL DIAMETER (mm)	PROTECTIVE CASING DIAMETER (mm)	GWO (m)	GWL (m)	SYMBOL	INTERVAL (m)	SOIL DESCRIPTION
0,0	0.26	146	178				0,20	Humus
1,0	-0.64					CL	1,10	Lean clay, stiff consistency, brown color, in places contains manganes concretions.
2,0	-1.84					CH	2,30	Fat clay, soft to medium consistency, brown color, in places contains manganes concretions.
3,0	-3.54					SC/CL	4,00	Clayey sand to sandy lean clay, fine sand, gray color, in places contains peat.
4,0–5,0	-5.64				4.2	SC	6,10	Clayey sand, fine, gray color.
6,0–7,0	-7.54					CL	8,00	Sandy lean clay, soft consistency, gray color, in places contains peat.
8,0–9,0	-9.14					SP	9,60	Poorly graded sand, medium to fine, gray color.
10,0–14,0	-14.54	146 / 101				CL	15,00	Lean clay with sand, soft consistency, gray color, organic smell, in places contains peat.
15,0–17,0	-17.54	146				CL	18,00	Lean clay, soft to medium consistency, gray color, in places contains some sand.
19,0–20,0		101						

Further column groups (no values entered): GROUP OF MATERIALS; STANDARD PENETRATION TEST (Blow count) – N_0, N_1, N_2, N, N_{60}; POCKET PENETROMETER q_u (kPa); FIELD VANE TEST c_u (kPa), c_r (kPa); SHEAR TESTS c/C_u (kPa), TIP; UNCONFINED COMPRESSION STRENGHT q_u (kPa); OEDOMETER TEST (MPa) 400, 800, 1600, 3200.

SAMPLE TYPE	SAMPLE ID	FROM (m)	TO (m)	w_L (%)	w_P (%)	I_P (%)	I_c	w_0 (%)	ρ (g/cm³)	$ρ_d$ (g/cm³)	$ρ_s$ (g/cm³)	G (%)	S (%)	M (%)	C (%)	k (cm/s)	k 100/300 (cm/s)	k 200/400 (cm/s)	k 400/500 (cm/s)
PU	1	1.00	1.10	37.32	21.78	15.54	0.88	23.58			2.72		11.00	64.00	25.00	3.16E-07			
NU	2	2.00	2.30	56.37	24.02	32.34	0.24	48.74	1.80	1.28	2.69		11.50	66.50	22.00	8.86E-07	6.30E-08	4.60E-08	2.50E-08
PU	3	3.40	3.50	35.06	22.42	12.64	0.19	32.60			2.73		53.40	28.00	18.60	2.57E-06			
PU	4	4.50	4.60					38.96			2.76		77.70	13.60	8.70	5.43E-04			
PU	5	6.80	6.90					41.86			2.68		30.10	49.50	20.40	1.34E-06			
PU	6	8.90	9.00									2.20	96.60	1.20		2.09E-02			
PU	7	10.50	10.60	36.64	21.79	14.86		37.92			2.71		27.20	54.10	18.70	2.26E-06			
NU	8	13.30	13.60	38.63	22.98	15.65	0.21	35.38	1.64	1.42	2.67		15.80	65.30	18.90	2.69E-06	6.90E-08	4.00E-08	3.80E-08
PU	9	15.50	15.80	37.56	21.34	16.22	0.07	36.46	1.89	1.43	2.68		18.80	62.40	18.80	2.73E-06			
PU	10	17.50	17.60	37.73	23.59	14.14	0.13	35.96			2.67		10.60	70.50	18.90	2.36E-06			
NU	11	18.50	18.80	39.90	22.02	17.88	0.04	39.17	1.83	1.33	2.69		2.80	60.40	36.80		6.90E-08	4.00E-08	3.60E-08

PHOTO DOCUMENTATION

SAMPLE DISTRIBUTION:		IN SITU TESTS:	
		STANDARD PENETRATION TEST:	-
DISTURBED SAMPLES	18	POCKET VANE TEST:	-
UNDISTURBED SAMPLES	4	POCKET PENETROMETER:	-
SPT	-	FIELD VANE TEST:	

LEGEND

STANDARD PENETRATION TEST (SPT):
- Split spoon sampler $N=(N_{30}*k_{60})+(N_{45}*k_{60})$
- Solid cone Š=0,75*N

"/" - Refusal (>50) (k_{60}=1,087)

FIELD VANE TEST (TYPE): Torvane (pocket in situ); Torvane (laboratory on US); Geonor

DIRECT SHEAR TEST: S – Standard; R – Reverse; KT – Krey - Tiedemann

TRIAXIAL SHEAR TEST: UU – Unconsolidated undrained; CU – Consolidated undrained; CD – Consolidated drained

POCKET PENETROMETER: In-situ; Laboratory

DRY / BULK DENSITY: Bulk density; Dry density; Specific density

COMMENTS:
- sample S-104-21-01-07 at depth 10,50-10,60 m combustible matter content 10,79%, content of organic matter 5,96%,
- sample S-104-21-01-08 at depth 13,30-13,60 m combustible matter content 15,17%, content of organic matter 6,23%,
- sample S-104-21-01-15 at depth 25,50-25,60 m combustible matter content 17,85%, content of organic matter 15,47% and
- sample S-104-21-01-17 at depth 26,90-27,00 m combustible matter content 17,57%, content of organic matter 11,27%.

GEOKON
GEOKON - ZAGREB d.d.

REPORT ID: E-104-21-01

APPENDIX N°: 2.1

CLIENT:			
UNIVERSITY OF SPLIT Faculty of Civil Engineering, Architecture and Geodesy Matice hrvatske 15, Split	FIELD CLASSIFICATION: Marijana JELIĆ, dipl.ing.geol. DRILL OPERATOR: Davor RIBIĆ DRILLING RIG: Nordmeyer DSB 1/3,5 HEAD OF INVSTIGATIONS: prof.dr.sc. Leo Matešić, dipl.ing.građ.	BOREHOLE COORDINATES: E: 583304,18 N: 4762640,16 GROUND LEVEL (m.a.s.l.): H: 0,46	START DATE: 28.01.2022. END DATE: 01.02.2022.

PROJECT: Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation

LOCATION: Lower Neretva

Borehole log: B-1 (S-104-21-01)

Scale: 1:100

Soil profile

DEPTH (m)	GROUND LEVEL (m.a.s.l.)	CORE BARREL DIAMETER (mm)	SYMBOL	INTERVAL (m)	SOIL DESCRIPTION
20,0–25,10	-24.64	146 / 101	CL	25,10	Lean clay, soft consistency, gray color, in places contains manganes concretions and shell fragments.
25,10–25,90	-25.44	101	OH	25,90	Organic clay, black color with gray, in places contains peat.
25,90–26,40	-25.94	131	SC	26,40	Clayey sand, fine, gray color.
26,40–27,60	-27.14	131	CL	27,60	Lean clay with sand, soft consistency, gray color with black, organic smell, in places contains peat.
27,60–28,20	-27.74	131	CL	28,20	Lean clay, medium to stiff consistency, gray color, contains manganes concretions and shell fragments.
28,20–30,60	-30.14	131	SC	30,60	Clayey sand, fine, gray color.
30,60–31,90	-31.44	131	CL	31,90	Lean clay, medium consistency, gray color, contains shell fragments.
31,90–33,10	-32.64	131	SC	33,10	Clayey sand, fine, gray color, at the end of the interval some gravel.
33,10–34,20	-33.74	131	CH	34,20	Fat clay, stiff consistency, reddish brown color, contains FeO and small fragments of limestone at the end of interval.
34,20–40,00	-39.54	101	V	40,00	Limestone, micritic to fine-crystalline, white to yellowish color, in some places contains thin calcite veins. Weathering rock class according to ISRM (1981) is W1 Fresh rock. DISCONTINUITIES SET 1: incline 0-10°, separation (aparture) 0,1-1,0 mm, infilling none or hard infilling, roughness slightly rough and weathering unweathered. JRC10 with Barton comb is 10-12. SET 2: incline 35-45°, separation (aparture) 0,1-1,0 mm, infilling none or hard infilling, roughness rough and weathering slightly weathered. JRC10 with Barton comb is 14-16. LIMESTONE; UPPER CRETACEOUS; V; K22,3 BEDROCK

Laboratory results

SAMPLE TYPE	SAMPLE ID	FROM	TO	w_L (%)	w_P (%)	I_P (%)	I_c	w_0 (%)	Bulk density (g/cm³)	Dry density (g/cm³)	Specific density (g/cm³)	G (%)	S (%)	M (%)	C (%)	k (cm/s)	Permeability oedometer/triaxial cell k (cm/s) 100/300	200/400	400/500
PU	12	20.50	20.80	40.20	23.24	16.96	0.08	38.89	1.86	1.37	2.73		6.40	75.00	18.60	2.17E-06			
PU	13	22.50	22.60	41.14	23.28	17.86	0.21	37.43			2.73		4.70	76.70	18.60	2.30E-06			
NU	14	24.70	25.00	37.31	22.49	14.83	0.10	35.79	1.90	1.42	2.74		3.00	75.20	21.80	1.18E-06	2.50E-07	1.20E-07	3.60E-08
PU	15	25.50	25.60	94.01	26.80	67.20	0.61	53.18			2.58		5.50	76.90	17.60	5.88E-06			
PU	16	26.10	26.20					20.48			2.76		71.40	16.50	12.10	1.52E-04			
PU	17	26.90	27.00	44.00	21.89	22.11		50.58			2.70		26.90	51.20	21.90	9.00E-07			
PU	18	27.80	27.90	35.91	22.95	12.96	1.25	29.78			2.71		2.50	53.40	44.10				
PU	19	29.40	29.50	27.91	20.87	7.04		28.69			2.75		62.90	25.00	12.10	2.83E-05			
PU	20	31.20	31.30	37.20	22.17	15.04	0.38	31.49			2.70		5.50	51.40	43.10				
PU	21	32.50	32.60					19.46			2.77		70.00	20.20	9.80	1.54E-04			
PU	22	33.50	33.60	53.86	24.19	29.67	0.90	27.17			2.72		5.10	29.50	65.40				

(Columns for standard penetration test, pocket penetrometer, field vane test, shear tests, unconfined compression strength and oedometer test are empty on this page.)

PHOTO DOCUMENTATION

SAMPLE DISTRIBUTION:		IN SITU TESTS:	
DISTURBED SAMPLES	18	STANDARD PENETRATION TEST:	-
UNDISTURBED SAMPLES	4	POCKET VANE TEST:	-
SPT	-	POCKET PENETROMETER:	-
		FIELD VANE TEST:	

LEGEND

STANDARD PENETRATION TEST (SPT):
- Split spoon sampler $N = (N_2 \cdot k_{60}) + (N_3 \cdot k_{60})$
- Solid cone $Š = 0{,}75 \cdot N$
- "/" - Refusal (>50) (k_{60}=1,087)

FIELD VANE TEST (TYPE):
- Torvane (pocket in situ)
- Torvane (laboratory on US)
- Geonor

DIRECT SHEAR TEST:
- S Standard
- R Reverse
- KT Krey - Tiedemann

[illegible]:
- [illegible]
- [illegible]

TRIAXIAL SHEAR TEST:
- UU Unconsolidated undrained
- CU Consolidated undrained
- CD Consolidated drained

POCKET PENETROMETER:
- In-situ
- Laboratory

DRY / BULK DENSITY:
- Bulk density
- Dry density
- Specific density

COMMENTS:
- sample S-104-21-01-07 at depth 10,50-10,60 m combustible matter content 10,79%, content of organic matter 5,96%,
- sample S-104-21-01-08 at depth 13,30-13,60 m combustible matter content 15,17%, content of organic matter 6,23%,
- sample S-104-21-01-15 at depth 25,50-25,60 m combustible matter content 17,85%, content of organic matter 15,47% and
- sample S-104-21-01-17 at depth 26,90-27,00 m combustible matter content 17,57%, content of organic matter 11,27%.

GEOKON GEOKON - ZAGREB d.d.

REPORT ID: E-104-21-01

APPENDIX Nº: 2.1

PAGE NUM.: 2

CLIENT:					
UNIVERSITY OF SPLIT	FIELD CLASSIFICATION:	Marijana JELIĆ, dipl.ing.geol.	BOREHOLE COORDINATES: E: 578928,63 N: 4764297,75	START DATE: 03.02.2022.	PROJECT: Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation
Faculty of Civil Engineering, Architecture and Geodesy	DRILL OPERATOR:	Davor RIBIĆ	GROUND LEVEL (m.a.s.l.):	END DATE: 01.03.2022.	LOCATION: Lower Neretva
Matice hrvatske 15, Split	DRILLING RIG:	Nordmeyer DSB 1/3,5	H: 1,26		Borehole log: B-2 (S-104-21-02)
	HEAD OF INVSTIGATIONS:	prof.dr.sc. Leo Matešić, dipl.ing.građ.			Scale: 1:100

Soil profile

DEPTH (m)	GROUND LEVEL (m.a.s.l.)	CORE BARREL DIAMETER (mm)	PROTECTIVE CASING DIAMETER (mm)	GWO (m)	GWL (m)	SYMBOL	INTERVAL (m)	GROUP OF MATERIALS	SOIL DESCRIPTION
0,0 – 2,40	-1.14	146			1.9	SP	2,40		Poorly graded sand, fine, brown color, at the end of the interval contains some clay and fragment of concrete.
2,40 – 6,30	-5.04	146				SC	6,30		Clayey sand, fine, gray color.
6,30 – 7,00	-5.74	146				CL/SC	7,00		Sandy lean clay to clayey sand, soft consistency, gray color, in places contains peat.
7,00 – 12,50	-11.24	146				SC	12,50		Clayey sand, fine, gray color, in places contains peat.
12,50 – 18,00	-16.74	146 / 101				CL	18,00		Lean clay, medium consistency, dark gray to black color, organic smell.
18,00 – 20,0		146							

Depth scale: 0,0; 1,0; 2,0; 3,0; 4,0; 5,0; 6,0; 7,0; 8,0; 9,0; 10,0; 11,0; 12,0; 13,0; 14,0; 15,0; 16,0; 17,0; 18,0; 19,0; 20,0

Test results

STANDARD PENETRATION TEST (Blow count): N_0, N_1, N_2, N, N_{60}; POCKET PENETROMETER q_u (kPa); FIELD VANE TEST c_u (kPa), c_r (kPa) — no data.

SAMPLE TYPE	SAMPLE ID	INTERVAL FROM (m)	INTERVAL TO (m)	w_L (%)	w_P (%)	I_P (%)	I_c	w_0 (%)	ρ (g/cm³)	$ρ_d$ (g/cm³)	$ρ_s$ (g/cm³)	G (%)	S (%)	M (%)	C (%)	Permeability (accord. to USBR) k (cm/s)	PERMEABILITY OEDOMETER / TRIAXIAL CELL k (cm/s) 100/300 – 800	200/400 – 1600	400/500
PU	1	1.00	1.10									3.60	95.40	1.00		1.51E-02			
PU	2	4.20	4.30								2.75		71.00	18.00	11.00	3.98E-04			
PU	3	6.70	6.80	48.96	24.09	24.87		53.81			2.74		46.90	34.50	18.60	3.67E-06			
PU	4	8.50	8.60								2.76		70.80	17.10	12.10	8.90E-05			
PU	5	11.50	11.60								2.76		77.30	14.00	8.70	4.68E-04			
PU	6	13.50	13.60	45.17	25.36	19.80	0.56	34.17			2.68		16.50	61.50	22.00	5.06E-07			
PU	7	15.50	15.60	40.75	24.35	16.40	0.40	34.16			2.71		5.10	59.30	35.60	1.13E-07			
NU	8	17.60	17.90	46.36	23.56	22.80	0.29	39.81	1.86	1.37	2.72		0.30	62.60	37.10		7.70E-08	6.00E-08	5.30E-08
PU	9	18.50	18.60	41.15	23.76	17.39	0.22	37.32			2.69		1.20	47.10	51.70				

SHEAR TESTS: c/C_u (kPa), φ (°), TIP; UNCONFINED COMPRESSION STRENGHT q_u (kPa); OEDOMETER TEST (MPa): 400, 800, 1600, 3200 — no data.

PHOTO DOCUMENTATION

SAMPLE DISTRIBUTION:

DISTURBED SAMPLES	68
UNDISTURBED SAMPLES	3
SPT	-

IN SITU TESTS:

STANDARD PENETRATION TEST:	-
POCKET VANE TEST:	-
POCKET PENETROMETER:	-
FIELD VANE TEST:	

LEGEND

STANDARD PENETRATION TEST (SPT):
- Split spoon sampler $N=(N_{30}*k_{60})+(N_{45}*k_{60})$
- Solid cone Š=0,75*N

"/" - Refusal (>50) (k_{60}=1,087)

FIELD VANE TEST (TYPE):
- Torvane (pocket in situ)
- Torvane (laboratory on US)
- Geonor

DIRECT SHEAR TEST:
- S Standard
- R Reverse
- KT Krey - Tiedemann

TRIAXIAL SHEAR TEST:
- UU Unconsolidated undrained
- CU Consolidated undrained
- CD Consolidated drained

POCKET PENETROMETER:
- In-situ
- Laboratory

DRY / BULK DENSITY:
- Bulk density
- Dry density
- Specific density

COMMENTS:
- sample S-104-21-02-06 at depth 13,50-13,60 m combustible matter content 13,93%, content of organic matter 4,19%,
- sample S-104-21-02-07 at depth 15,50-15,60 m combustible matter content 13,86%, content of organic matter 5,16%,
- sample S-104-21-02-08 at depth 17,60-17,90 m combustible matter content 11,11%, content of organic matter 2,67%,
- sample S-104-21-02-10 at depth 20,40-20,80 m combustible matter content 9,30%, content of organic matter 2,22% and
- sample S-104-21-02-16 at depth 30,70-30,80 m combustible matter content 12,52%, content of organic matter 35,12%.

GEOKON
GEOKON - ZAGREB d.d.

REPORT ID: E-104-21-01	APPENDIX Nº: 2.2
	PAGE NUM.: 1

CLIENT:				
UNIVERSITY OF SPLIT Faculty of Civil Engineering, Architecture and Geodesy Matice hrvatske 15, Split	FIELD CLASSIFICATION: Marijana JELIĆ, dipl.ing.geol. DRILL OPERATOR: Davor RIBIĆ DRILLING RIG: Nordmeyer DSB 1/3,5 HEAD OF INVSTIGATIONS: prof.dr.sc. Leo Matešić, dipl.ing.građ.	BOREHOLE COORDINATES: E: 578928,63 N: 4764297,75 GROUND LEVEL (m.a.s.l.): H: 1,26	START DATE: 03.02.2022. END DATE: 01.03.2022.	PROJECT: Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation LOCATION: Lower Neretva **Borehole log: B-2 (S-104-21-02)** **Scale: 1:100**

Soil profile

DEPTH (m)	GROUND LEVEL (m.a.s.l.)	CORE BARREL DIAMETER (mm)	PROTECTIVE CASING DIAMETER (mm)	SYMBOL	INTERVAL (m)	SOIL DESCRIPTION
to 24,0	-22.74	101 / 146 / 101	178	CL	24,00	Lean clay, soft to medium consistency, gray color.
24,0–26,5	-25.24	146 / 131		CL	26,50	Lean clay, soft consistency, gray color, contains shell fragments.
26,5–29,0	-27.74	131		SC	29,00	Clayey sand, fine, gray color, in places contains shell fragments.
29,0–30,5	-29.24	131		SC/CL	30,50	Clayey sand to sandy lean clay, fine sand, gray color.
30,5–31,0	-29.74	131		OH	31,00	Organic clay with sand, black color with gray, contains peat.
31,0–31,5	-30.24	131		CL	31,50	Lean clay, stiff consistency, gray color, contains shell fragments.
31,5–32,4	-31.14	131		SC	32,40	Clayey sand, fine, gray color, organic smell.
32,4–		146		GC		Clayey gravel with sand, fine, gray color, rounded, maximum particle size up to 10 cm.

Depth scale: 21,0; 22,0; 23,0; 24,0; 25,0; 26,0; 27,0; 28,0; 29,0; 30,0; 31,0; 32,0; 33,0; 34,0; 35,0; 36,0

Columns also present (no entries): GWO (m), GWL (m), GROUP OF MATERIALS, STANDARD PENETRATION TEST (Blow count) N_0, N_1, N_2, N, N_{60}; POCKET PENETROMETER q_u (kPa); FIELD VANE TEST c_u (kPa), c_r (kPa); SHEAR TESTS c/C_u (kPa); UNCONFINED COMPRESSION STRENGHT q_u (kPa); OEDOMETER TEST (MPa).

Laboratory tests

SAMPLE TYPE	SAMPLE ID	FROM	TO	w_L (%)	w_P (%)	I_P (%)	I_c	w_0 (%)	ρ (g/cm³)	$ρ_d$ (g/cm³)	$ρ_s$ (g/cm³)	G (%)	S (%)	M (%)	C (%)	k (cm/s)	Permeability oedometer/triaxial cell k (cm/s)
NU	10	20.40	20.80	46.94	23.48	23.46	0.33	39.25	1.88	1.40	2.70		0.30	71.40	28.30	3.07E-07	1.30E-07 / 6.50E-08 / 3.40E-08
PU	11	22.00	22.10	44.97	24.62	20.34	0.34	38.07			2.69		0.10	45.20	54.70		
NU	12	23.50	23.90	51.17	27.35	23.82	0.50	39.35	1.85	1.42	2.68		1.10	51.90	47.00		2.90E-08 / 2.70E-08 / 1.40E-08
PU	13	24.50	24.60	48.38	23.57	24.81	0.26	41.87			2.70		2.80	73.00	24.20	3.65E-07	
PU	14	27.50	27.60								2.76		81.90	12.00	6.10	9.73E-04	
PU	15	29.50	29.60								2.68		56.90	29.10	14.00	6.20E-06	
PU	16	30.70	30.80	88.88	29.54	59.33	0.58	54.46			2.57		24.10	46.70	29.20	1.91E-07	
PU	17	31.20	31.30	39.69	22.91	16.78	0.78	26.66			2.69		3.00	40.80	56.20		
PU	18	31.90	32.00					16.89			2.78		63.10	27.10	9.80	2.92E-05	
PU	19	33.00	33.10									48.90	32.10	12.80	6.20	2.73E-03	
PU	32	34.90	35.00									56.20	30.10	6.80	6.90	1.40E-02	
PU	20	36.00	36.10									47.70	35.60	9.60	7.10	7.02E-03	
PU	33	37.90	38.00									48.60	32.90	9.20	9.30	2.71E-03	
PU	21	39.00	39.10									54.90	33.60	5.80	5.70	1.03E-01	
PU	34	40.00	40.10									39.20	42.00	8.60	10.20	2.73E-03	

PHOTO DOCUMENTATION

SAMPLE DISTRIBUTION:		IN SITU TESTS:	
		STANDARD PENETRATION TEST:	-
DISTURBED SAMPLES	68	POCKET VANE TEST:	-
UNDISTURBED SAMPLES	3	POCKET PENETROMETER:	-
SPT	-	FIELD VANE TEST:	

LEGEND

STANDARD PENETRATION TEST (SPT):
- Split spoon sampler $N=(N_2{}^*k_{60})+(N_3{}^*k_{60})$
- Solid cone Š=0,75"N
- "/" - Refusal (>50) (k_{60}=1,087)

FIELD VANE TEST (TYPE): Torvane (pocket in situ); Torvane (laboratory on US); Geonor

DIRECT SHEAR TEST: S Standard; R Reverse; KT Krey - Tiedemann

[illegible]

TRIAXIAL SHEAR TEST: UU Unconsolidated undrained; CU Consolidated undrained; CD Consolidated drained

POCKET PENETROMETER: In-situ; Laboratory

DRY / BULK DENSITY: Bulk density; Dry density; Specific density

COMMENTS:
- sample S-104-21-02-06 at depth 13,50-13,60 m combustible matter content 13,93%, content of organic matter 4,19%,
- sample S-104-21-02-07 at depth 15,50-15,60 m combustible matter content 13,86%, content of organic matter 5,16%,
- sample S-104-21-02-08 at depth 17,60-17,90 m combustible matter content 11,11%, content of organic matter 2,67%,
- sample S-104-21-02-10 at depth 20,40-20,80 m combustible matter content 9,30%, content of organic matter 2,22% and
- sample S-104-21-02-16 at depth 30,70-30,80 m combustible matter content 12,52%, content of organic matter 35,12%.

GEOKON GEOKON - ZAGREB d.d.

REPORT ID: E-104-21-01 | APPENDIX Nº: 2.2 | PAGE NUM.: 2

CLIENT:			
UNIVERSITY OF SPLIT Faculty of Civil Engineering, Architecture and Geodesy Matice hrvatske 15, Split			

FIELD CLASSIFICATION:	Marijana JELIĆ, dipl.ing.geol.
DRILL OPERATOR:	Davor RIBIĆ
DRILLING RIG:	Nordmeyer DSB 1/3,5
HEAD OF INVSTIGATIONS:	prof.dr.sc. Leo Matešić, dipl.ing.građ.

BOREHOLE COORDINATES:
E: 578928,63
N: 4764297,75
GROUND LEVEL (m.a.s.l.): H: 1,26

START DATE: 03.02.2022.
END DATE: 01.03.2022.

PROJECT: Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation
LOCATION: Lower Neretva

Borehole log: B-2 (S-104-21-02)
Scale: 1:100

Soil description

Ground level (m.a.s.l.)	Core barrel diameter (mm)	Symbol	Interval (m)	Soil description
-42.44	131	GC, GP-GC	43,70	
-48.74	131	GC, GP-GC	50,00	Clayey gravel with sand to poorly graded gravel with clay and sand, fine, gray color, rounded, maximum particle size up to 8 cm, in next intervals contains conglomerate fragments up to 8 cm: 43,7-43,9 m, 45,0-45,1 m, 47,9-48,0 m.
-53.14	116	GC/Kon	54,40	Clayey gravel with sand and Conglomerate, yellowish gray color, fine gravel, rounded, maximum particle size up to 8 cm, conglomerate fragments from 5 to 10 cm, clasts of different lithological composition, clast supported, rounded clasts.
-54.44	116	CL	55,70	Lean clay, medium consistency, brown and gray color, contains shell fragments.

Laboratory results

Sample type	Sample ID	From	To	w_L (%)	w_P (%)	I_P (%)	I_c	w_0 (%)	ρ (g/cm³)	$ρ_d$ (g/cm³)	$ρ_s$ (g/cm³)	G (%)	S (%)	M (%)	C (%)	k (cm/s)
PU	34	40.00	40.10									39.20	42.00	8.60	10.20	2.73E-03
PU	35	41.50	41.60									53.60	34.00	6.10	6.30	1.05E-01
PU	22	42.00	42.10									56.00	31.10	6.10	6.80	7.51E-02
PU	36	43.00	43.10									64.90	25.50	4.90	4.70	5.21E-01
PU	23	43.90	44.00									65.50	25.60	4.20	4.70	7.91E-01
PU	37	45.00	45.10									45.00	40.00	7.60	7.40	6.72E-02
PU	24	46.90	47.00									65.70	27.40	3.80	3.10	5.08E-01
PU	38	47.90	48.00									56.90	30.20	6.50	6.40	3.01E-02
PU	39	48.90	49.00									40.40	38.20	8.80	12.60	3.53E-04
PU	25	49.90	50.00									33.00	38.50	11.70	16.80	6.82E-06
PU	40	50.90	50.10									51.50	34.70	6.50	7.30	2.65E-02
PU	42	50.00	53.00													
PU	41	51.90	52.00									50.80	33.10	7.60	8.50	4.89E-02
PU	26	52.90	53.00									52.20	29.80	7.60	10.40	2.41E-02
PU	43	53.90	54.00									62.30	23.40	6.70	7.60	2.97E-02
PU	27	54.70	55.00	39.21	24.28	14.93	0.61	30.04	1.91	1.46	2.67		2.60	68.90	28.50	4.88E-07
PU	44	56.00	56.10									45.80	25.40	11.00	17.80	4.80E-06
PU	28	57.00	57.10									45.10	34.10	9.00	11.80	3.79E-04
PU	45	58.00	58.10									58.00	26.70	6.60	8.70	2.27E-02
PU	46	59.00	59.10									57.30	23.00	7.10	12.60	3.61E-03
PU	29	60.00	60.10									51.30	34.00	5.60	9.10	9.31E-02

PHOTO DOCUMENTATION

SAMPLE DISTRIBUTION:		IN SITU TESTS:	
		STANDARD PENETRATION TEST:	-
DISTURBED SAMPLES	68	POCKET VANE TEST:	-
UNDISTURBED SAMPLES	3	POCKET PENETROMETER:	-
SPT	-	FIELD VANE TEST:	

LEGEND

STANDARD PENETRATION TEST (SPT):
- Split spoon sampler $N=(N_{30}*k_{60})+(N_{45}*k_{60})$
- Solid cone Š=0,75*N

"/" - Refusal (>50) (k_{60}=1,087)

FIELD VANE TEST (TYPE): Torvane (pocket in situ); Torvane (laboratory on US); Geonor

[illegible]

POCKET PENETROMETER: In-situ; Laboratory

DIRECT SHEAR TEST: S Standard; R Reverse; KT Krey - Tiedemann

TRIAXIAL SHEAR TEST: UU Unconsolidated undrained; CU Consolidated undrained; CD Consolidated drained

DRY / BULK DENSITY: Bulk density; Dry density; Specific density

COMMENTS:
- sample S-104-21-02-06 at depth 13,50-13,60 m combustible matter content 13,93%, content of organic matter 4,19%,
- sample S-104-21-02-07 at depth 15,50-15,60 m combustible matter content 13,86%, content of organic matter 5,16%,
- sample S-104-21-02-08 at depth 17,60-17,90 m combustible matter content 11,11%, content of organic matter 2,67%,
- sample S-104-21-02-10 at depth 20,40-20,80 m combustible matter content 9,30%, content of organic matter 2,22% and
- sample S-104-21-02-16 at depth 30,70-30,80 m combustible matter content 12,52%, content of organic matter 35,12%.

GEOKON
GEOKON - ZAGREB d.d.

REPORT ID: E-104-21-01
APPENDIX Nº: 2.2
PAGE NUM.: 3

CLIENT:		BOREHOLE COORDINATES:	START DATE:	PROJECT: Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation
UNIVERSITY OF SPLIT Faculty of Civil Engineering, Architecture and Geodesy Matice hrvatske 15, Split	FIELD CLASSIFICATION: Marijana JELIĆ, dipl.ing.geol. DRILL OPERATOR: Davor RIBIĆ DRILLING RIG: Nordmeyer DSB 1/3,5 HEAD OF INVSTIGATIONS: prof.dr.sc. Leo Matešić, dipl.ing.građ.	E: 578928,63 N: 4764297,75 GROUND LEVEL (m.a.s.l.): H: 1,26	03.02.2022. END DATE: 01.03.2022.	LOCATION: Lower Neretva **Borehole log: B-2 (S-104-21-02)** **Scale: 1:100**

Column headings: DEPTH (m) | GROUND LEVEL (m.a.s.l.) | CORE BARREL DIAMETER (mm) | PROTECTIVE CASING DIAMETER (mm) | GWO (m) | GWL (m) | SYMBOL | INTERVAL (m) | GROUP OF MATERIALS | SOIL DESCRIPTION | STANDARD PENETRATION TEST (Blow count): N_0, N_1, N_2, N, N_{60} | POCKET PENETROMETER q_u (kPa) | FIELD VANE TEST c_u (kPa), c_r (kPa) | SAMPLE TYPE | SAMPLE ID | INTERVAL (m) FROM, TO | PLASTICITY LIMITS w_L (%), w_P (%) | PLASTICITY INDEX I_P (%) | CONSISTENCY INDEX I_c | WATER CONTENT w_0 (%) | DRY / BULK DENSITY (g/cm³) | PARTICLE SIZE ANALYSIS G (%), S (%), M (%), C (%) | Permeability (accord. to USBR) k (cm/s) | SHEAR TESTS c/C_u (kPa) | UNCONFINED COMPRESSION STRENGHT q_u (kPa) | OEDOMETER TEST (MPa) | PERMEABILITY OEDOMETER / TRIAXIAL CELL k (cm/s) | PHOTO DOCUMENTATION

Core barrel diameter: 101 mm; Protective casing diameter: 116 mm; Symbol: GC

SOIL DESCRIPTION: Clayey gravel with sand, fine, light brown to gray color, rounded, maximum particle size up to 8 cm, in next intervals contains conglomerate fragments up to 5 cm: 59,6-59,7 m, 60,8-60,9 m, 65,9-66,0 m, 66,8-66,9 m, 67,0-67,1 m, 70,9-71,0 m, 75,5-75,6 m, 76,9-77,0 m i 82,5-82,6 m.

SAMPLE TYPE	SAMPLE ID	FROM	TO	G (%)	S (%)	M (%)	C (%)	k (cm/s)
PU	47	61.00	61.10	31.90	39.70	12.30	16.10	6.54E-06
PU	48	62.00	62.10	52.80	30.40	6.90	9.90	4.19E-02
PU	30	63.00	63.10	40.50	34.10	9.70	15.70	2.29E-05
PU	49	63.90	64.00	72.50	25.10	1.50	0.90	9.48E-01
PU	50	64.50	64.60	60.10	26.50	5.80	7.60	1.01E-01
PU	51	65.50	65.60	51.20	25.60	8.60	14.60	1.21E-04
PU	31	66.00	66.10	66.10	23.50	4.50	5.90	1.90E-01
PU	52	67.50	67.60	61.90	26.20	6.00	5.90	4.99E-02
PU	53	68.50	68.60	47.30	32.20	7.80	12.70	6.13E-04
PU	54	69.50	69.60	66.70	21.70	6.20	5.40	1.00E-01
PU	55	70.50	70.60	67.40	23.00	4.50	5.10	3.50E-01
PU	56	71.50	71.60	56.30	29.90	5.10	8.70	3.77E-02
PU	57	72.50	72.60	54.40	29.80	6.00	9.80	3.60E-02
PU	58	73.50	73.60	52.80	29.60	8.10	9.50	6.74E-03
PU	59	74.90	75.00	61.70	27.70	4.90	5.70	1.60E-01
PU	60	75.90	76.00	46.50	34.60	7.20	11.70	2.60E-03
PU	61	76.90	77.00	58.40	28.40	6.00	7.20	1.26E-01
PU	62	77.90	78.00	48.10	31.50	6.80	13.60	3.69E-04
PU	63	78.90	79.00	47.40	30.40	7.80	14.40	2.35E-04
PU	64	79.90	80.00	41.00	32.80	8.70	17.50	9.07E-06

SAMPLE DISTRIBUTION:		IN SITU TESTS:	
		STANDARD PENETRATION TEST:	-
DISTURBED SAMPLES	68	POCKET VANE TEST:	-
UNDISTURBED SAMPLES	3	POCKET PENETROMETER:	-
SPT	-	FIELD VANE TEST:	

LEGEND

STANDARD PENETRATION TEST (SPT):
- Split spoon sampler $N=(N_1{}^*k_{60})+(N_2{}^*k_{60})$
- Solid cone Š=0,75*N
- "/" - Refusal (>50) (k_{60}=1,087)

FIELD VANE TEST (TYPE):
- Torvane (pocket in situ)
- Torvane (laboratory on US)
- Geonor

[illegible]
- [illegible]
- [illegible]

DIRECT SHEAR TEST:
- S Standard
- R Reverse
- KT Krey - Tiedemann

TRIAXIAL SHEAR TEST:
- UU Unconsolidated undrained
- CU Consolidated undrained
- CD Consolidated drained

POCKET PENETROMETER:
- In-situ
- Laboratory

DRY / BULK DENSITY:
- Bulk density
- Dry density
- Specific density

COMMENTS:
- sample S-104-21-02-06 at depth 13,50-13,60 m combustible matter content 13,93%, content of organic matter 4,19%,
- sample S-104-21-02-07 at depth 15,50-15,60 m combustible matter content 13,86%, content of organic matter 5,16%,
- sample S-104-21-02-08 at depth 17,60-17,90 m combustible matter content 11,11%, content of organic matter 2,67%,
- sample S-104-21-02-10 at depth 20,40-20,80 m combustible matter content 9,30%, content of organic matter 2,22% and
- sample S-104-21-02-16 at depth 30,70-30,80 m combustible matter content 12,52%, content of organic matter 35,12%.

GEOKON
GEOKON - ZAGREB d.d.

REPORT ID: E-104-21-01
APPENDIX Nº: 2.2
PAGE NUM.: 4

CLIENT:				
UNIVERSITY OF SPLIT Faculty of Civil Engineering, Architecture and Geodesy Matice hrvatske 15, Split	FIELD CLASSIFICATION: Marijana JELIĆ, dipl.ing.geol. DRILL OPERATOR: Davor RIBIĆ DRILLING RIG: Nordmeyer DSB 1/3,5 HEAD OF INVSTIGATIONS: prof.dr.sc. Leo Matešić, dipl.ing.građ.	BOREHOLE COORDINATES: E: 578928,63 N: 4764297,75 GROUND LEVEL (m.a.s.l.): H: 1,26	START DATE: 03.02.2022. END DATE: 01.03.2022.	PROJECT: Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation LOCATION: Lower Neretva Borehole log: B-2 (S-104-21-02) Scale: 1:100

SAMPLE TYPE	SAMPLE ID	FROM	TO	G (%)	S (%)	M (%)	C (%)	k (cm/s)
PU	65	81.00	81.10	65.30	19.20	6.70	8.80	3.84E-02
PU	66	82.00	82.10	54.10	29.80	7.50	8.60	1.19E-02
PU	67	83.00	83.10	56.20	30.10	4.70	9.00	7.84E-02
PU	68	84.00	84.10	63.50	26.90	4.50	5.10	3.90E-01
PU	69	85.00	85.10	85.30	10.60	2.90	1.20	1.91E+01
PU	70	86.50	86.60	78.80	16.20	3.10	1.90	9.65E+00
PU	71	88.00	88.10	75.30	21.40	1.80	1.50	5.45E+00
PU	72	89.90	90.00	55.40	31.70	6.50	6.40	9.20E-02

Ground level at base: -88.74; Interval: 90,00

Column headers: DEPTH (m); GROUND LEVEL (m.a.s.l.); CORE BARREL DIAMETER (mm); PROTECTIVE CASING DIAMETER (mm); GWO (m); GWL (m); SYMBOL; INTERVAL (m); GROUP OF MATERIALS; SOIL DESCRIPTION; STANDARD PENETRATION TEST (Blow count) N_0, N_1, N_2, N, N_{60}; POCKET PENETROMETER q_u (kPa); FIELD VANE TEST c_u (kPa), c_r (kPa); SAMPLE TYPE; SAMPLE ID; INTERVAL (m) FROM, TO; PLASTICITY LIMITS w_L (%), w_P (%); PLASTICITY INDEX I_P (%); CONSISTENCY INDEX I_c; WATER CONTENT w_0 (%); DRY / BULK DENSITY (g/cm³); PARTICLE SIZE ANALYSIS G (%), S (%), M (%), C (%); Permeability (accord. to USBR) k (cm/s); SHEAR TESTS c/C_u (kPa), TIP; UNCONFINED COMPRESSION STRENGHT q_u (kPa); OEDOMETER TEST (MPa); PERMEABILITY OEDOMETER / TRIAXIAL CELL k (cm/s); PHOTO DOCUMENTATION

SAMPLE DISTRIBUTION:		IN SITU TESTS:	
		STANDARD PENETRATION TEST:	-
DISTURBED SAMPLES	68	POCKET VANE TEST:	-
UNDISTURBED SAMPLES	3	POCKET PENETROMETER:	-
SPT	-	FIELD VANE TEST:	

LEGEND

STANDARD PENETRATION TEST (SPT):
- Split spoon sampler $N=(N_{15}*k_{60})+(N_{30}*k_{60})$
- Solid cone Š=0,75*N
- "/" - Refusal (>50) (k_{60}=1,087)

FIELD VANE TEST (TYPE): Torvane (pocket in situ); Torvane (laboratory on US); Geonor

DIRECT SHEAR TEST: S Standard; R Reverse; KT Krey - Tiedemann

TRIAXIAL SHEAR TEST: UU Unconsolidated undrained; CU Consolidated undrained; CD Consolidated drained

POCKET PENETROMETER: In-situ; Laboratory

DRY / BULK DENSITY: Bulk density; Dry density; Specific density

COMMENTS:
- sample S-104-21-02-06 at depth 13,50-13,60 m combustible matter content 13,93%, content of organic matter 4,19%,
- sample S-104-21-02-07 at depth 15,50-15,60 m combustible matter content 13,86%, content of organic matter 5,16%,
- sample S-104-21-02-08 at depth 17,60-17,90 m combustible matter content 11,11%, content of organic matter 2,67%,
- sample S-104-21-02-10 at depth 20,40-20,80 m combustible matter content 9,30%, content of organic matter 2,22% and
- sample S-104-21-02-16 at depth 30,70-30,80 m combustible matter content 12,52%, content of organic matter 35,12%.

GEOKON - ZAGREB d.d.

REPORT ID: E-104-21-01

APPENDIX N°: 2.2

CLIENT:	FIELD CLASSIFICATION:	Marijana JELIĆ, dipl.ing.geol.	BOREHOLE COORDINATES:	START DATE:	PROJECT: Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation
UNIVERSITY OF SPLIT	DRILL OPERATOR:	Davor RIBIĆ	E: 578606,07	08.03.2022.	LOCATION: Lower Neretva
Faculty of Civil Engineering, Architecture and Geodesy	DRILLING RIG:	Nordmeyer DSB 1/3,5	N: 4764959,54	END DATE:	**Borehole log: B-3 (S-104-21-03)**
Matice hrvatske 15, Split	HEAD OF INVSTIGATIONS:	prof.dr.sc. Leo Matešić, dipl.ing.građ.	GROUND LEVEL (m.a.s.l.): H: -0,81	09.03.2022.	**Scale: 1:100**

SOIL DESCRIPTION

DEPTH (m)	GROUND LEVEL (m.a.s.l.)	CORE BARREL DIAMETER (mm)	PROTECTIVE CASING DIAMETER (mm)	GWO (m)	GWL (m)	SYMBOL	INTERVAL (m)	GROUP OF MATERIALS	SOIL DESCRIPTION
0,0 – 0,80	-1.61	146	178		0.8	SC	0,80		Clayey sand, medium size, brown color.
0,80 – 10,00	-10.81					SP	10,00		Poorly graded sand, medium size, gray color, at the beginning of the interval with gravel.
10,00 – 13,00	-13.81					SC	13,00		Clayey sand, fine, gray color.
13,00 – 14,50	-15.31					SC/CL	14,50		Clayey sand to sandy lean clay, fine sand, gray color, organic smell.
14,50 – 20,00	-20.81					CL	20,00		Lean clay, soft to medium consistency, gray color, at the end of the interval sandy, contains manganes concretions and shell fragments.

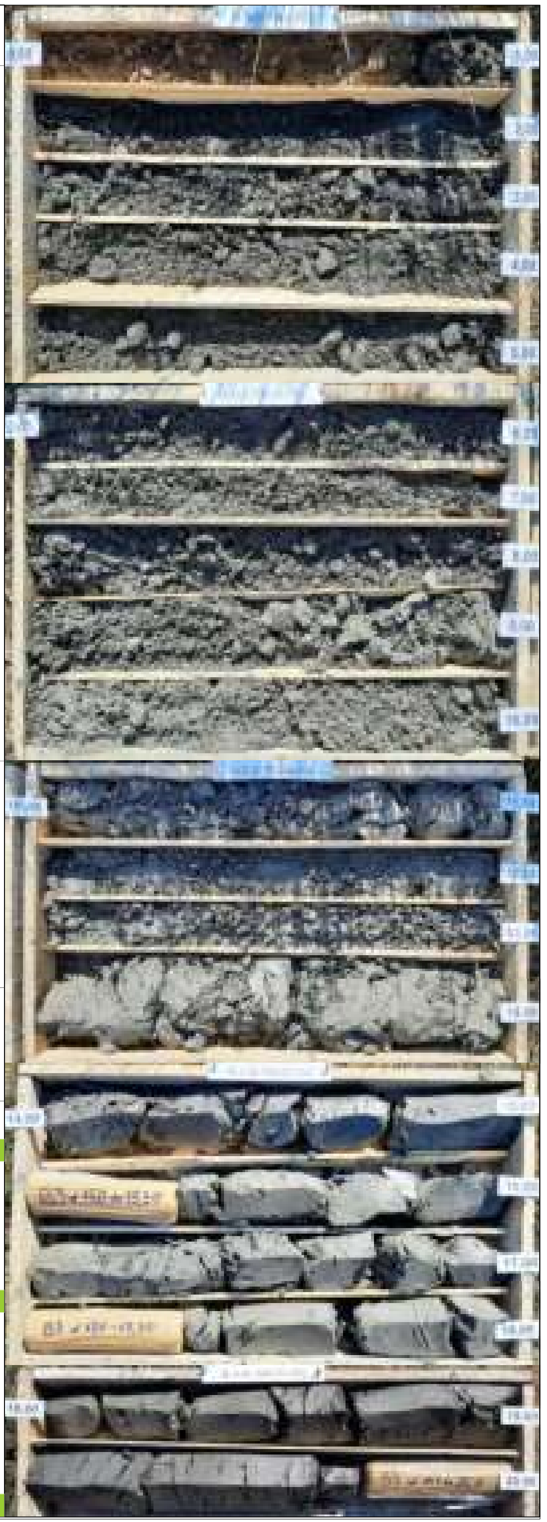
Depth scale: 0,0; 1,0; 2,0; 3,0; 4,0; 5,0; 6,0; 7,0; 8,0; 9,0; 10,0; 11,0; 12,0; 13,0; 14,0; 15,0; 16,0; 17,0; 18,0; 19,0; 20,0

Standard penetration test (Blow count): N_0, N_1, N_2, N, N_{60} – no data. Pocket penetrometer q_u (kPa) – no data. Field vane test c_u (kPa), c_r (kPa) – no data.

SAMPLE TYPE	SAMPLE ID	INTERVAL FROM (m)	INTERVAL TO (m)	w_L (%)	w_P (%)	I_P (%)	I_c	w_0 (%)	ρ (g/cm³)	$ρ_d$ (g/cm³)	$ρ_s$ (g/cm³)	G (%)	S (%)	M (%)	C (%)	k (cm/s)	Permeability oedometer/triaxial cell k (cm/s) 100/300	200/400	400/500
PU	1	0.50	0.60								2.75	0.90	71.60	10.30	17.20	9.32E-06			
PU	2	1.50	1.60								2.78	15.20	84.60	0.20		3.36E-02			
PU	3	4.50	4.60								2.78	10.40	89.00	0.60		2.57E-02			
PU	4	7.50	7.60								2.78	9.90	89.90	0.20		5.61E-02			
PU	5	10.00	10.10								2.78		74.90	17.50	7.60	3.42E-04			
PU	6	12.50	12.60								2.78		75.40	17.00	7.60	3.42E-04			
PU	7	13.50	13.60	32.23	22.41	9.82		34.33			2.78		56.50	26.60	16.90	3.33E-06			
NU	8	15.00	15.30	44.84	21.48	23.37	0.28	38.36	1.88	1.41	2.69		4.80	58.40	36.80	2.59E-07	4.10E-08	2.10E-08	1.30E-08
NU	9	17.00	17.30	46.75	22.70	24.05	0.35	38.43	1.85	1.36	2.69		3.10	53.70	43.20		3.70E-08	2.60E-08	2.20E-08
NU	10	19.70	20.00	49.79	23.13	26.66	0.44	38.09	1.83	1.34	2.69		33.20	34.20	32.60		2.60E-08	2.20E-08	2.10E-08

Shear tests (c/C_u (kPa),), TIP), unconfined compression strength (q_u (kPa)), oedometer test (MPa) (400, 800, 1600, 3200) – no data.

PHOTO DOCUMENTATION



SAMPLE DISTRIBUTION:		IN SITU TESTS:	
		STANDARD PENETRATION TEST:	-
DISTURBED SAMPLES	7	POCKET VANE TEST:	-
UNDISTURBED SAMPLES	3	POCKET PENETROMETER:	-
SPT	-	FIELD VANE TEST:	

LEGEND

FIELD VANE TEST (TYPE): Torvane (pocket in situ); Torvane (laboratory on US); Geonor

PERMEABILITY: [illegible]

POCKET PENETROMETER: In-situ; Laboratory

STANDARD PENETRATION TEST (SPT):
- Split spoon sampler $N=(N_{30}*k_{60})+(N_{45}*k_{60})$
- Solid cone Š=0,75*N

"/" - Refusal (>50) (k_{60}=1,087)

DIRECT SHEAR TEST: S – Standard; R – Reverse; KT – Krey - Tiedemann

TRIAXIAL SHEAR TEST: UU – Unconsolidated undrained; CU – Consolidated undrained; CD – Consolidated drained

DRY / BULK DENSITY: Bulk density; Dry density; Specific density

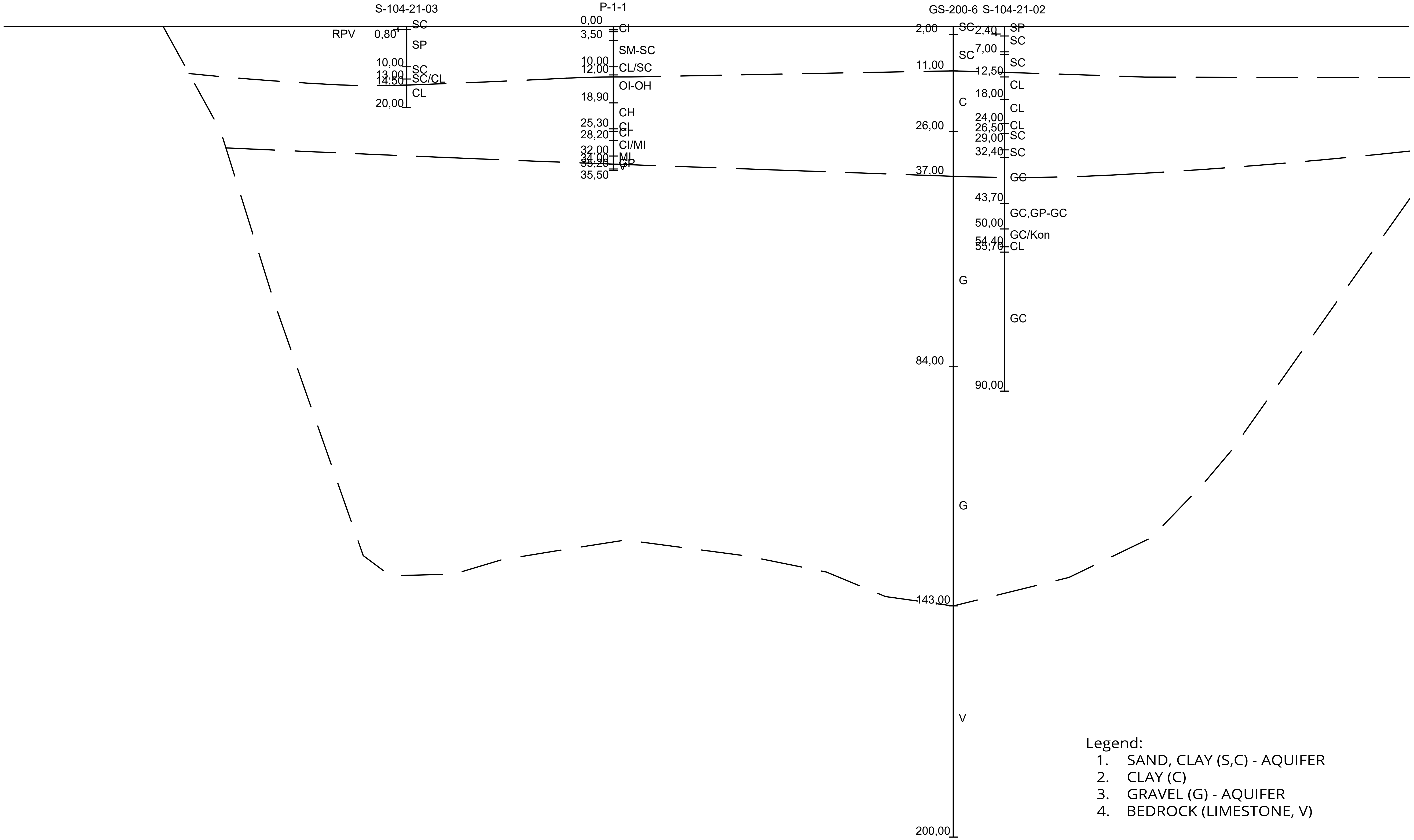
COMMENTS:
- sample S-104-21-03-07 at depth 13,50-13,60 m combustible matter content 9,12%, content of organic matter 1,76%.

GEOKON
GEOKON - ZAGREB d.d.

REPORT ID:	APPENDIX Nº: 2.3
E-104-21-01	PAGE NUM.: 1

GEOKON

GEOKON - ZAGREB d.d.



Legend:

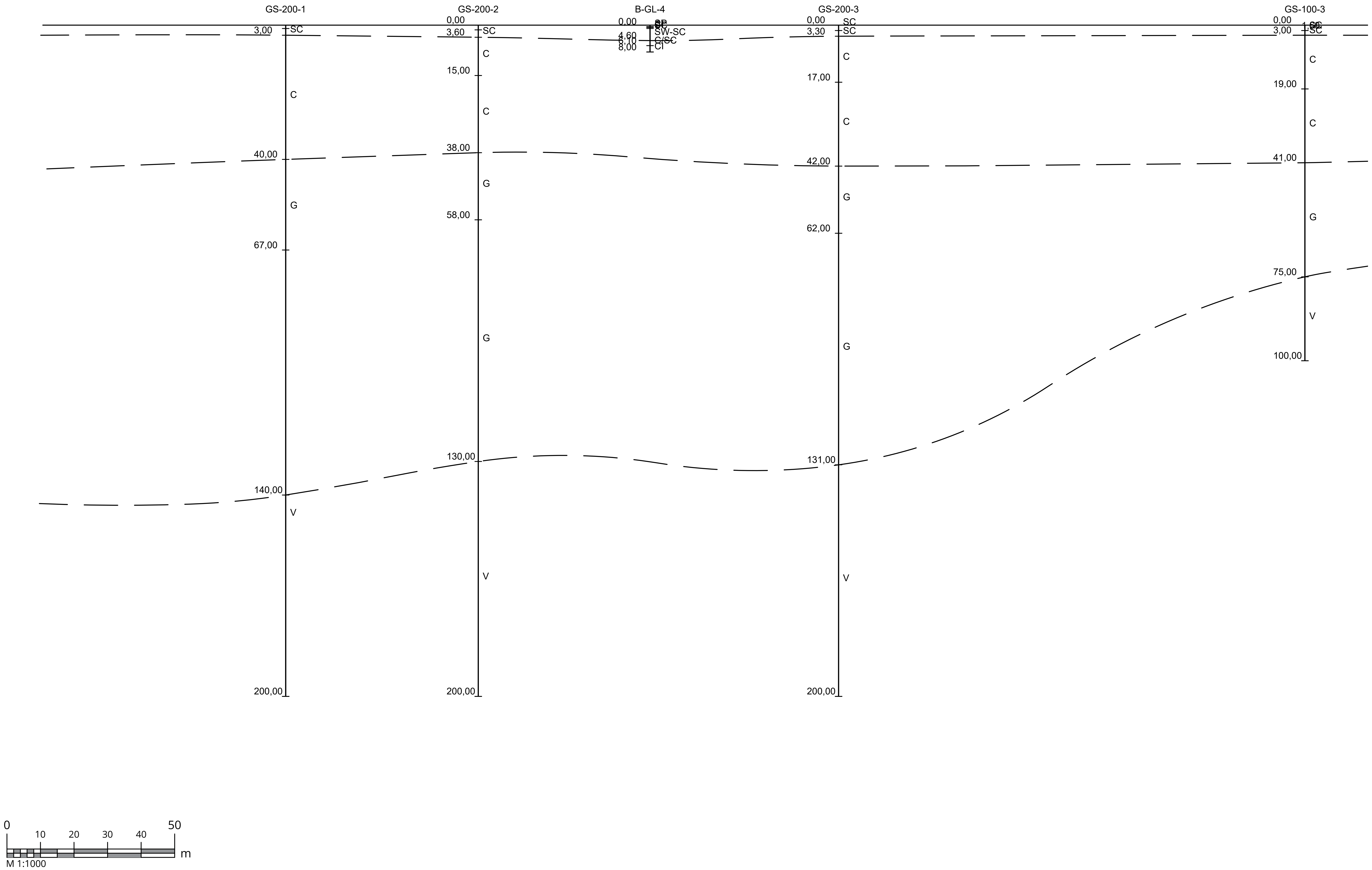
1. SAND, CLAY (S,C) - AQUIFER
2. CLAY (C)
3. GRAVEL (G) - AQUIFER
4. BEDROCK (LIMESTONE, V)

Hydrogeological profile P-1 Diga

M 1:5000/1000

E-104-21-01

prilog br.:3.1



GEOKON

GEOKON - ZAGREB d.d.

Legend:

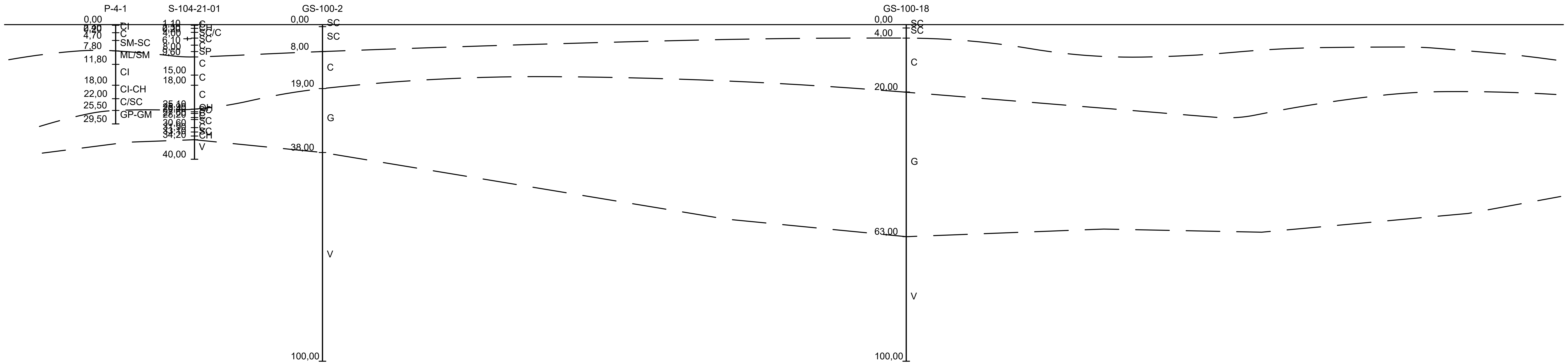
1. SAND, CLAY (S,C) - AQUIFER
2. CLAY (C)
3. GRAVEL (G) - AQUIFER
4. BEDROCK (LIMESTONE, V)

Hydrogeological profile P-2 Crepina
M 1:5000/1000

E-104-21-01
prilog br.:3.2

GEOKON

GEOKON - ZAGREB d.d.

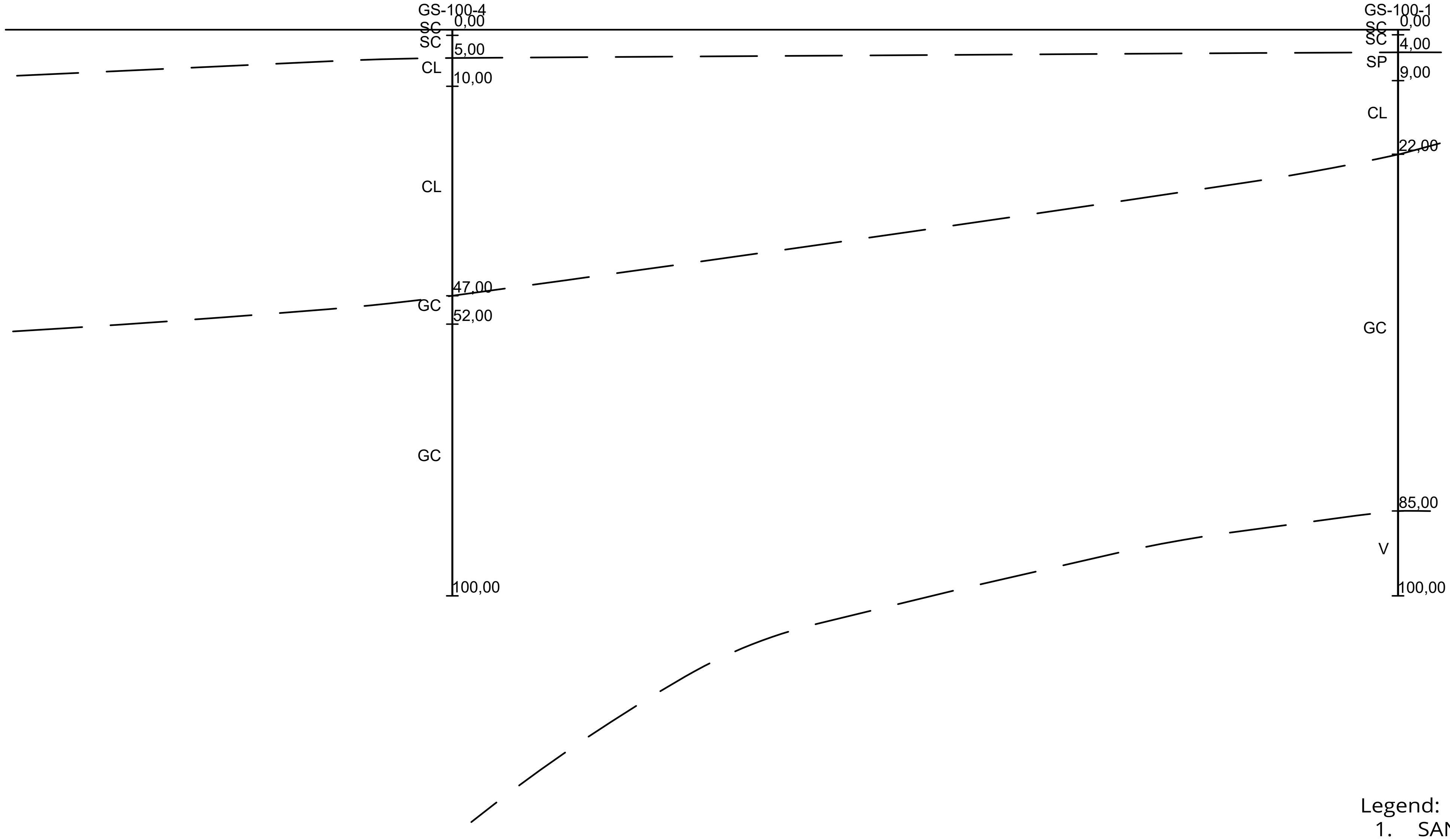


Legend:
1. SAND, CLAY (S,C) - AQUIFER
2. CLAY (C)
3. GRAVEL (G) - AQUIFER
4. BEDROCK (LIMESTONE, V)

Hydrogeological profile P-3 Vidrice
M 1:5000/1000

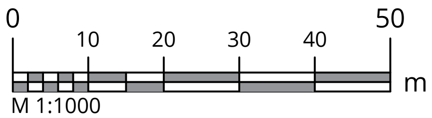
0 10 20 30 40 50 m
M 1:1000

E-104-21-01
prilog br.:3.3



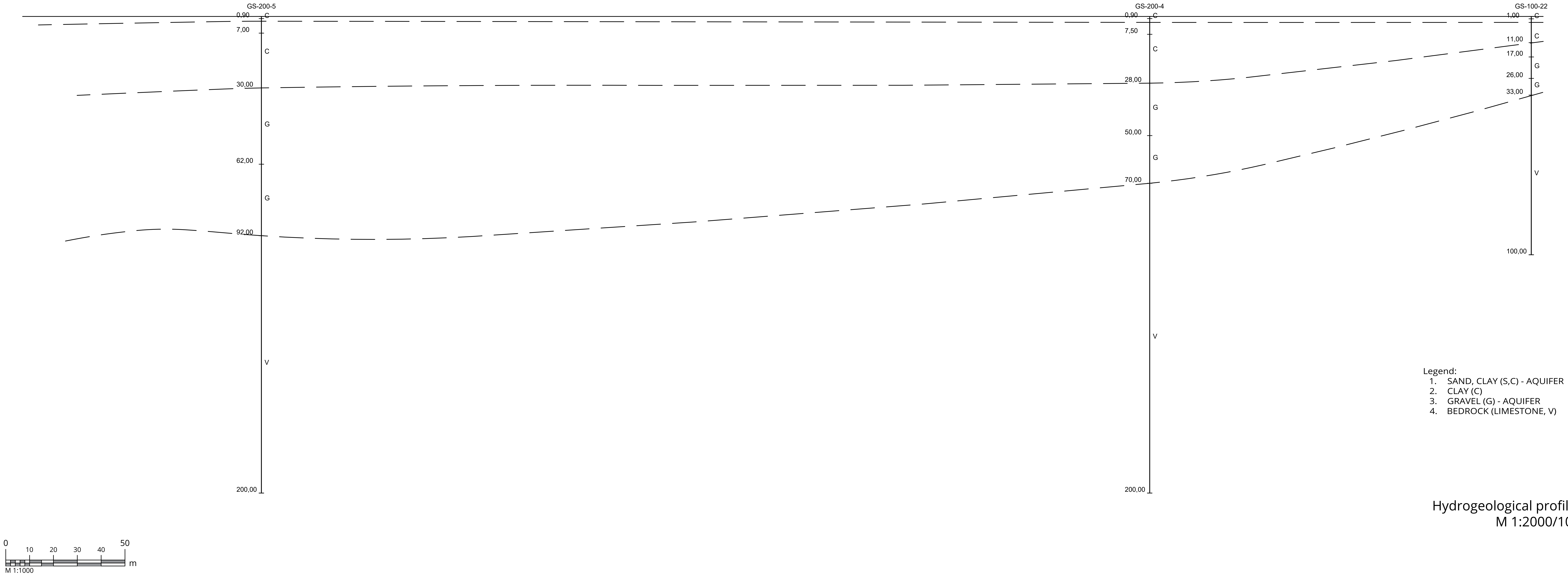
Legend:
1. SAND, CLAY (S,C) - AQUIFER
2. CLAY (C)
3. GRAVEL (G) - AQUIFER
4. BEDROCK (LIMESTONE, V)

Hydrogeological profile P-4 Opuzen - magistrala
M 1:2500/1000



E-104-21-01
prilog br.:3.4

GEOKON
GEOKON - ZAGREB d.d.

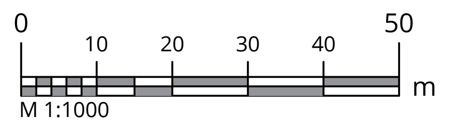


Legend:
1. SAND, CLAY (S,C) - AQUIFER
2. CLAY (C)
3. GRAVEL (G) - AQUIFER
4. BEDROCK (LIMESTONE, V)

Hydrogeological profile P-5 Opuzen
M 1:2000/1000

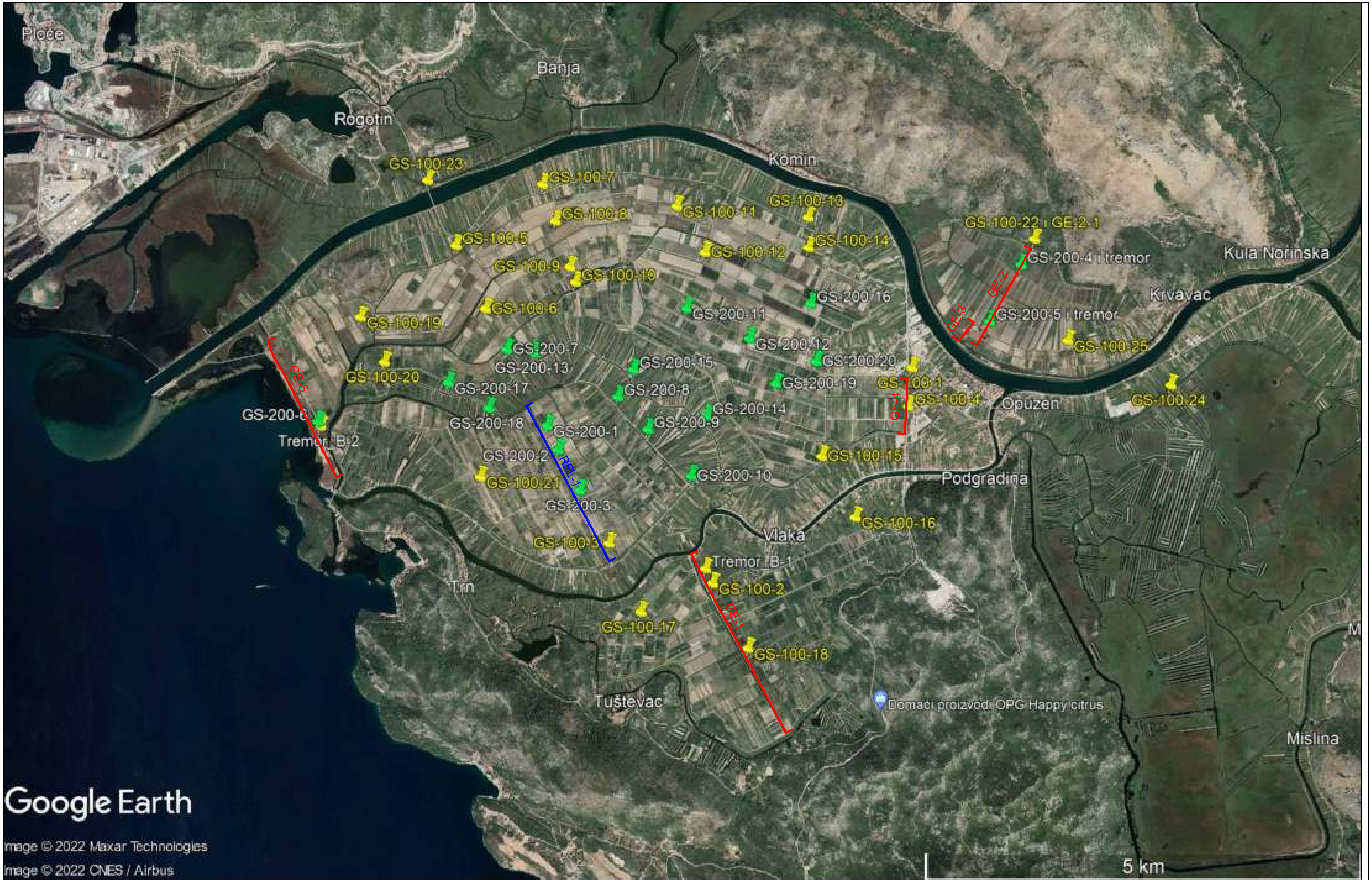
E-104-21-01
prilog br.:3.5

Legend:
1. SAND, CLAY (S,C) - AQUIFER
2. CLAY (C)
3. GRAVEL (G) - AQUIFER
4. BEDROCK (LIMESTONE, V)



Hydrogeological profile P-6 Diga-Opuzen
M 1:10000/1000

E-104-21-01
prilog br.:3.6



Legend:

RFL-1	Seismic reflection
GE-1	Geoelectric tomography
	Geoelectrical sounding AB/2=600m
	Geoelectrical sounding AB/2=200m

LOCATION: Neretva Valley	TERRA COMPACTA	Terra Compacta d.o.o. Psunjska 3, Zagreb
CONTENT: Locations of geophysical measurements	CONTRACTING AUTHORITY: Faculty of civil Engineering, Architecture and Geodesy of the university of Split	M 1:40000
		APPENDIX: 1

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: SHALLOW SEISMIC REFLECTION

TERRA COMPACTA

INTERPRETED SEISMIC PROFILE RFL-1 (CREPINE)

COARSE GRAVEL, POORLY BONDED CONGLOMERATE LAYER ?

SMALL GRAIN GRAVEL TO SAND LAYER ?

BEDROCK ?

GS- POSITION OF GEOELECTRICAL SOUNDING

FAULT

SCALE: 1:2500/2500

Processing and interpretation: mr.sc. Božo Padovan, dipl.ing.fiz.

Appendix: 2.1

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL TOMOGRAPHY

ELECTRODE SPACING: 10 m
NUMBER OF ACTIVE ELECTRODES: 64

INTERPRETED GEOELECTRICAL PROFILE GE-1 (VIDRICE)

SCALE: 1:2000/1000

1	<1 ohm m	CLAY, SATURATED WITH SALT WATER
2	1 - 10 ohm m	CLAY SANDY, SATURATED WITH SALT WATER
3	> 10 ohm m	WHEATERED AND FRACTURED LIMESTONE, SATURATED WITH SALT WATER, BEDROCK
4	>10 ohm m	SAND, CLAYEY (DRY ZONE NEAR SURFACE)

RESISTIVITY (ohm m): 0.3, 0.7, 1.7, 4, 10, 20, 45, 110

ELECTRODE POSITION

GS- POSITION OF GEOELECTRICAL SOUNDING

B-1 BOREHOLE POSITION

Processing and interpretation: mr.sc. Božo Padovan, dipl.ing.fiz.

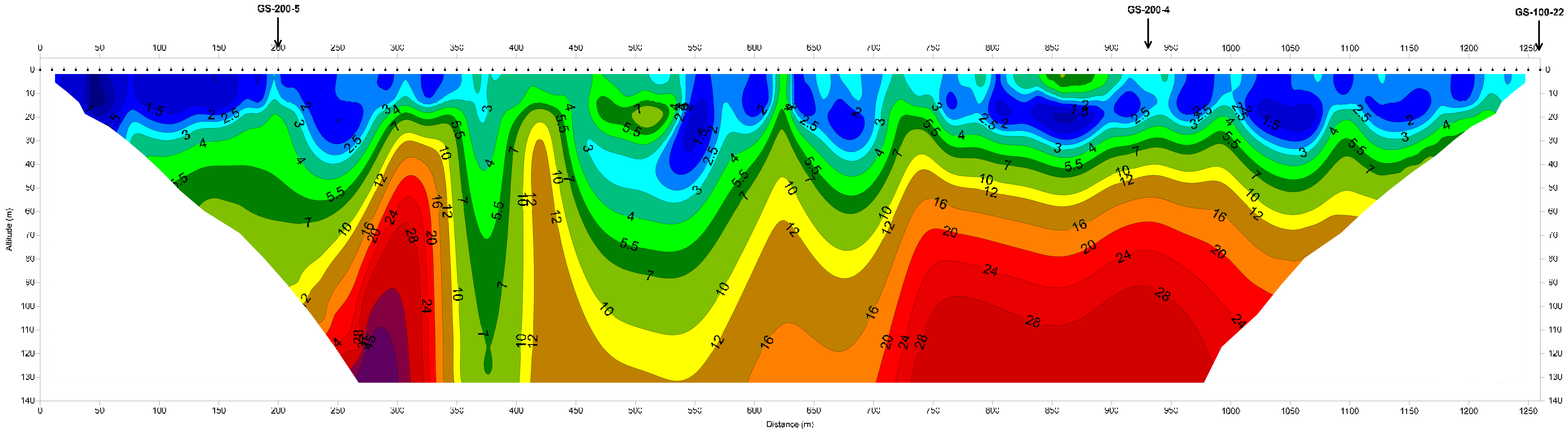
Appendix: 3.1

Location: Neretva Valley

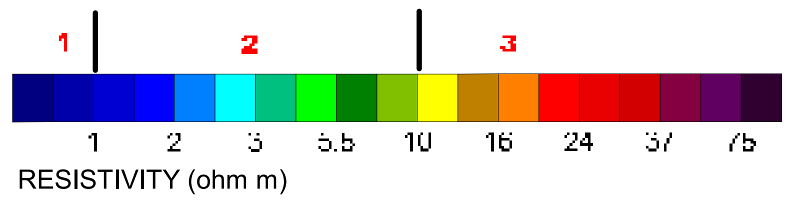
GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL TOMOGRAPHY

ELECTRODE SPACING: 10 m
NUMBER OF ACTIVE ELECTRODES: 64

INTERPRETED GEOELECTRICAL PROFILE GE-2 (OPUZEN)



SCALE: 1:2000/1000



1	<1 ohm m	CLAY, SATURATED WITH SALT WATER
2	1 - 10 ohm m	CLAY SANDY, SATURATED WITH SALT WATER
3	10 - 90 ohm m	GRAVEL CLAYEY, WHEATERED AND FRACTURED LIMESTONE, SATURATED WITH SALT WATER
4	>90 ohm m	BEDROCK - LIMESTONE

ELECTRODE POSITION

GS- POSITION OF GEOELECTRICAL SOUNDING

Processing and interpretation: mr.sc. Božo Padovan, dipl.ing.fiz.

Appendix: 3.2

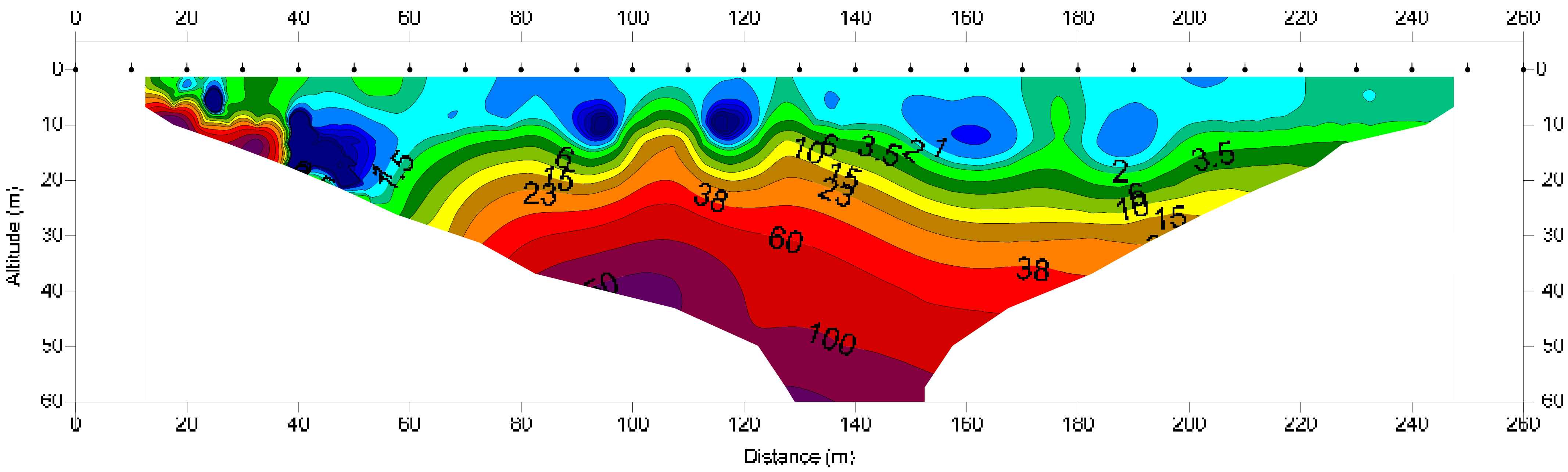
Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL TOMOGRAPHY

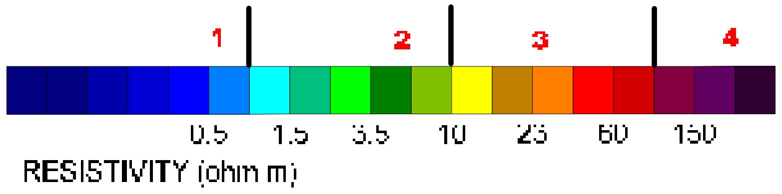
ELECTRODE SPACING: 10 m
NUMBER OF ACTIVE ELECTRODES: 27

TERRA COMPACTA

INTERPRETED GEOELECTRICAL PROFILE GE-3 (OPUZEN)



SCALE: 1:1000/1000



1	<1 ohm m	CLAY, SATURATED WITH SALT WATER
2	1 - 10 ohm m	CLAY SANDY, SATURATED WITH SALT WATER
3	10 - 90 ohm m	GRAVEL CLAYEY, WHEATERED AND FRACTURED LIMESTONE, SATURATED WITH SALT WATER
4	>90 ohm m	BEDROCK - LIMESTONE

ELECTRODE POSITION

GS-

POSITION OF GEOELECTRICAL SOUNDING

Processing and interpretation: mr.sc. Božo Padovan, dipl.ing.fiz.

Appendix: 3.3

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL TOMOGRAPHY

ELECTRODE SPACING: 10 m
NUMBER OF ACTIVE ELECTRODES: 64

TERRA COMPACTA

INTERPRETED GEOELECTRICAL PROFILE GE-4 (OPUZEN - MAGISTRALA)

1	<1 ohm m	CLAY, SATURATED WITH SALT WATER
2	1 - 10 ohm m	CLAY SANDY, SATURATED WITH SALT WATER
3	10 - 90 ohm m	GRAVEL CLAYEY, WHEATERED AND FRACTURED LIMESTONE, SATURATED WITH SALT WATER
4	>90 ohm m	BEDROCK - LIMESTONE)
5	>10 ohm m	SAND, GRAVEL (DRY ZONE NEAR SURFACE)

RESISTIVITY (ohm m): 1, 0.7, 2.5, 10, 25, 90, 300, 1850

ELECTRODE POSITION

GS- POSITION OF GEOELECTRICAL SOUNDING

SCALE: 1:1000/1000

Processing and interpretation: mr.sc. Božo Padovan, dipl.ing fiz

Appendix: 3.4

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOLECTRICAL TOMOGRAPHY

ELECTRODE SPACING: 10 m
NUMBER OF ACTIVE ELECTRODES: 64

TERRA COMPACTA

INTERPRETED GEOELECTRICAL PROFILE GE-5 (DIGA)

1 2 3 4

1 3 10 25 50 80 130 280 750 1750

RESISTIVITY (ohm m)

1	<1 ohm m	CLAY, SATURATED WITH SALT WATER
2	1 - 10 ohm m	CLAY SANDY, SATURATED WITH SALT WATER
3	10 - 130 ohm m	GRAVEL CLAYEY, CONGLOMERATE, WHEATERED AND FRACTURED LIMESTONE, SATURATED WITH SALT WATER
4	>130 ohm m	BEDROCK - LIMESTONE
5	>10 ohm m	SAND CLAYEY,SILTY (DRY ZONE NEAR SURFACE)

ELECTRODE POSITION

GS- POSITION OF GEOELECTRICAL SOUNDING

FAULT

B-2 BOREHOLE POSITION

SCALE: 1:2000/1000

Processing and interpretation: mr.sc. Božo Padovan, dipl.ing.fiz.

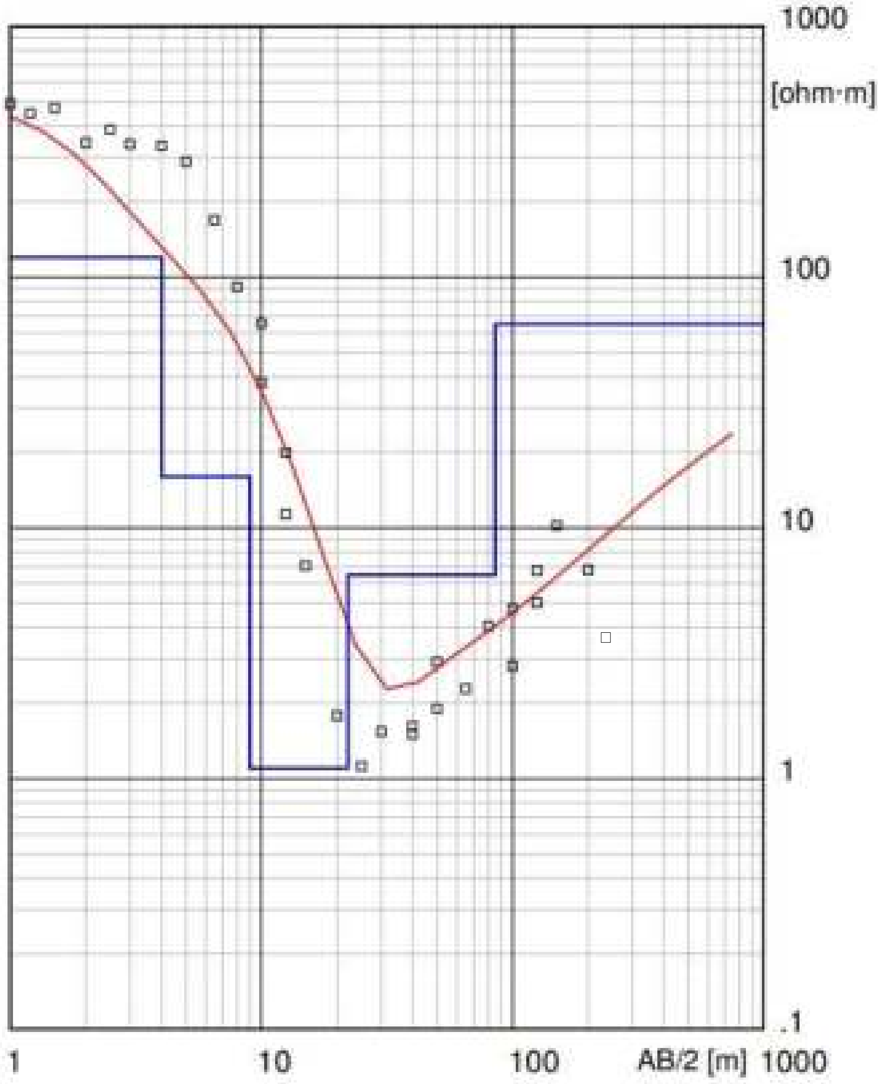
Appendix: 3.5

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-1



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	500	0.9	0.9
2	120	3.1	4
3	16	5	9
4	1.1	13	22
5	6.5	63	85
6	65	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1, 2	SAND, CLAY (DRY ZONE)
3	SANDY CLAY, SATURATED WITH SALT WATER
4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

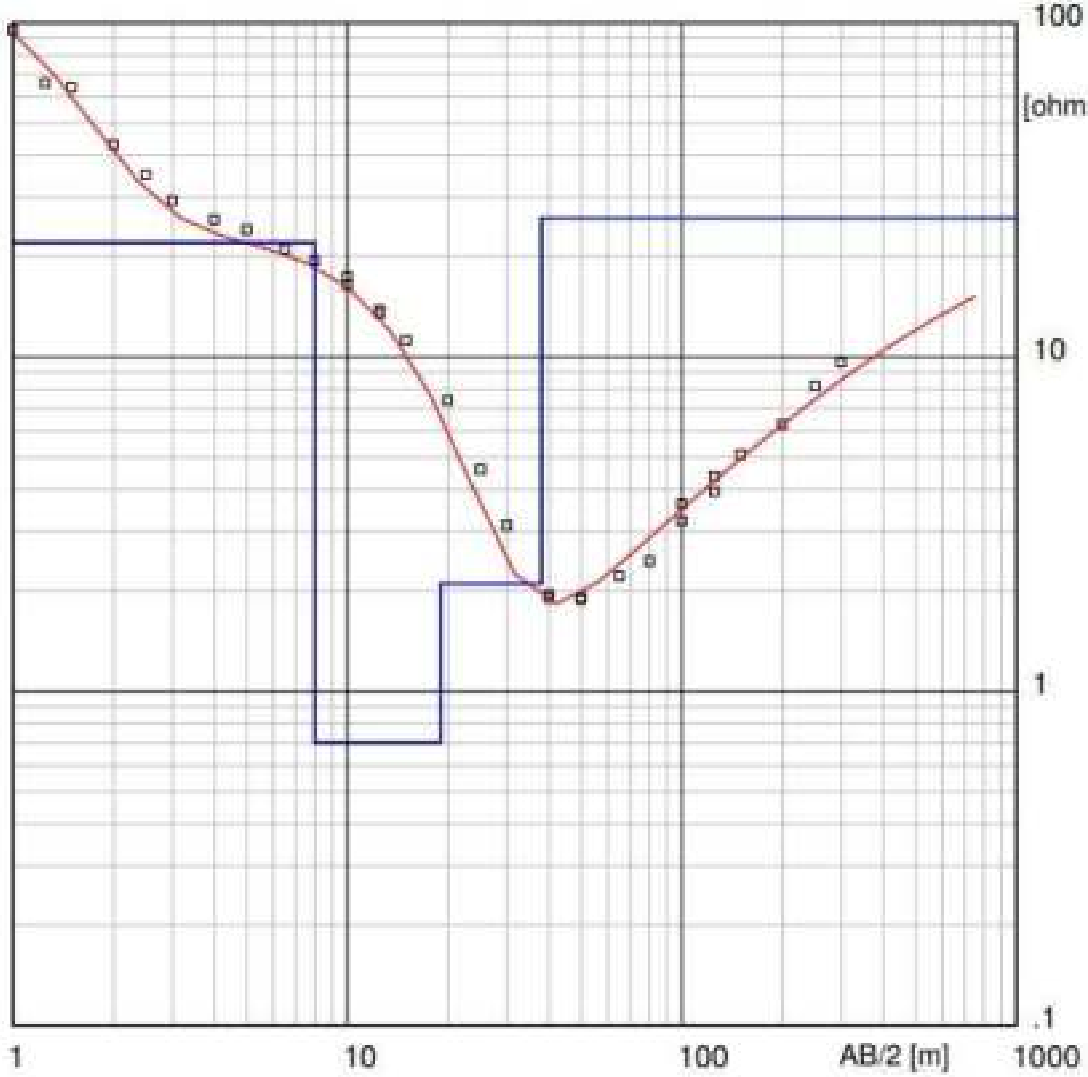
Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-2



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	140	0.6	0.6
2	22	7.4	8
3	0.7	11	19
4	2.1	19	38
5	26	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

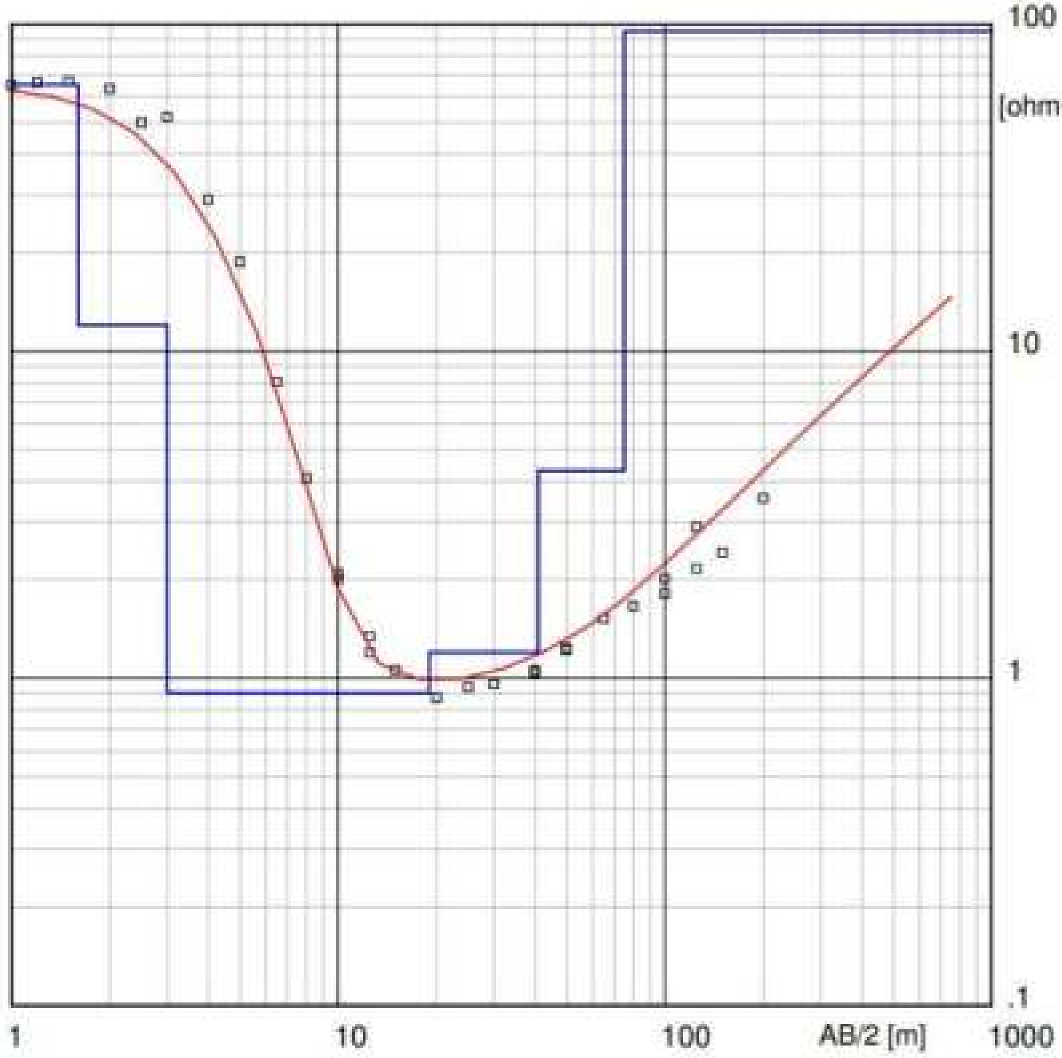
Appendix. 4.2

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-3



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	65	1.6	1.6
2	12	1.4	3
3	0.9	16	19
4	1.2	22	41
5	4.3	34	75
6	95	–	–

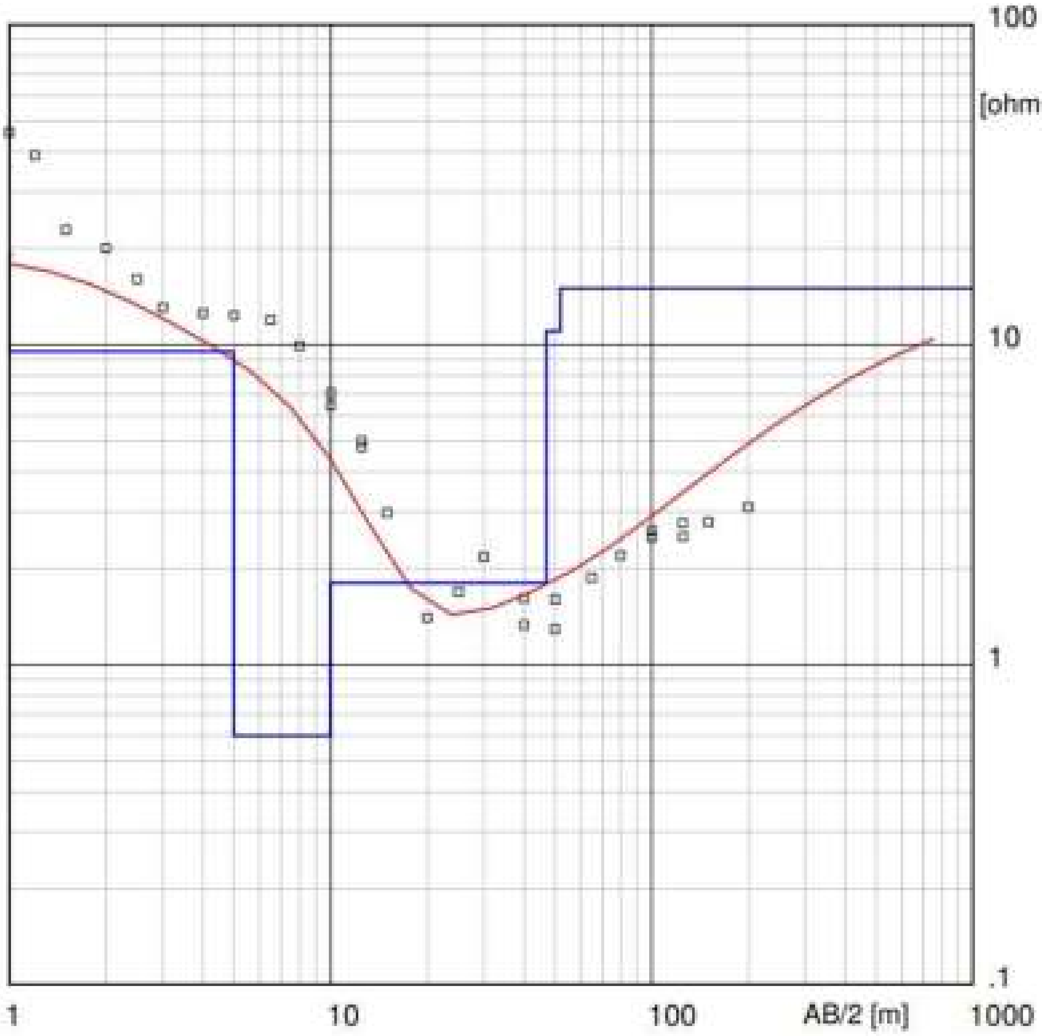
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-4



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	19	1	1
2	9.5	4	5
3	0.6	5	10
4	1.8	37	47
5	11	5	52
6	15	–	–

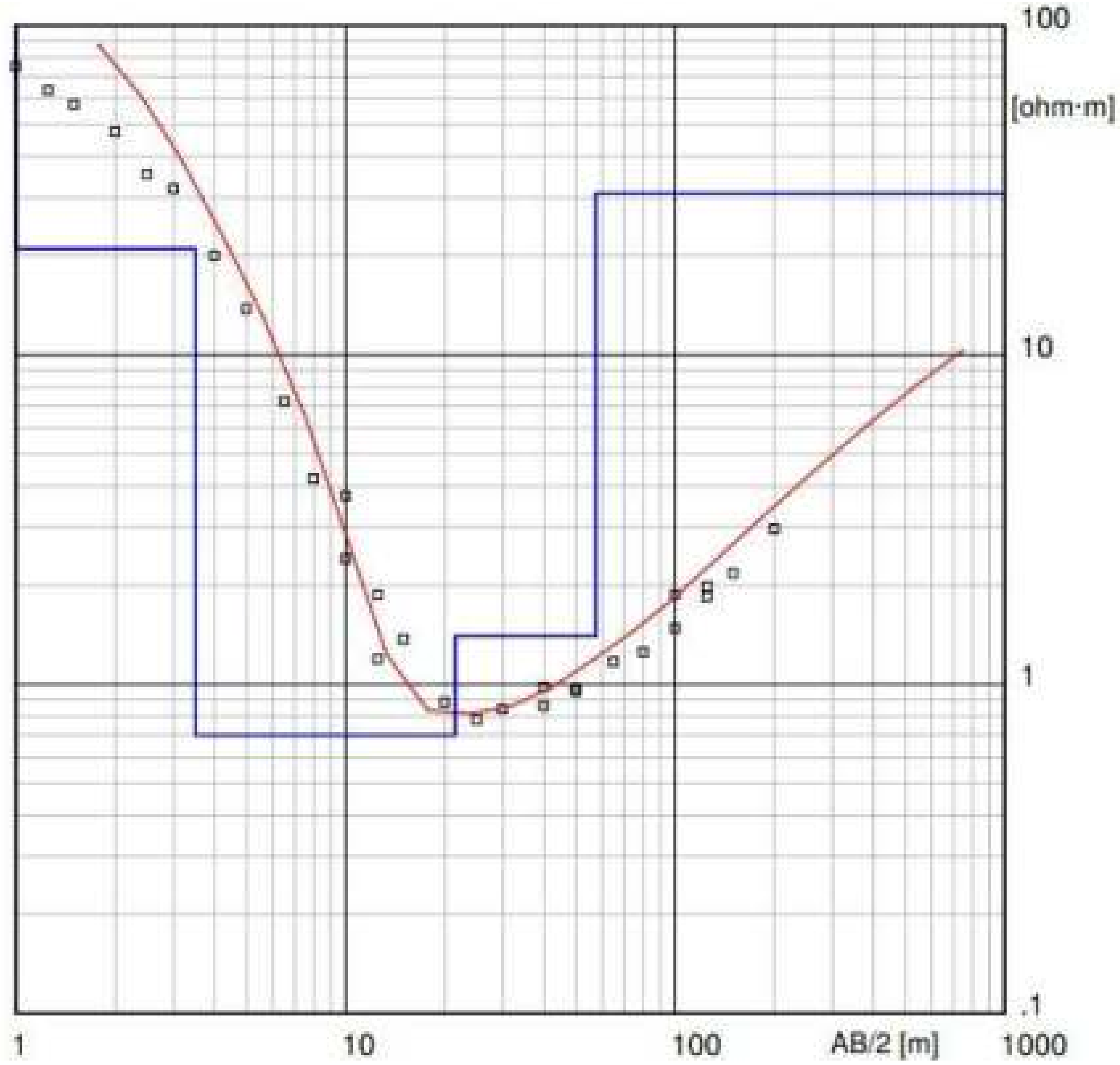
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5, 6	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-5



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	141	1	1
2	21	2.5	3.5
3	0.7	18	22
4	1.4	36	58
5	31	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

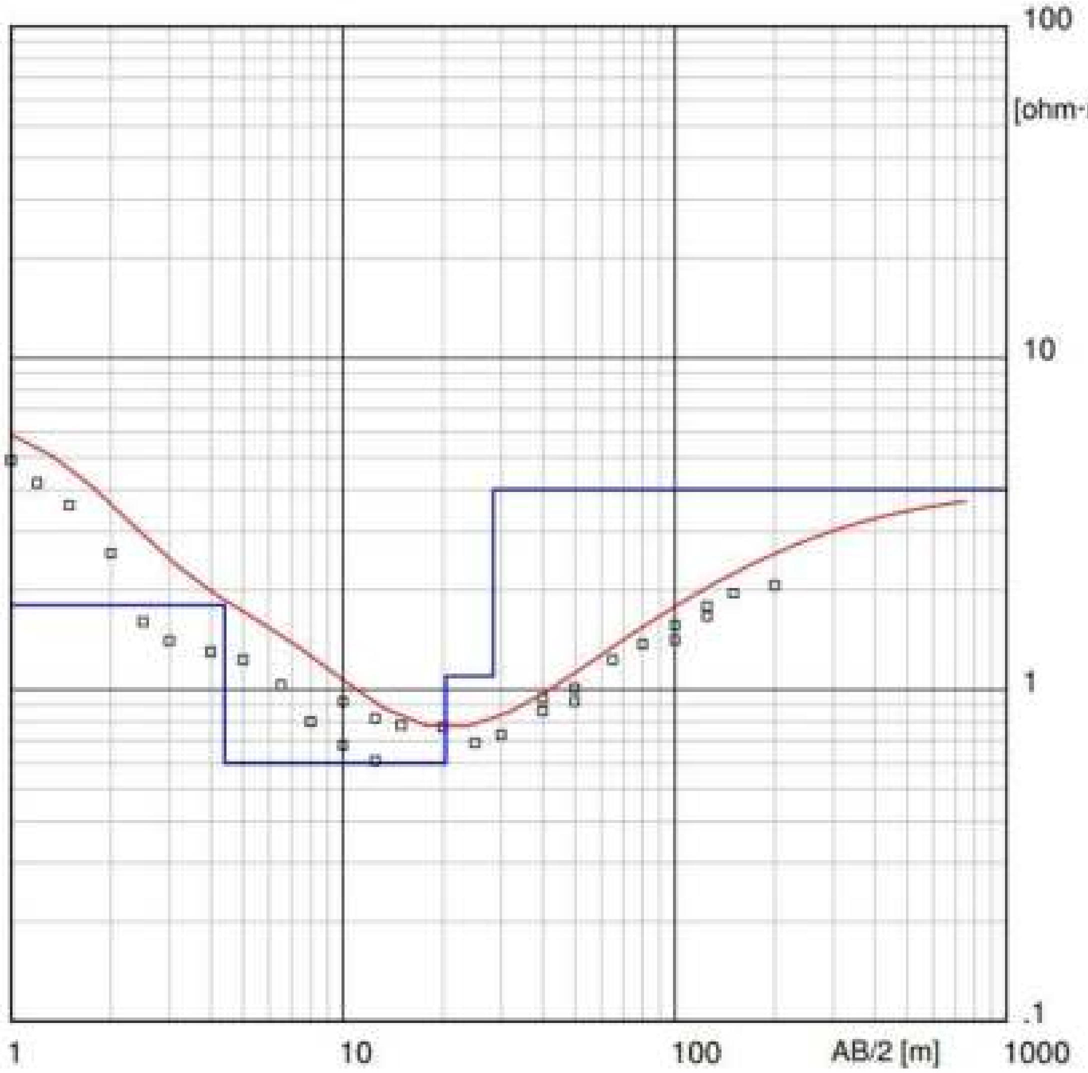
Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Appendix: 4.5

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

GEOELECTRICAL PROBE GS-100-6



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	7	0.8	0.8
2	1.8	3.6	4.4
3	0.6	16	20
4	1.1	8	28
5	4	–	–

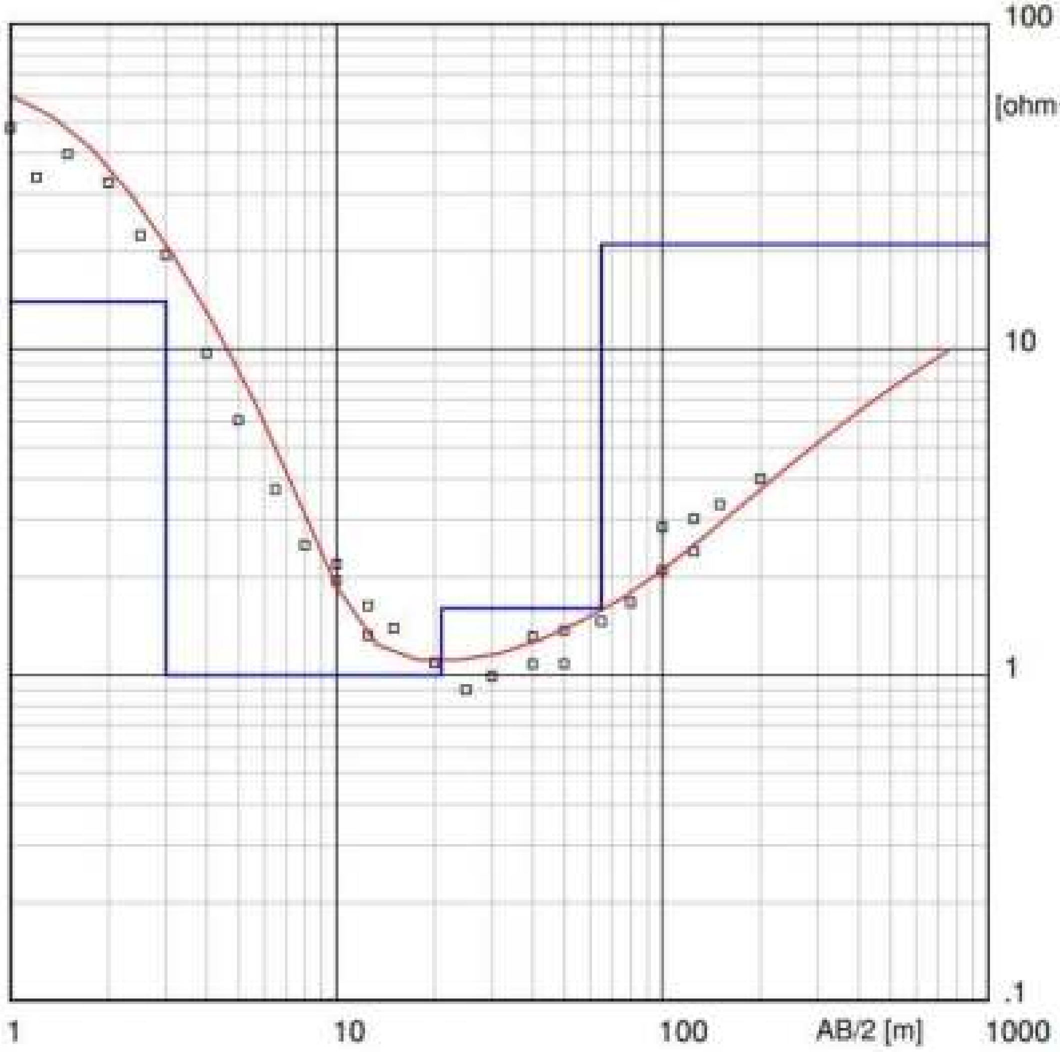
INTERVAL	LITHOLOGICAL DETERMINATION
1	SANDY CLAY, SATURATED WITH SALT WATER
2, 3, 4	CLAY SATURATED WITH SALT WATER
5	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-7



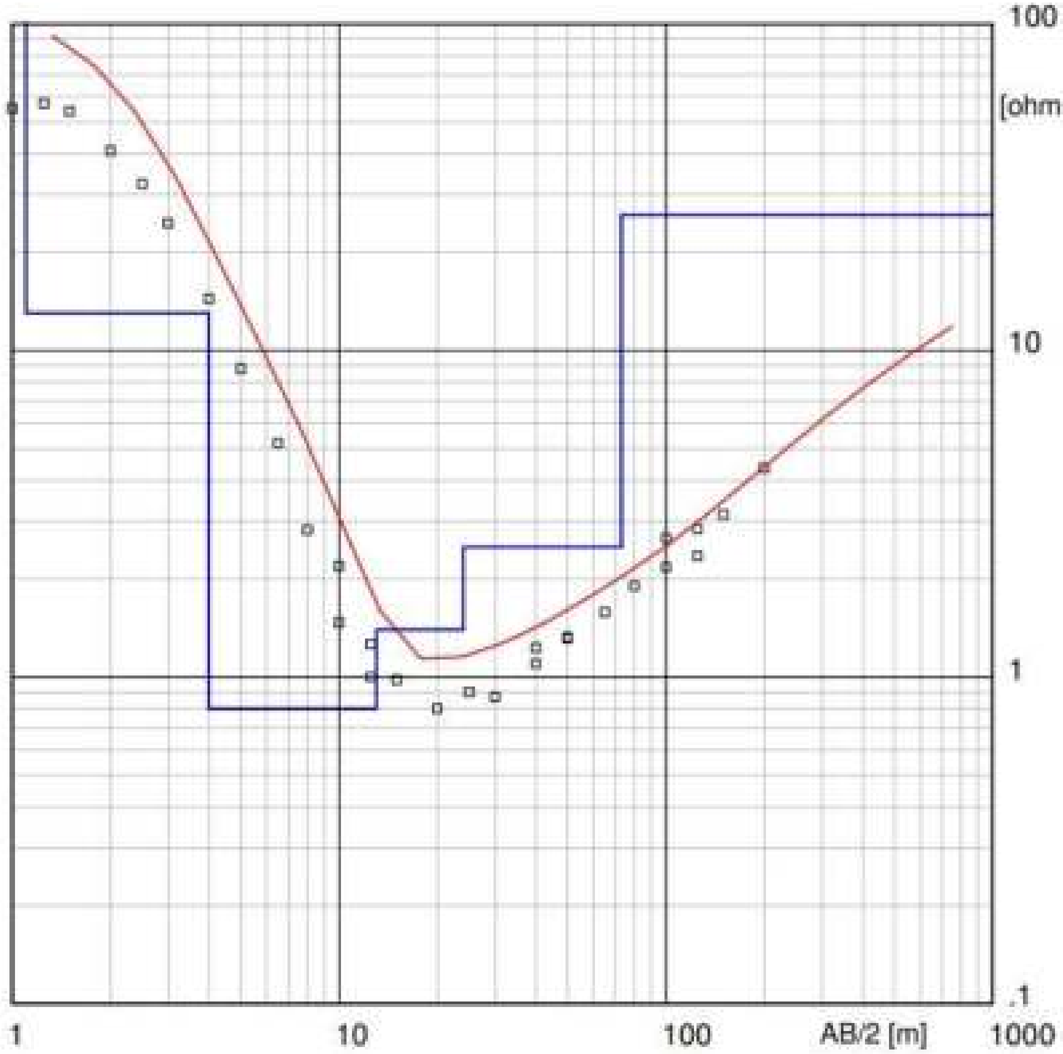
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	70	0.9	0.9
2	14	2.1	3
3	1	18	21
4	1.6	44	65
5	21	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

GEOELECTRICAL PROBE GS-100-8



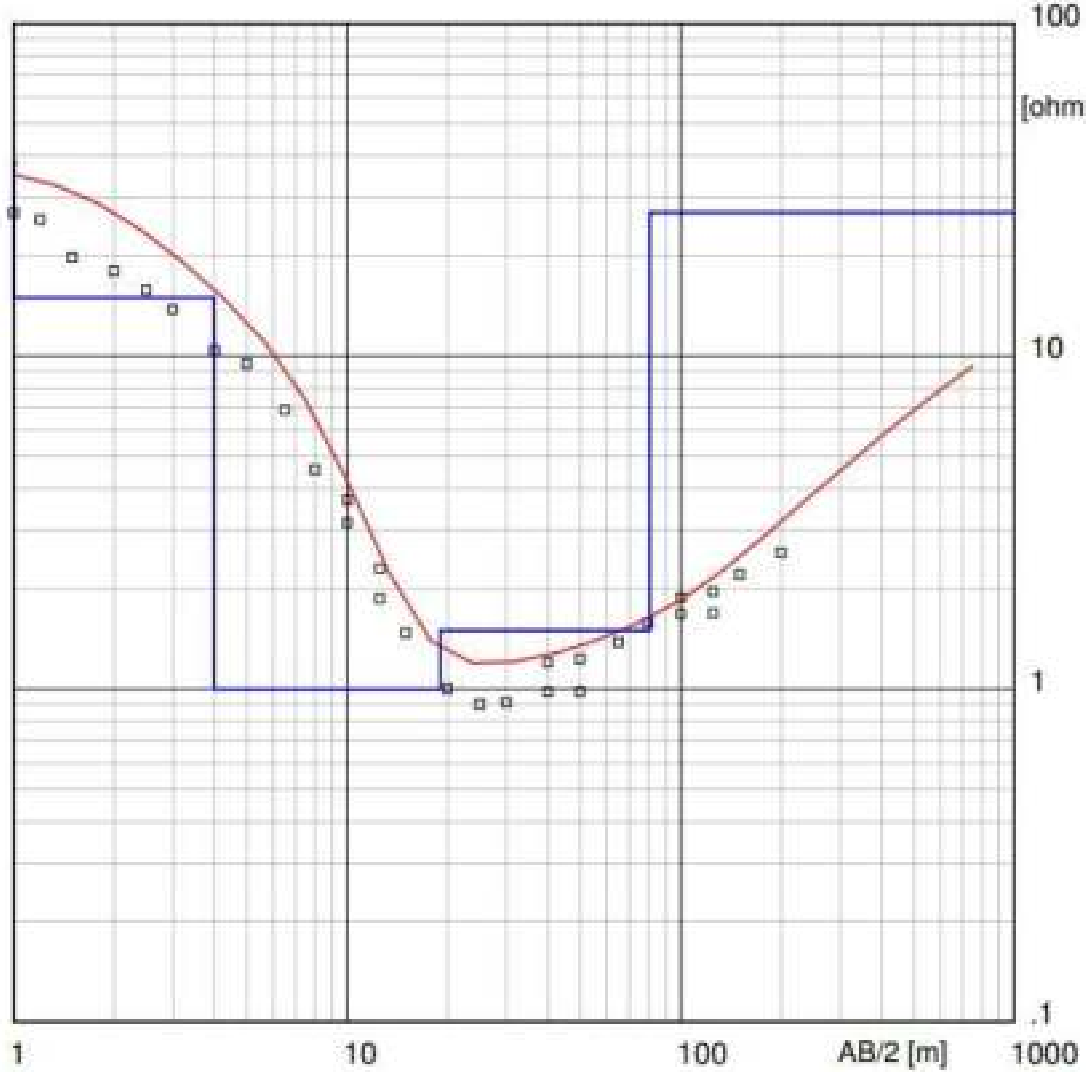
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	114	1.1	1.1
2	13	2.9	4
3	0.8	9	13
4	1.4	11	24
5	2.5	49	73
6	26	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4, 5	CLAY SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

GEOELECTRICAL PROBE GS-100-9



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	38	1	1
2	15	3	4
3	1	15	19
4	1.5	62	81
5	27	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAYEY SAND
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

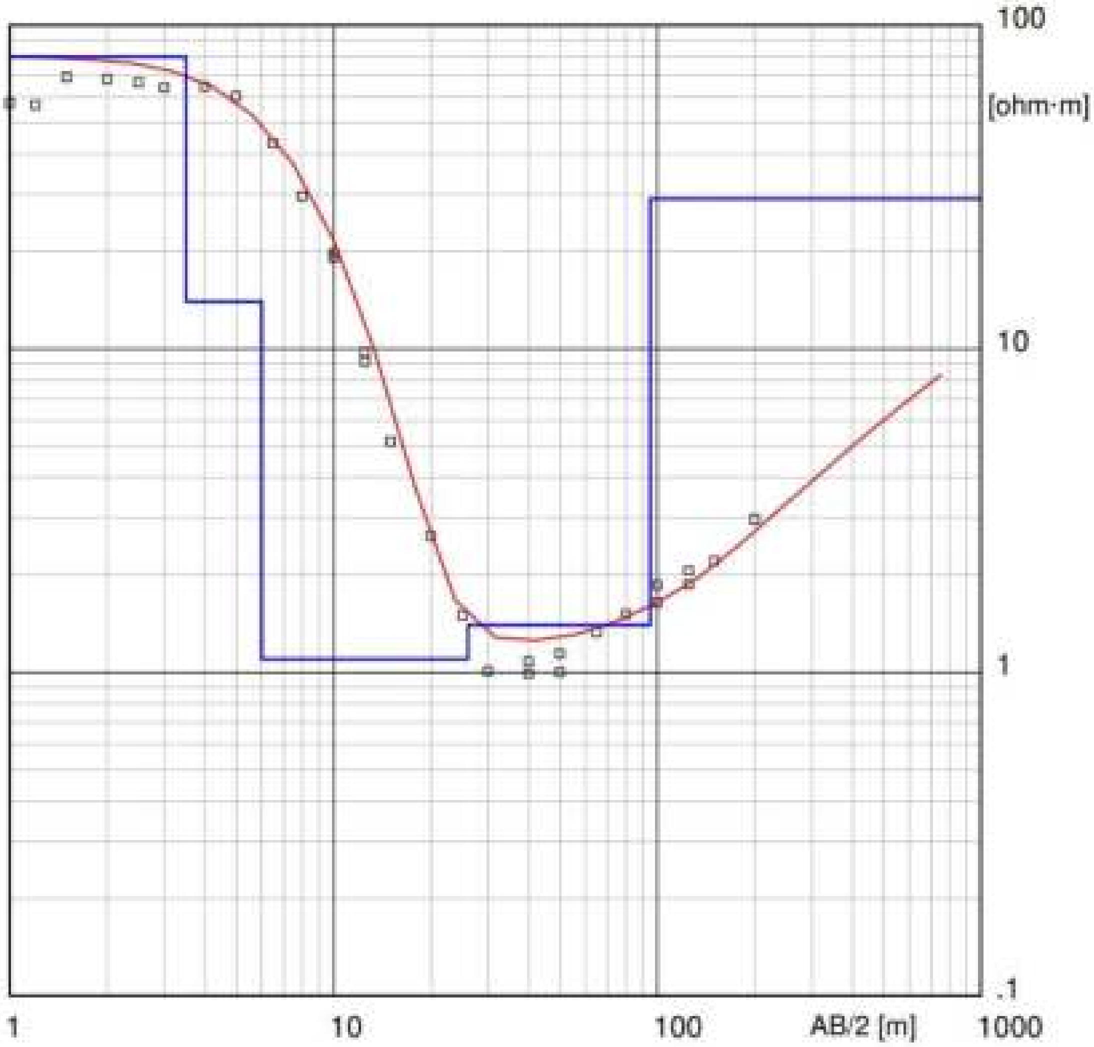
Processing and interpretation: mr. sc. Božo Padovan dipl.ing.fiz.

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-10



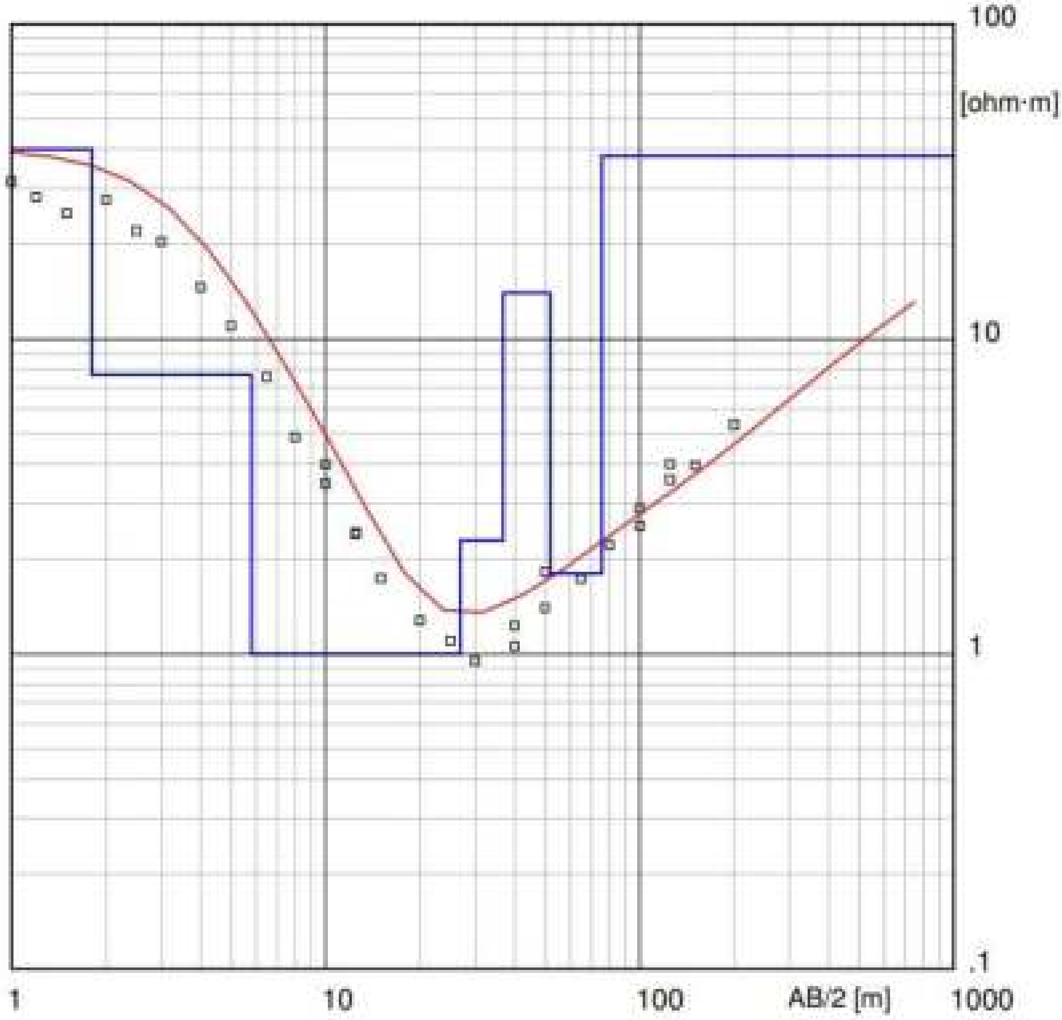
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	80	3.5	3.5
2	14	2.5	6
3	1.1	20	26
4	1.4	69	95
5	29	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

GEOELECTRICAL PROBE GS-100-11



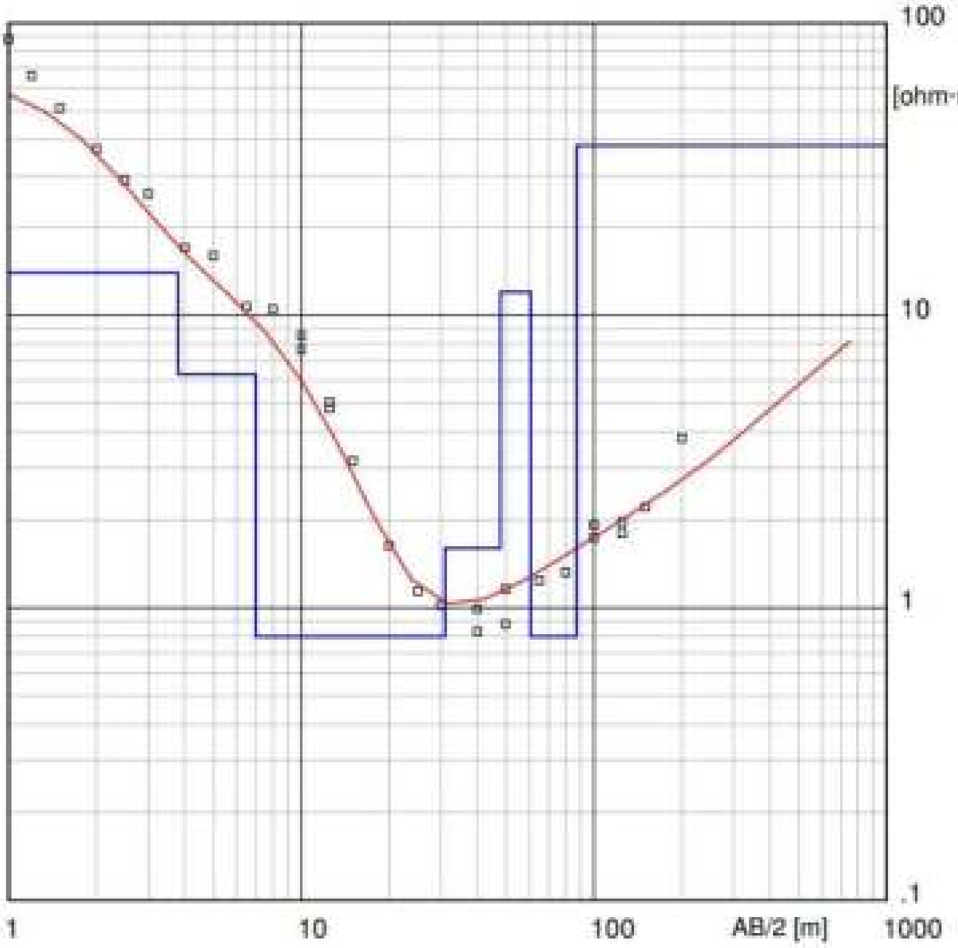
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	40	1.8	1.8
2	7.7	4	5.8
3	1	21	27
4	2.3	10	37
5	14	15	52
6	1.8	24	76
7	38	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

GEOELECTRICAL PROBE GS-100-12



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	66	0.9	0.9
2	14	2.9	3.8
3	6.3	3.2	7
4	0.8	24	31
5	1.6	17	48
6	12	13	61
7	0.8	26	87
8	38	–	–

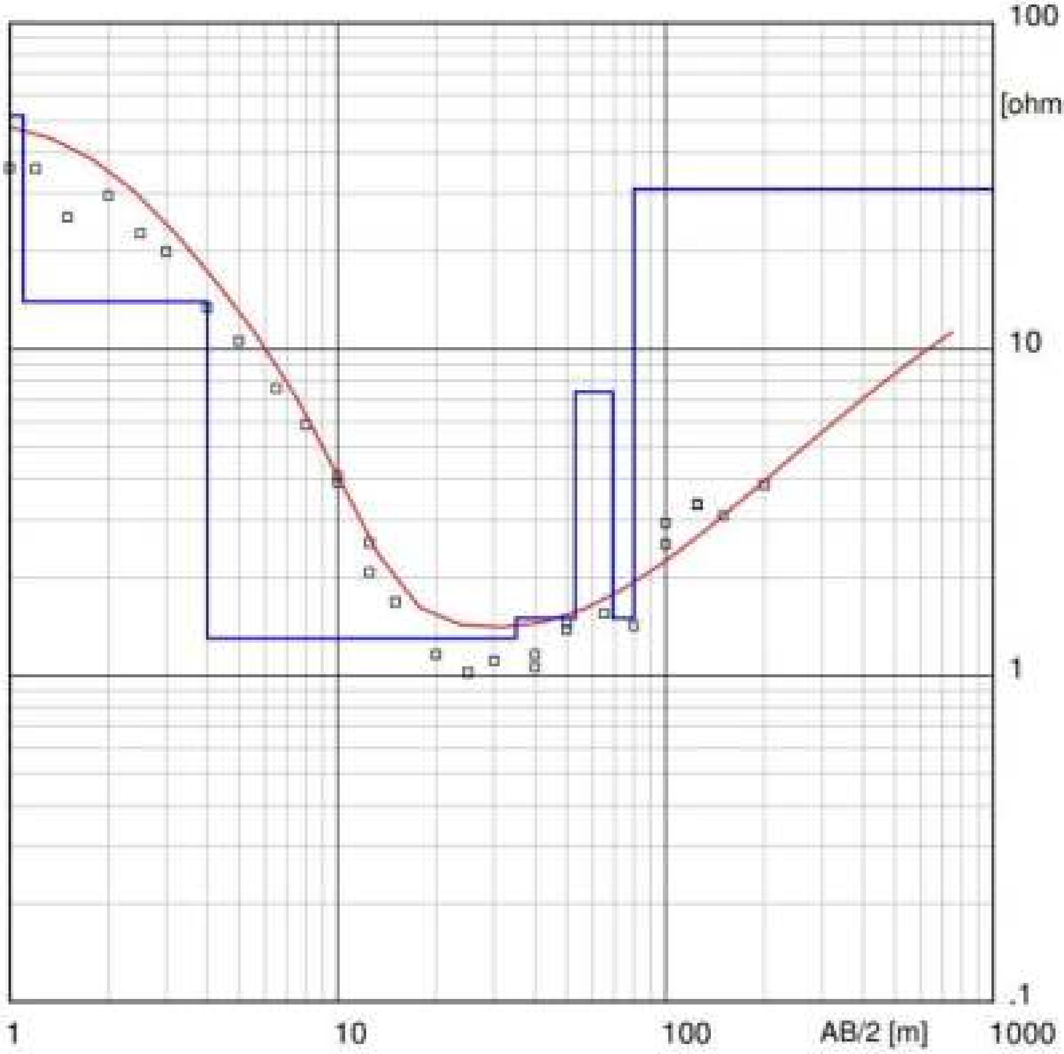
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2, 3	SANDY CLAY, SATURATED WITH SALT WATER
4, 5	CLAY SATURATED WITH SALT WATER
6	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
7	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
8	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Processing and interpretation: mr. sc. Božo Padovan dipl.ing.fiz.

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

GEOELECTRICAL PROBE GS-100-13



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	52	1.1	1.1
2	14	2.9	4
3	1.3	31	35
4	1.5	18	53
5	7.4	16	69
6	1.5	11	80
7	31	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

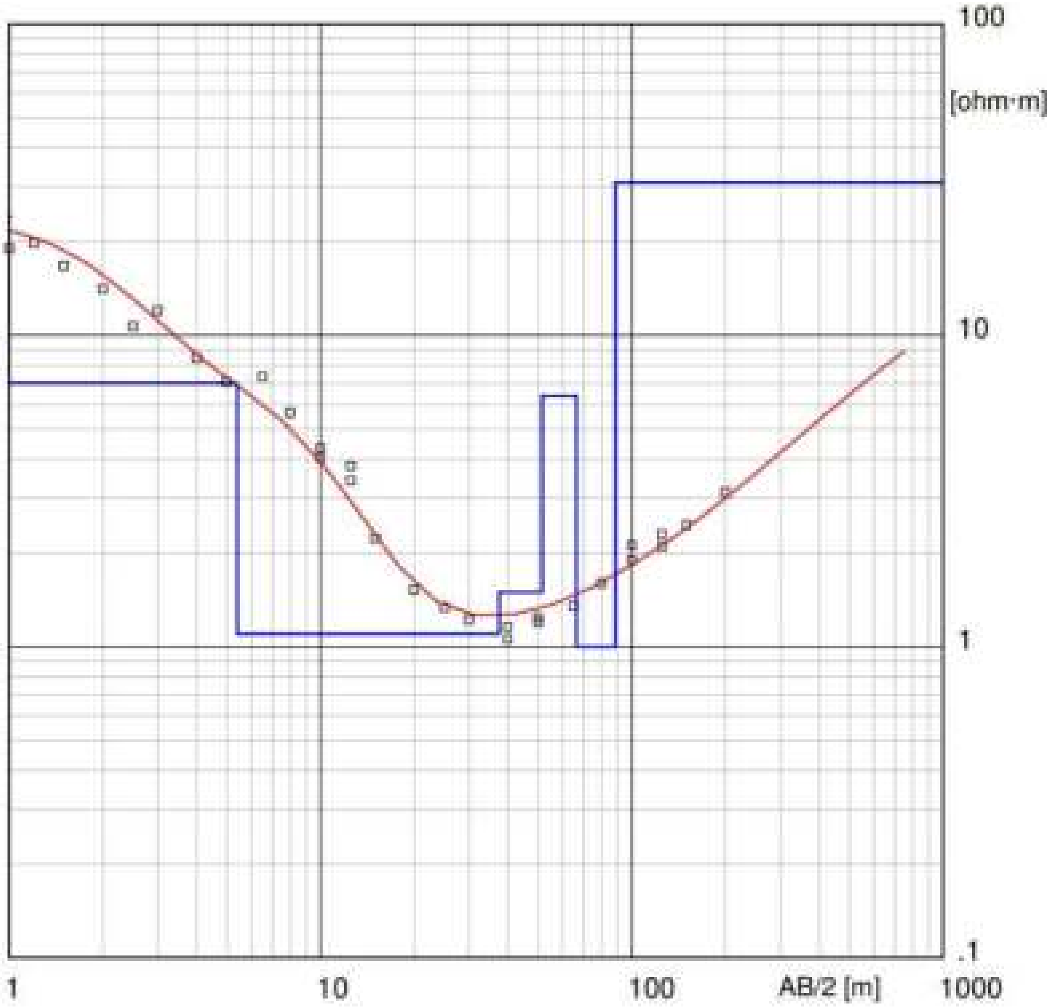
Appendix: 4.13

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-14



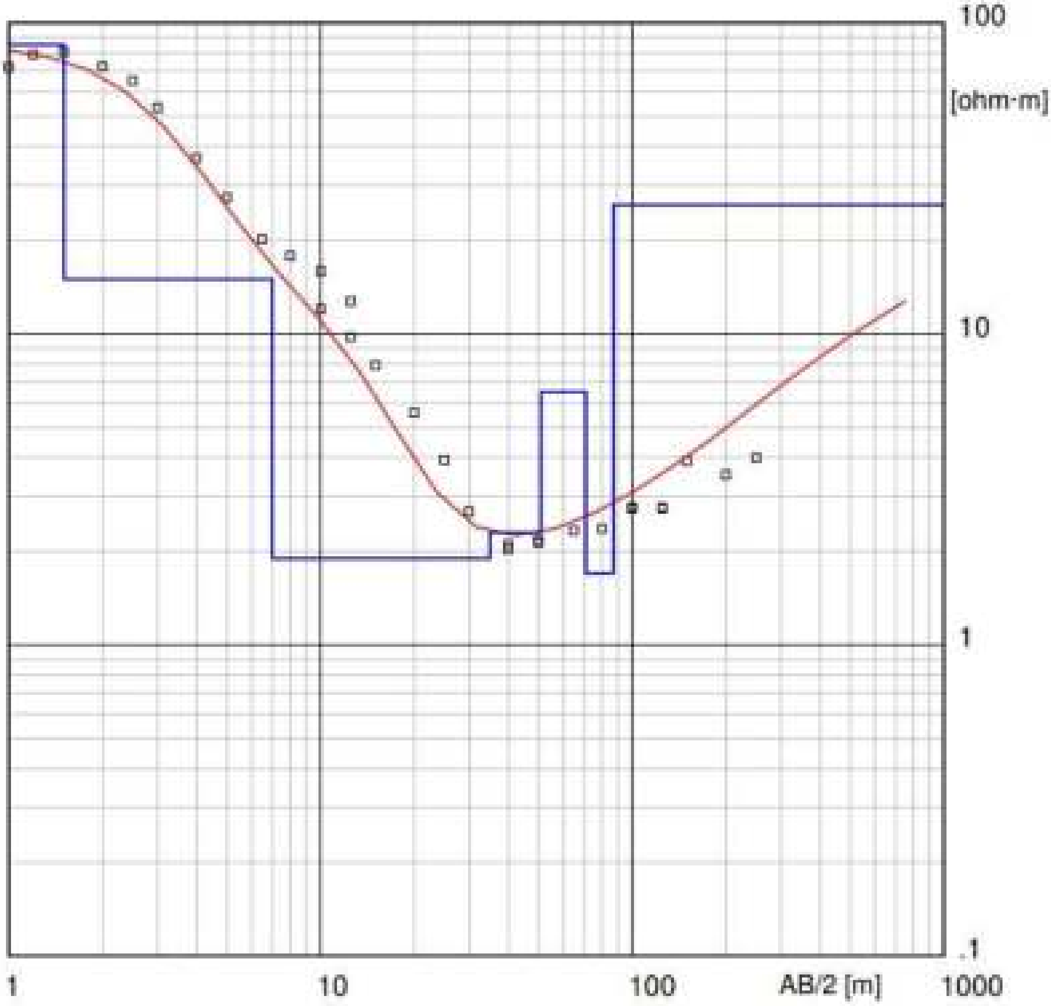
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	24	1	1
2	7	4.4	5.4
3	1.1	32	37
4	1.5	14	51
5	6.4	15	66
6	1	22	88
7	31	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

GEOELECTRICAL PROBE GS-100-15



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	85	1.5	1.5
2	15	5.5	7
3	1.9	28	35
4	2.3	16	51
5	6.5	20	71
6	1.7	16	87
7	26	–	–

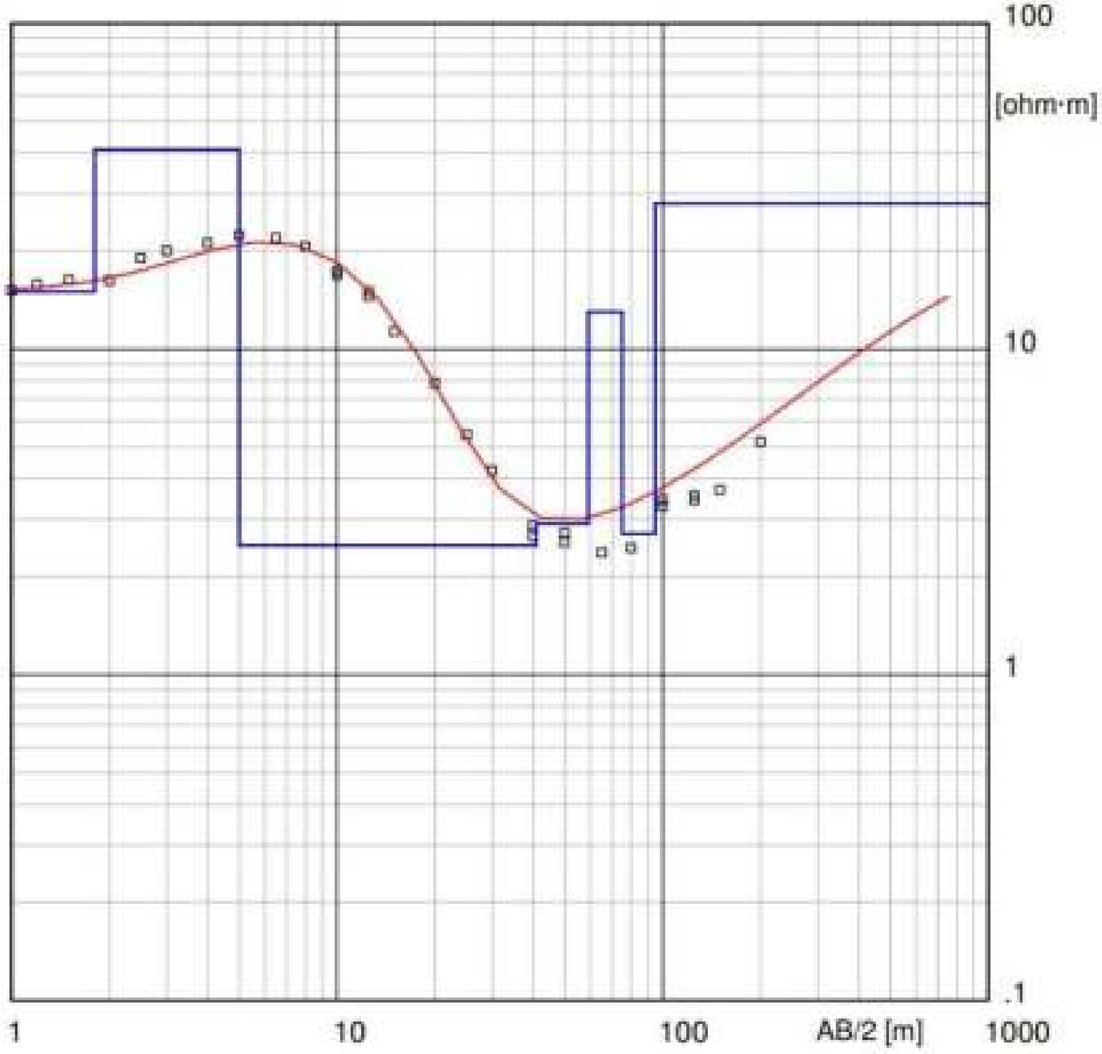
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-16



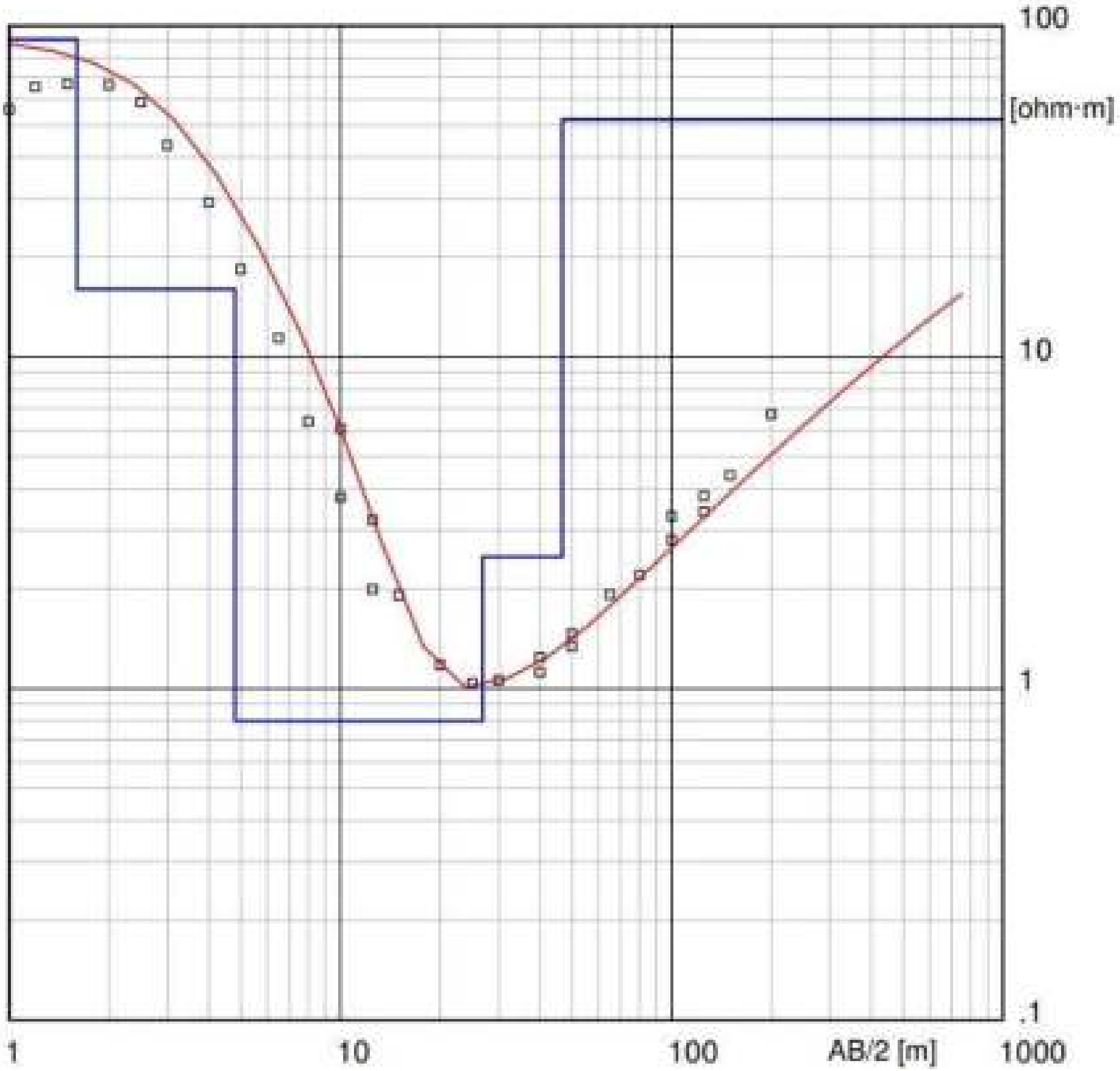
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	15	1.8	1.8
2	41	3.2	5
3	2.5	36	41
4	2.9	18	59
5	13	16	75
6	2.7	20	95
7	28	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

GEOELECTRICAL PROBE GS-100-17



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	91	1.6	1.6
2	16	3.2	4.8
3	0.8	22	27
4	2.5	20	47
5	25	–	–

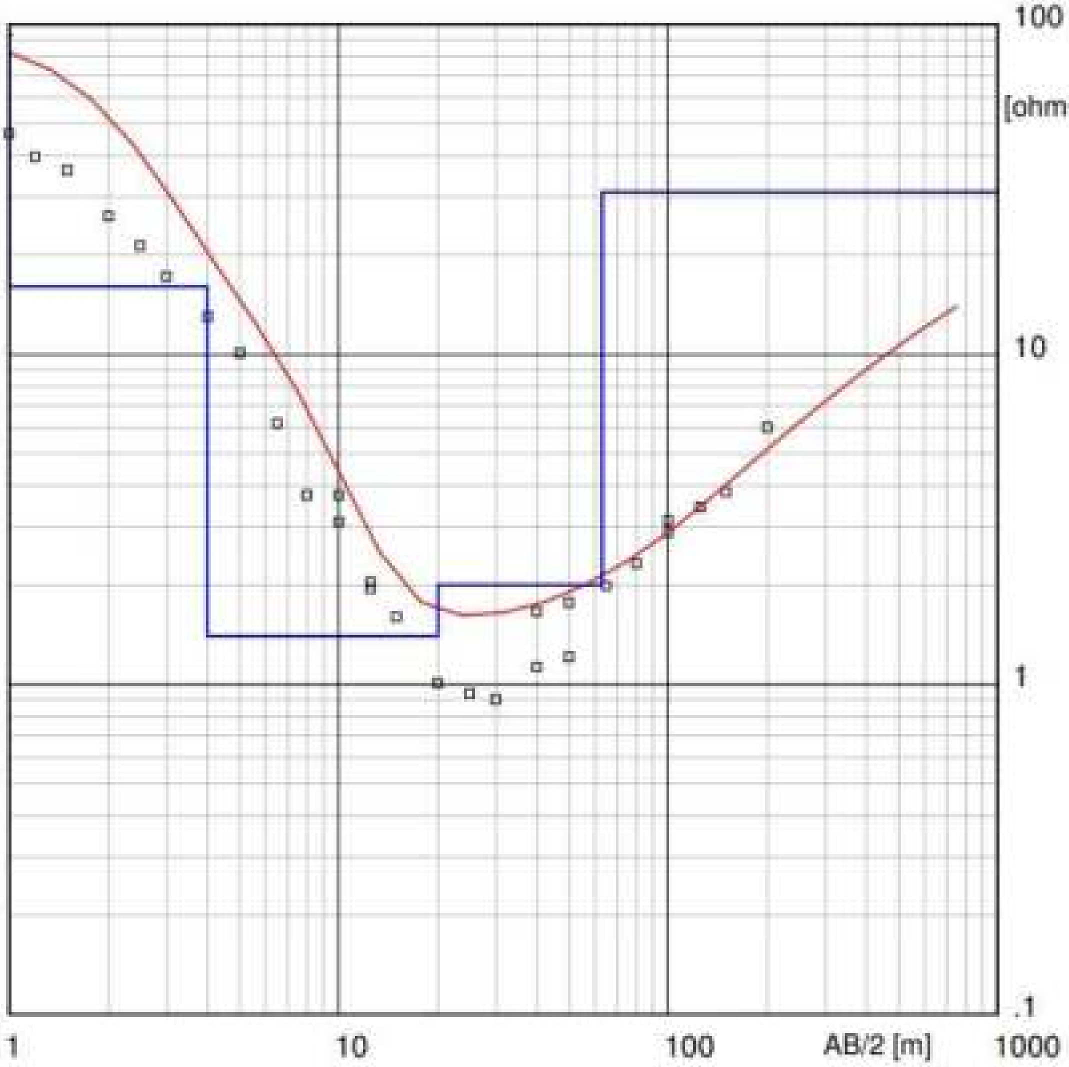
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-18



INTERVAL	OTPORNOST	DEBLJINA	DUBINA
/	ohmm	m	m
1	93	1	1
2	16	3	4
3	1.4	16	20
4	2	43	63
5	31	–	–

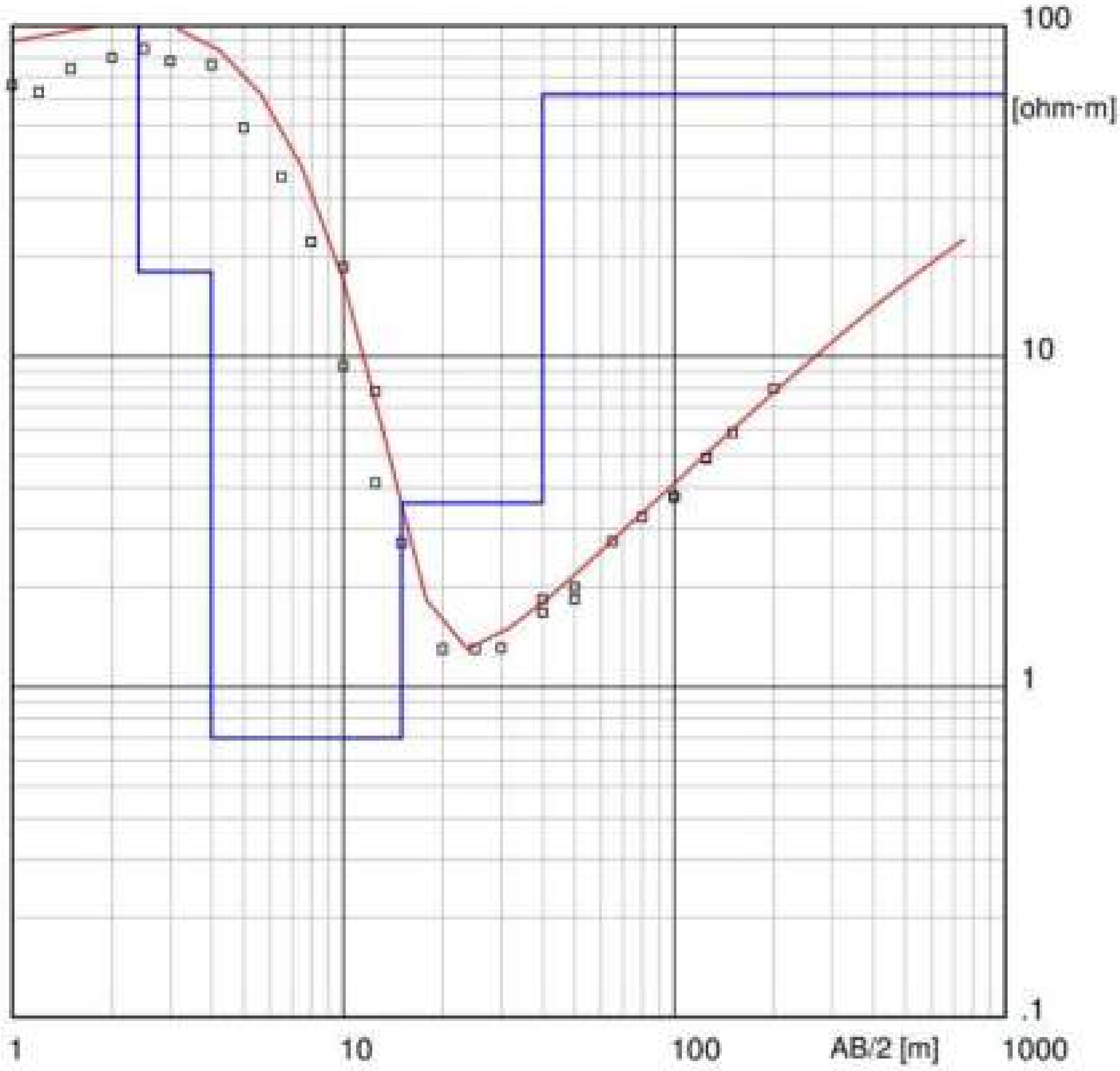
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-19



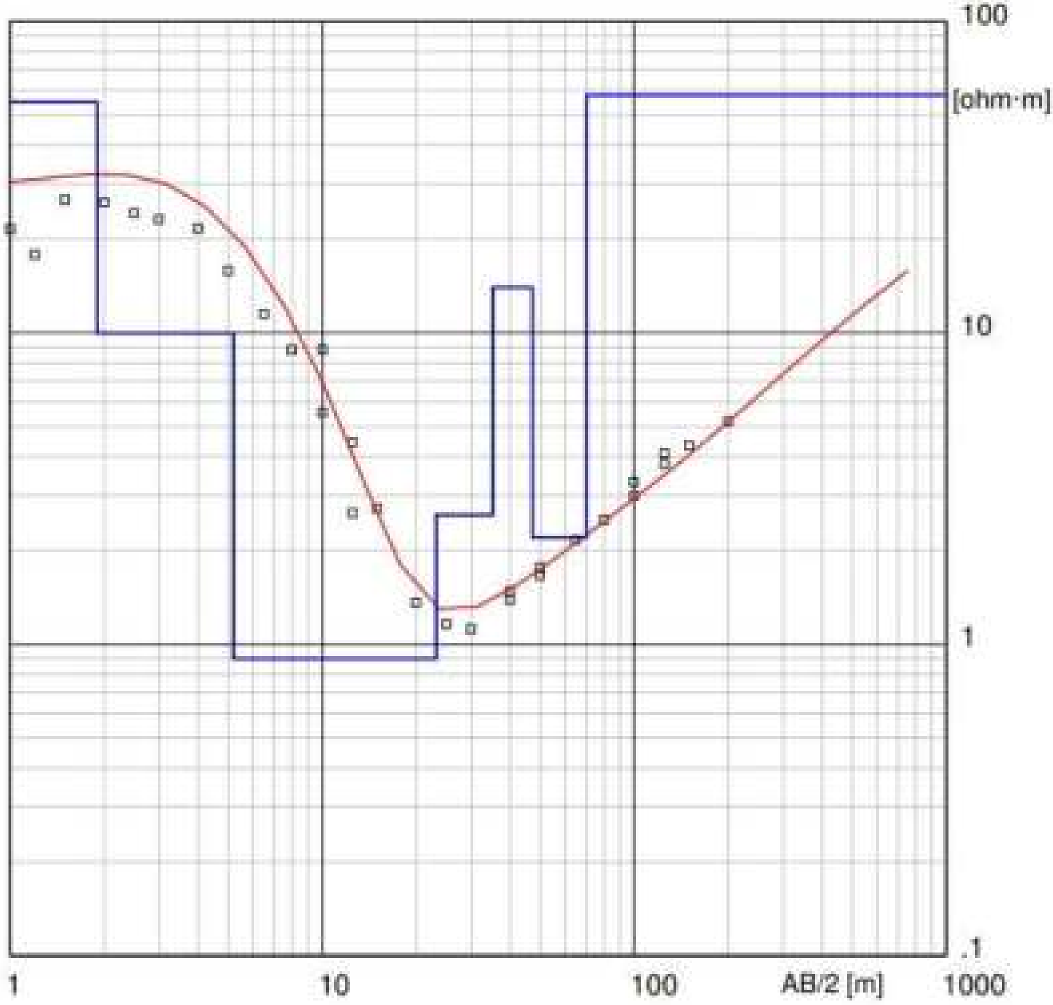
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	83	0.8	0.8
2	157	1.6	2.4
3	18	1.6	4
4	0.7	11	15
5	3.6	25	40
6	62	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1, 2	SAND, CLAY (DRY ZONE)
3	SANDY CLAY, SATURATED WITH SALT WATER
4, 5	CLAY SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

GEOELECTRICAL PROBE GS-100-20



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	29	0.9	0.9
2	55	1	1.9
3	10	3.3	5.2
4	0.9	18	23
5	2.6	12	35
6	14	12	47
7	2.2	23	70
8	58	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1, 2	SAND, CLAY (DRY ZONE)
3	SANDY CLAY, SATURATED WITH SALT WATER
4, 5	CLAY SATURATED WITH SALT WATER
6	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
7	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
8	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

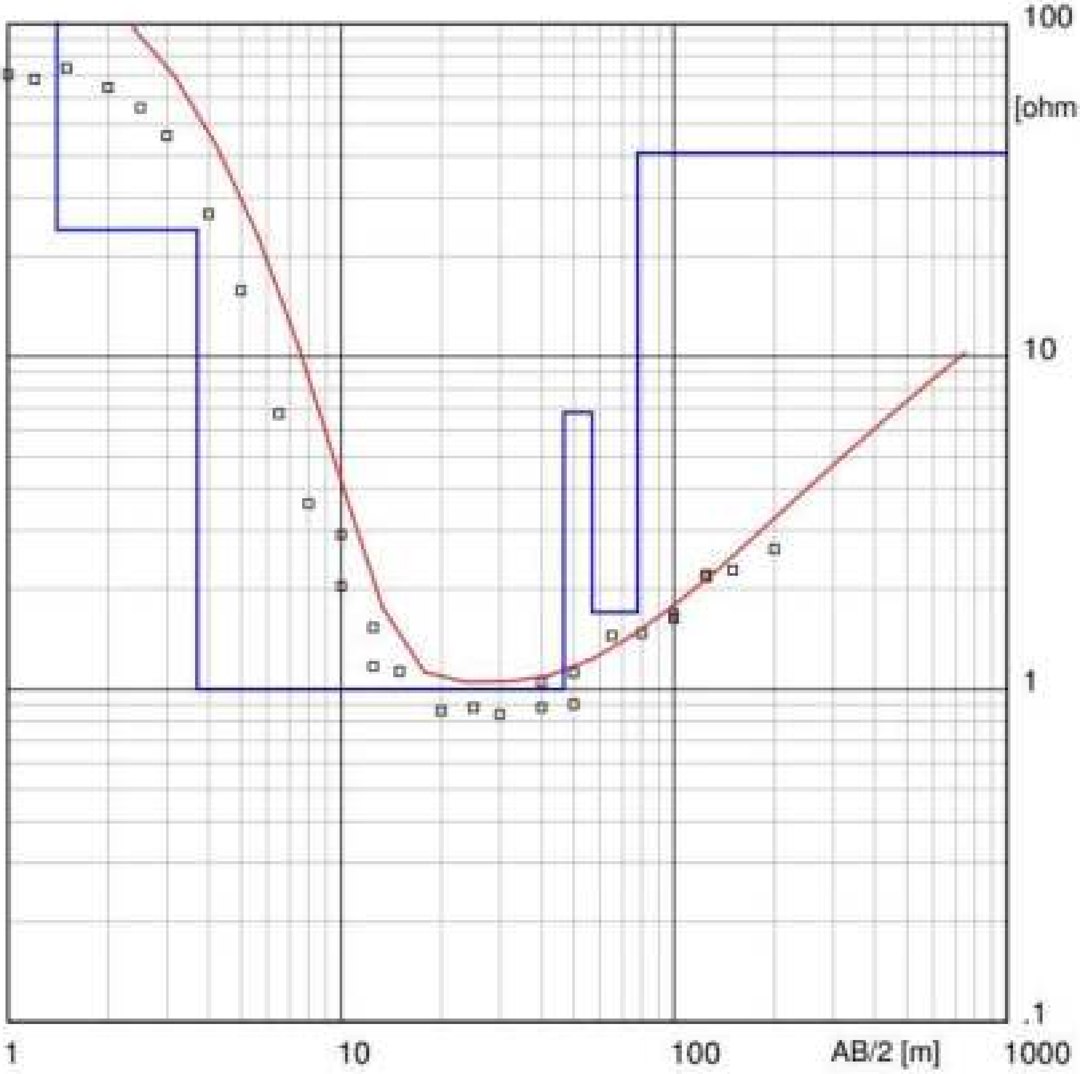
Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH. 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-21



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	150	1.4	1.4
2	24	2.3	3.7
3	1	43	47
4	6.8	10	57
5	1.7	21	78
6	41	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3	CLAY SATURATED WITH SALT WATER
4	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
5	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

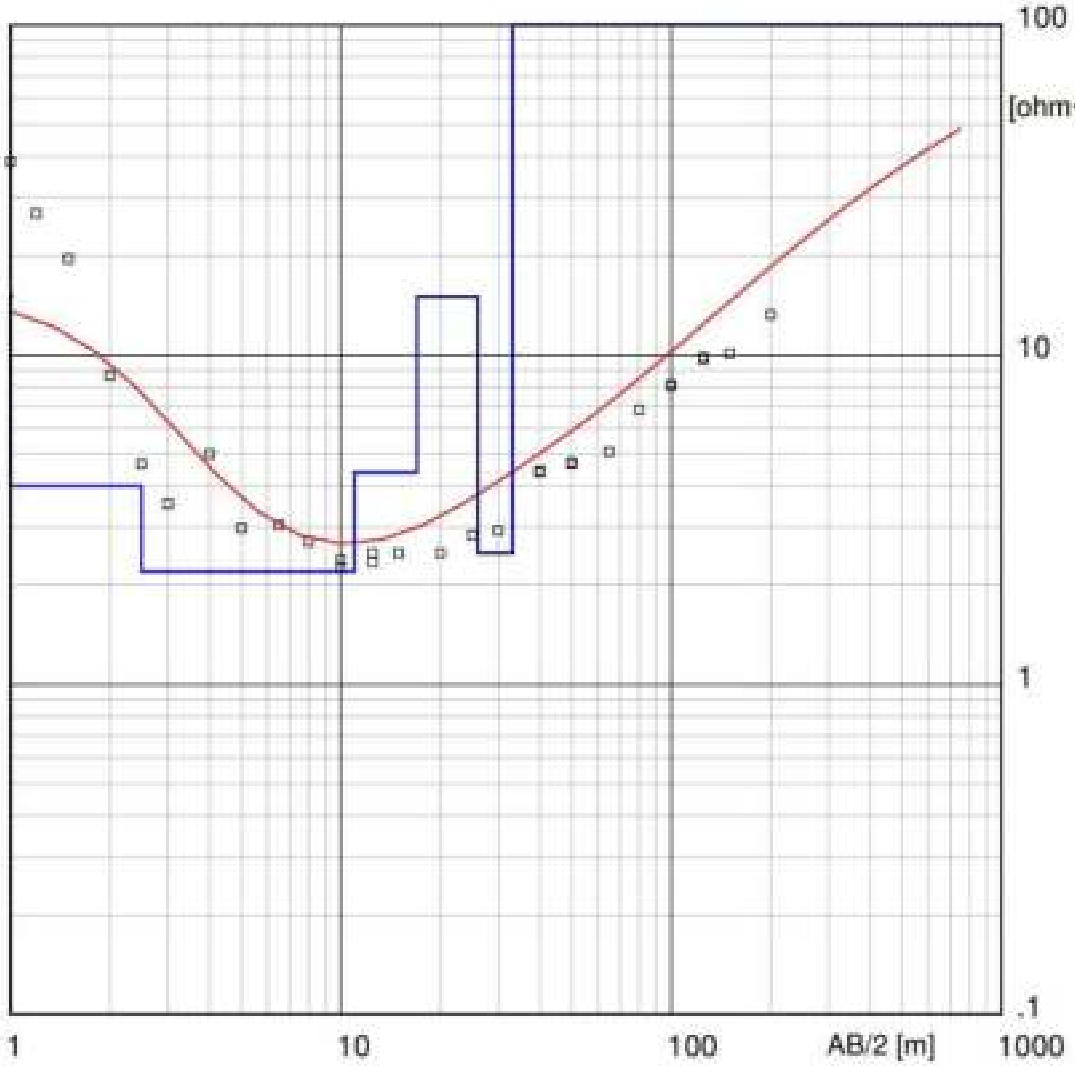
Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Appendix: 4.21

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

GEOELECTRICAL PROBE GS-100-22



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	15	1	1
2	4	1.5	2.5
3	2.2	8.5	11
4	4.4	6	17
5	15	9	26
6	2.5	7	33
7	100	–	–

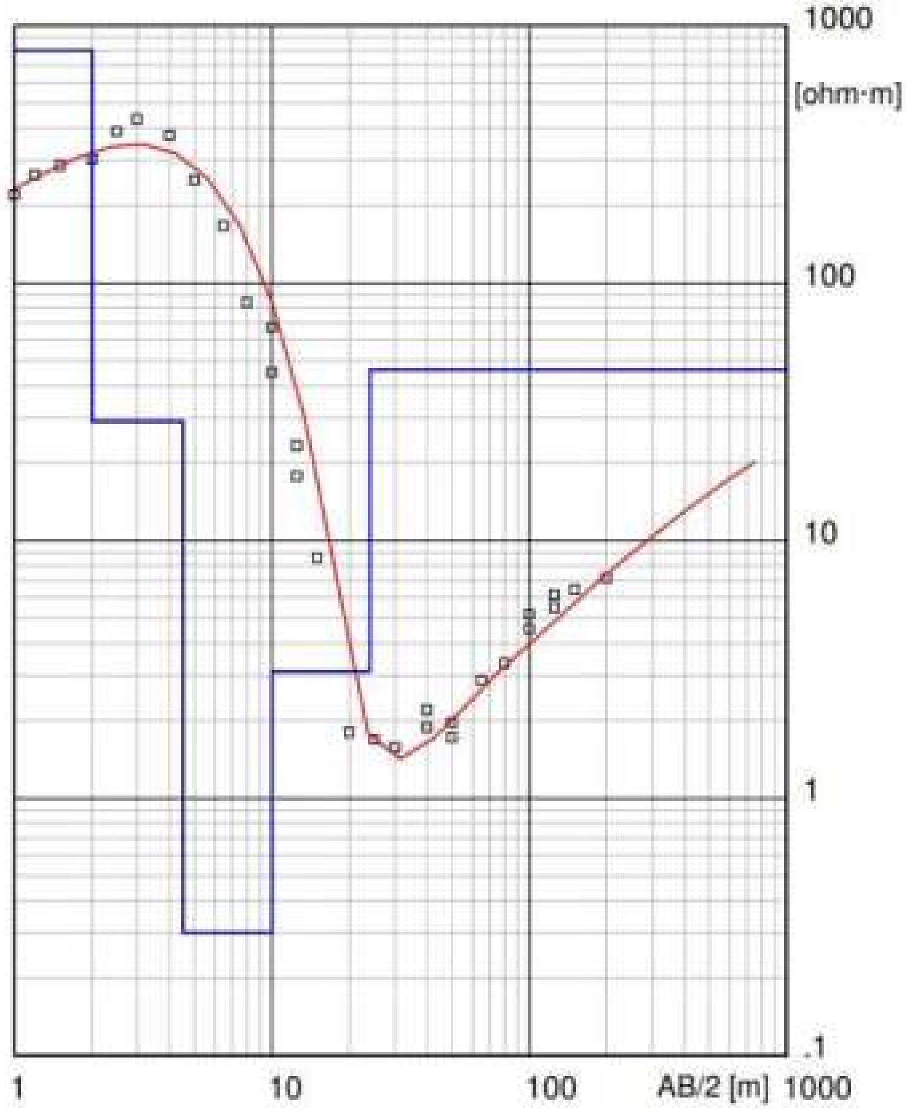
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2, 3, 4	SANDY CLAY, SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-23



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	170	0.6	0.6
2	800	1.4	2
3	29	2.5	4.5
4	0.3	5.5	10
5	3.1	14	24
6	46	–	–

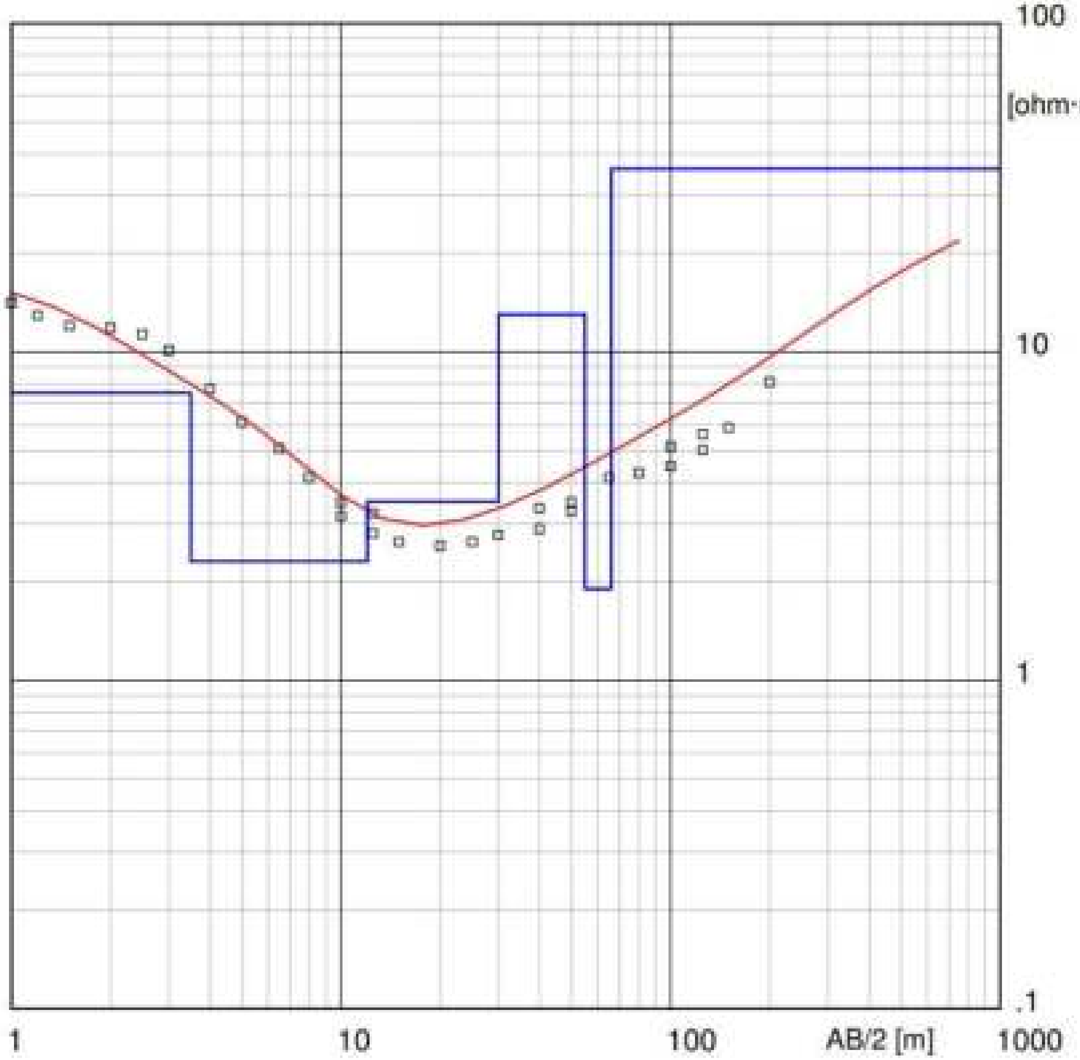
INTERVAL	LITHOLOGICAL DETERMINATION
1, 2	SAND, CLAY (DRY ZONE)
3	SANDY CLAY, SATURATED WITH SALT WATER
4, 5	CLAY SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-24



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	17	0.8	0.8
2	7.5	2.7	3.5
3	2.3	8.5	12
4	3.5	18	30
5	13	25	55
6	1.9	11	66
7	36		

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2, 3, 4	SANDY CLAY, SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

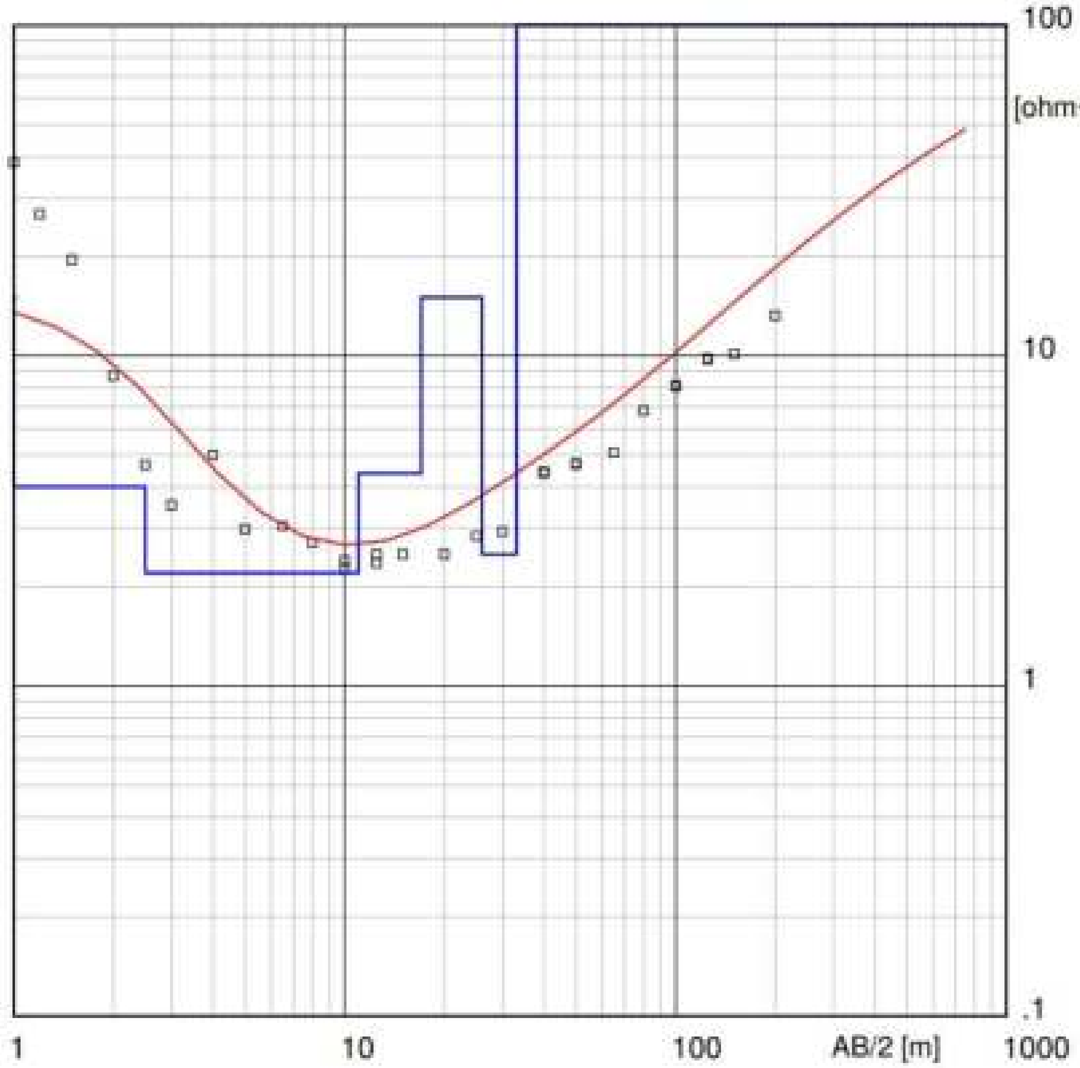
Appendix: 4.24

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH. 100 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-100-25



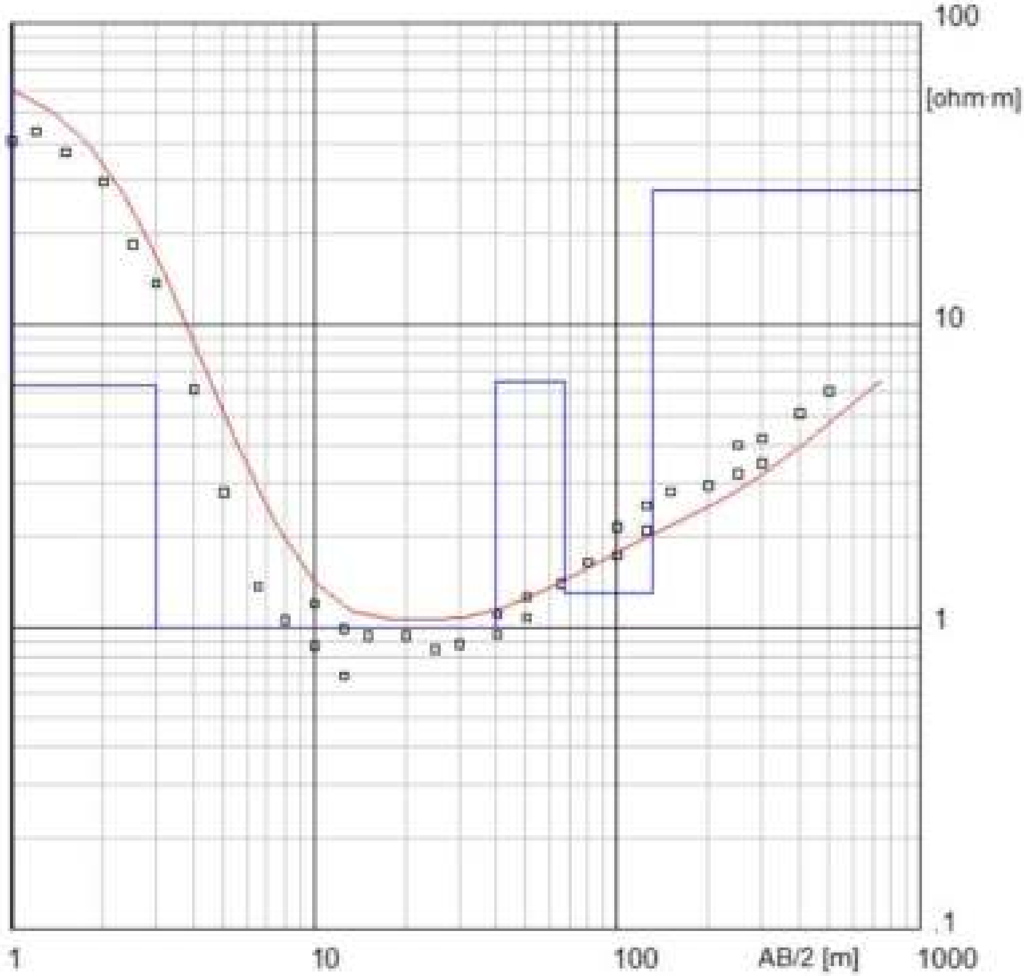
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	60	0.9	0.9
2	16	1.1	2
3	1.7	9	11
4	2.6	21	32
5	12	23	55
6	3	25	80
7	27		

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-1



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	69	1	1
2	6.3	2	3
3	1	37	40
4	6.5	27	67
5	1.3	73	140
6	28	–	–

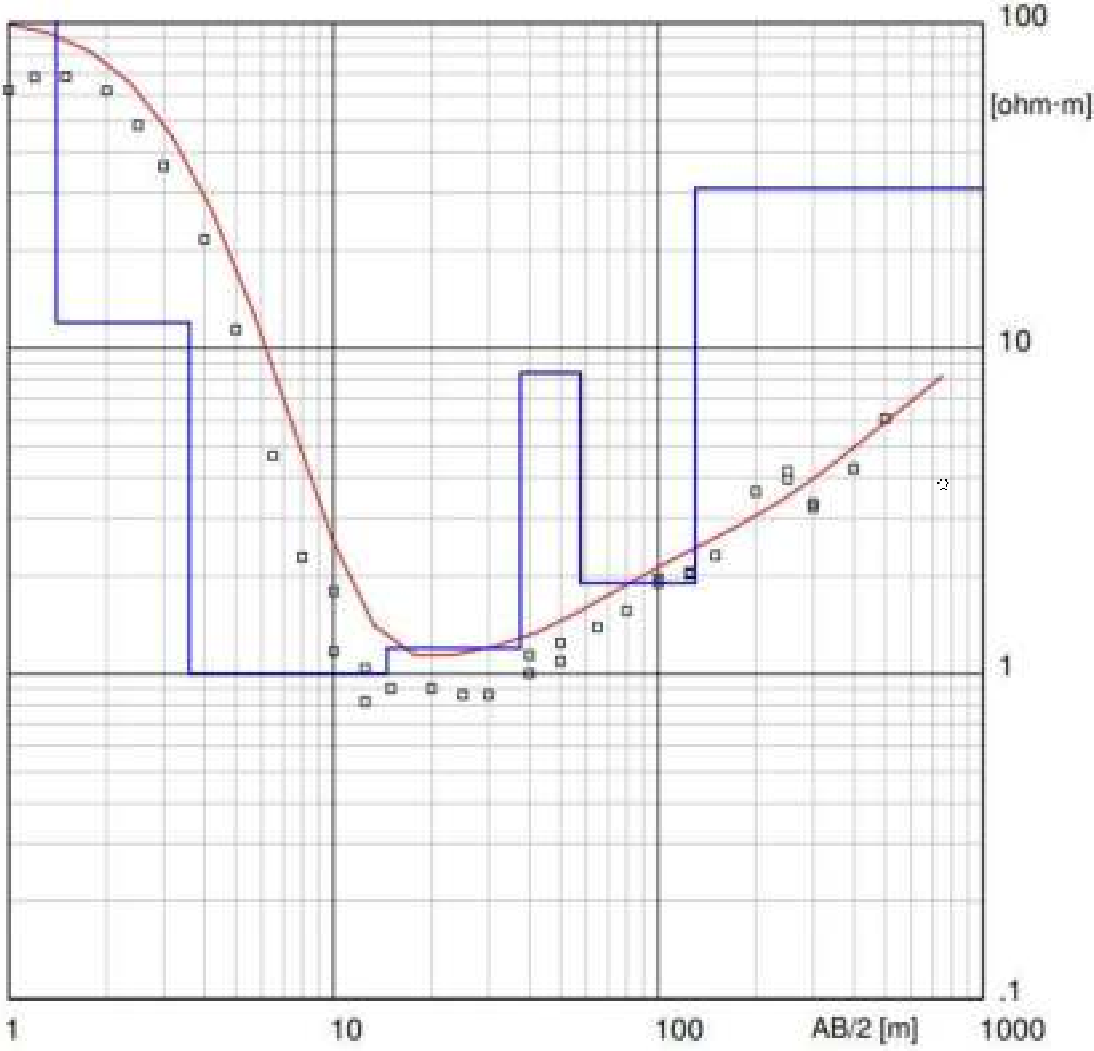
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3	CLAY SATURATED WITH SALT WATER
4	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
5	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
6	WEATHERED AND FRACTURED LIMESTONE

Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-2



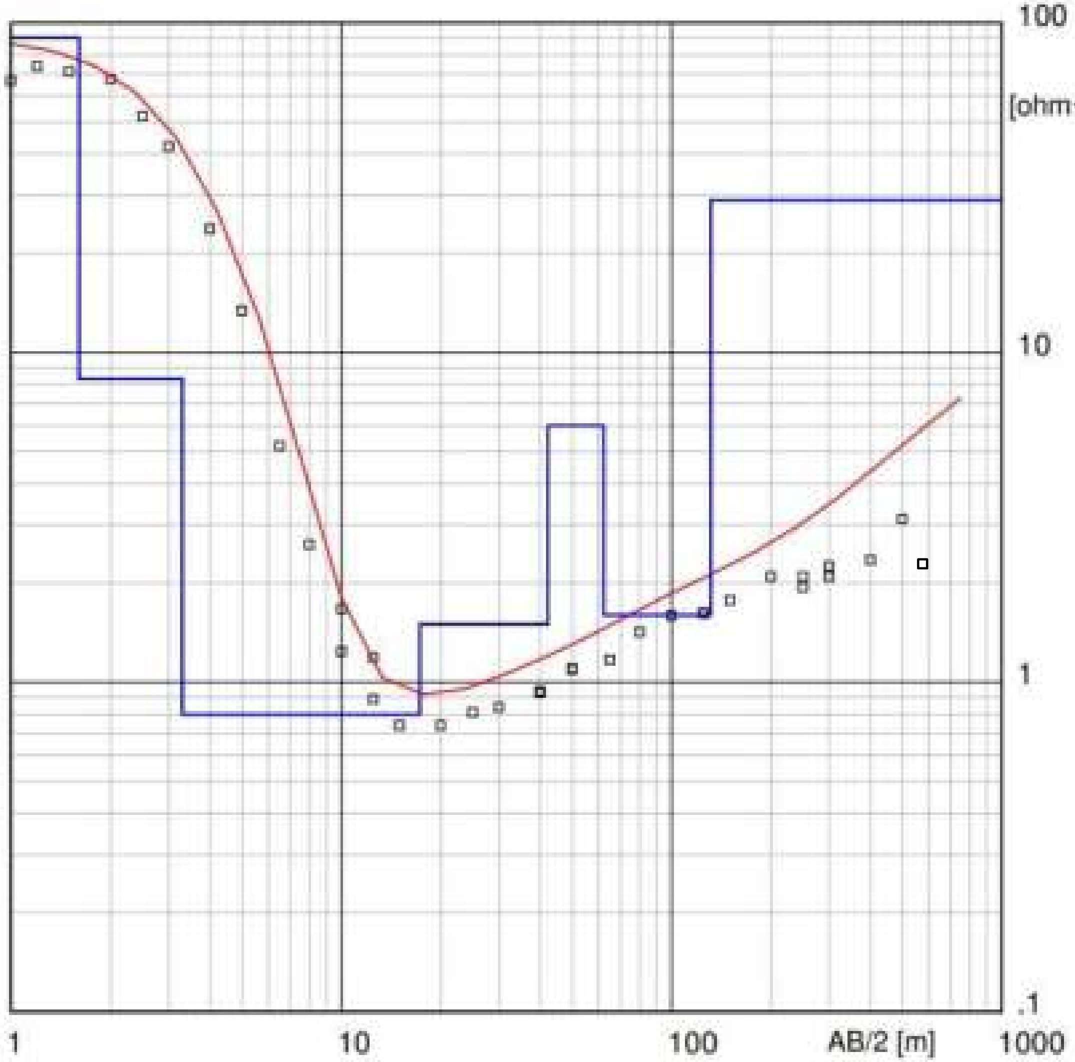
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	105	1.4	1.4
2	12	2.2	3.6
3	1	11	15
4	1.2	23	38
5	8.4	20	58
6	1.9	72	130
7	31	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-3



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	90	1.6	1.6
2	8.3	1.7	3.3
3	0.8	14	17
4	1.5	25	42
5	6	20	62
6	1.6	69	131
7	29	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Appendix: 5.3

Location: Neretva Valley

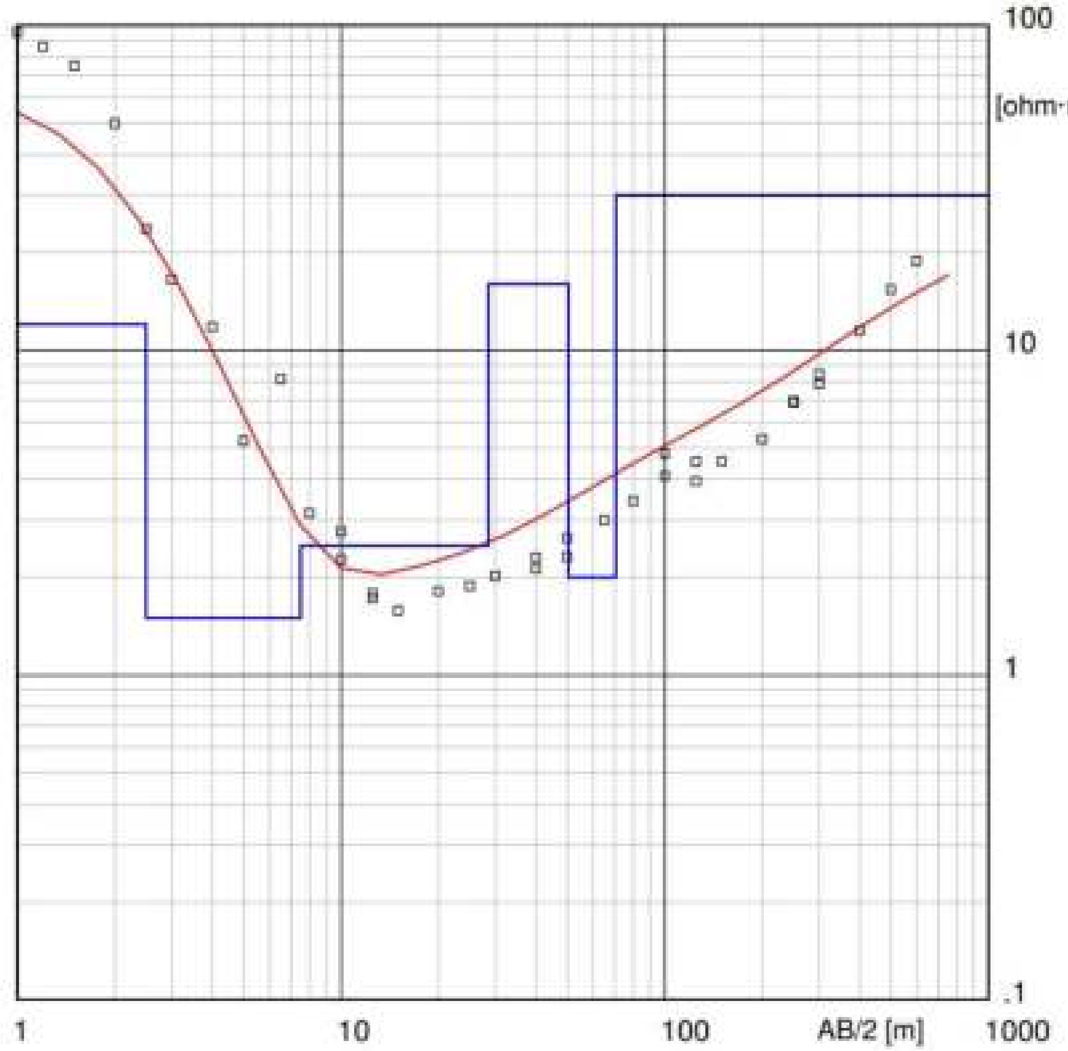
GEOPHYSICAL INVESTIGATION

METHOD: GEOELECTRICAL SOUNDING

INTERPRETATION DEPTH: 200 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-200-4



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	63	0.9	0.9
2	12	1.6	2.5
3	1.5	5	7.5
4	2.5	21.5	28
5	16	22	50
6	2	20	70
7	30		

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2, 3, 4	SANDY CLAY, SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

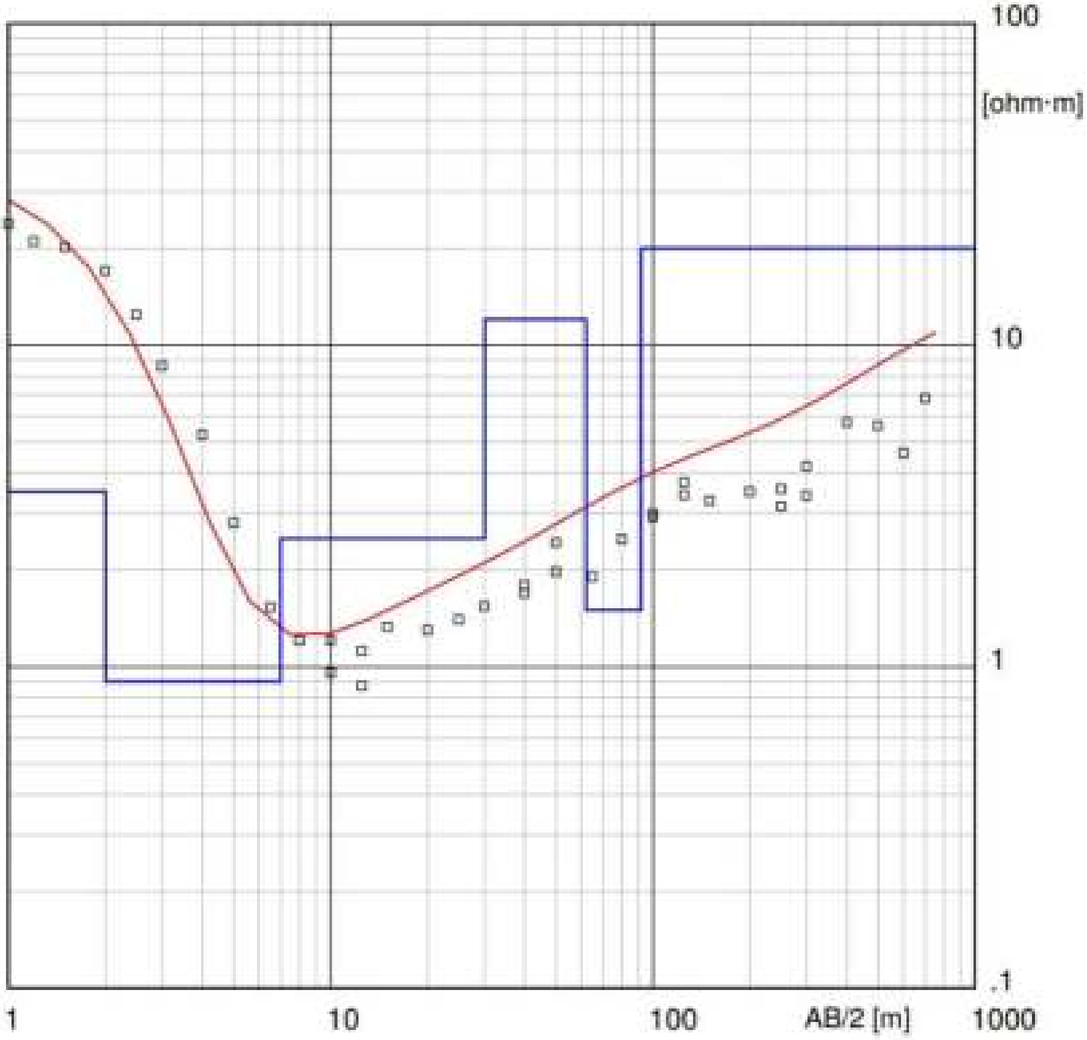
Appendix: 5.4

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-200-5



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	34	0.9	0.9
2	3.5	1.1	2
3	0.9	5	7
4	2.5	23	30
5	12	32	62
6	1.5	30	92
7	20	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2, 3, 4	SANDY CLAY, SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Processing and interpretation: mr. sc. Božo Padovan dipl.ing.fiz.

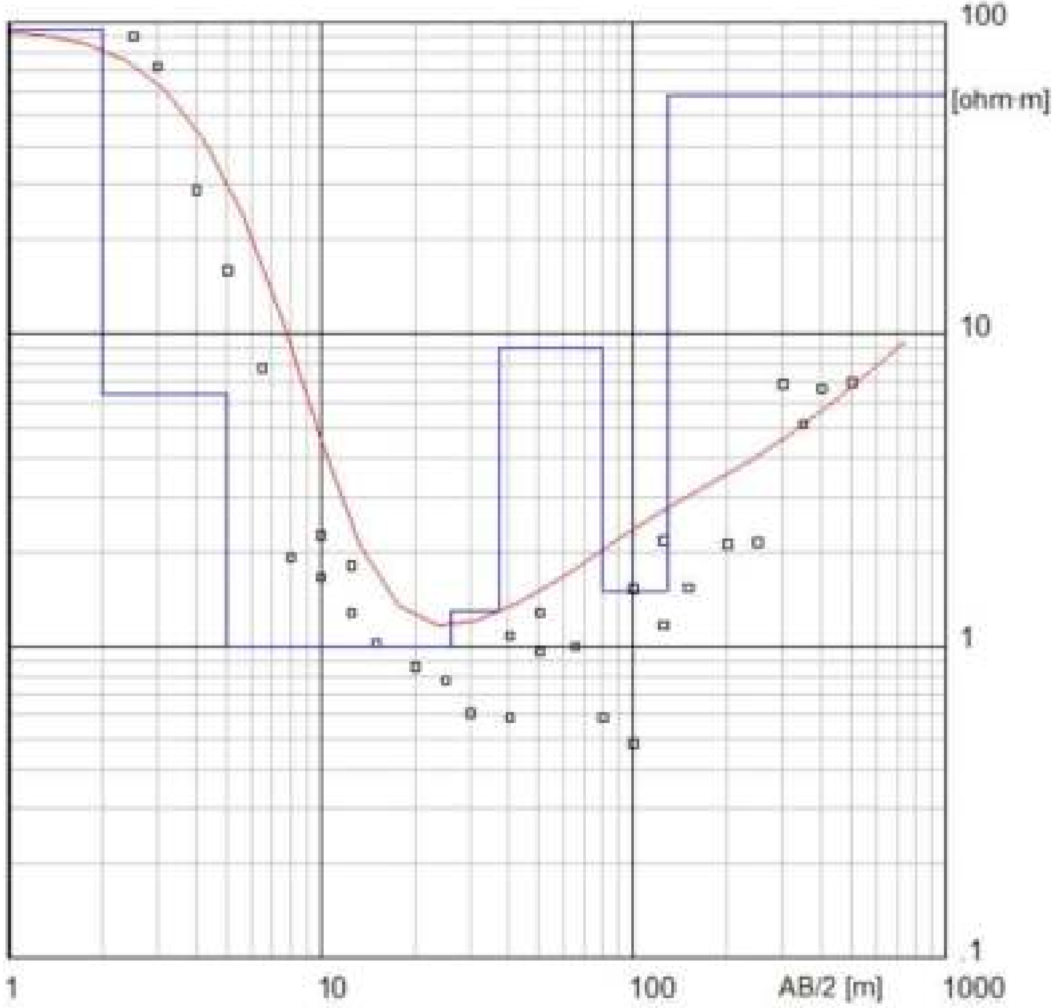
Appendix: 5.5

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-200-6



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	95	2	2
2	6.4	10	11
3	1	14	26
4	1.3	11	37
5	9	47	84
6	1.5	59	143
7	58	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

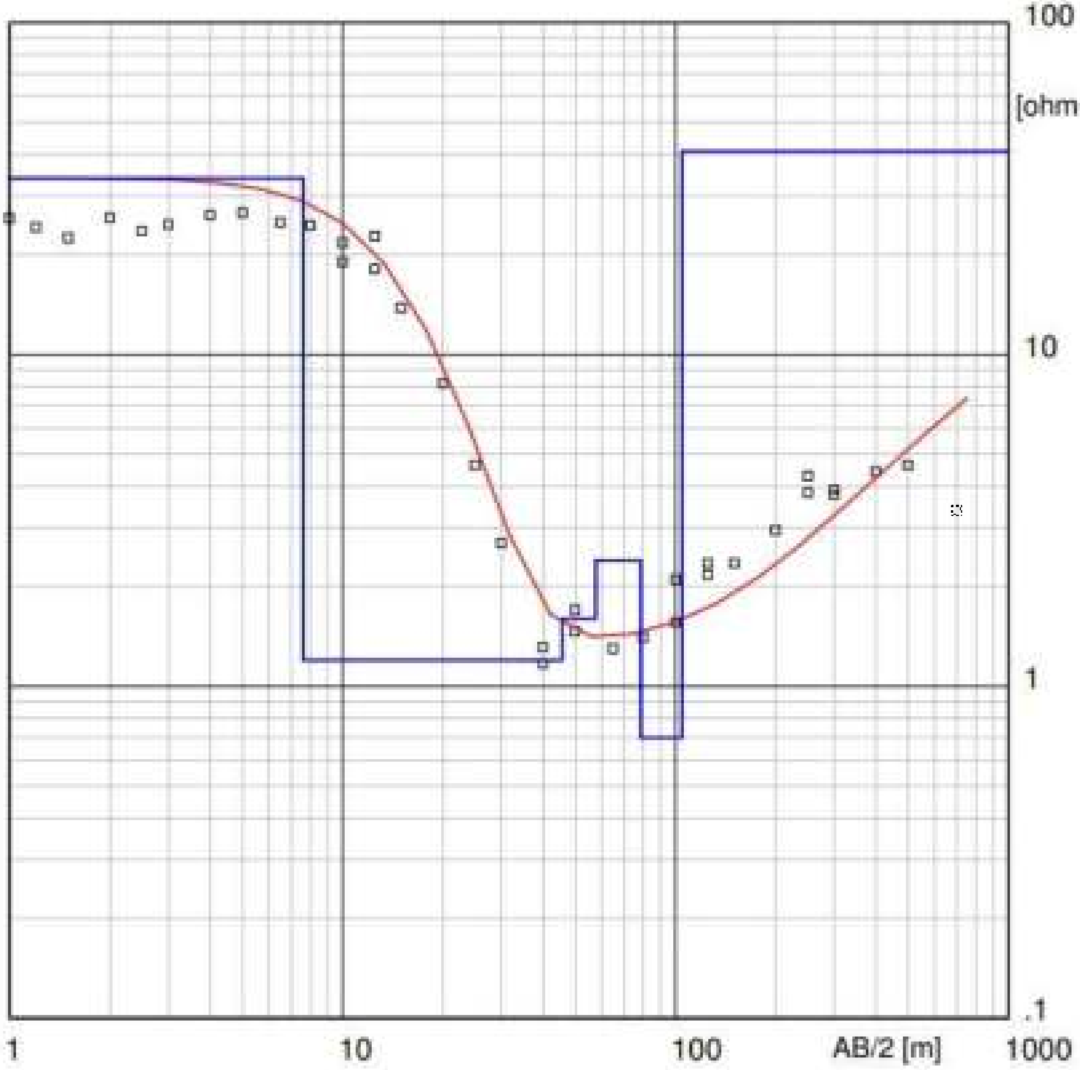
Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Appendix: 5.6

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-7



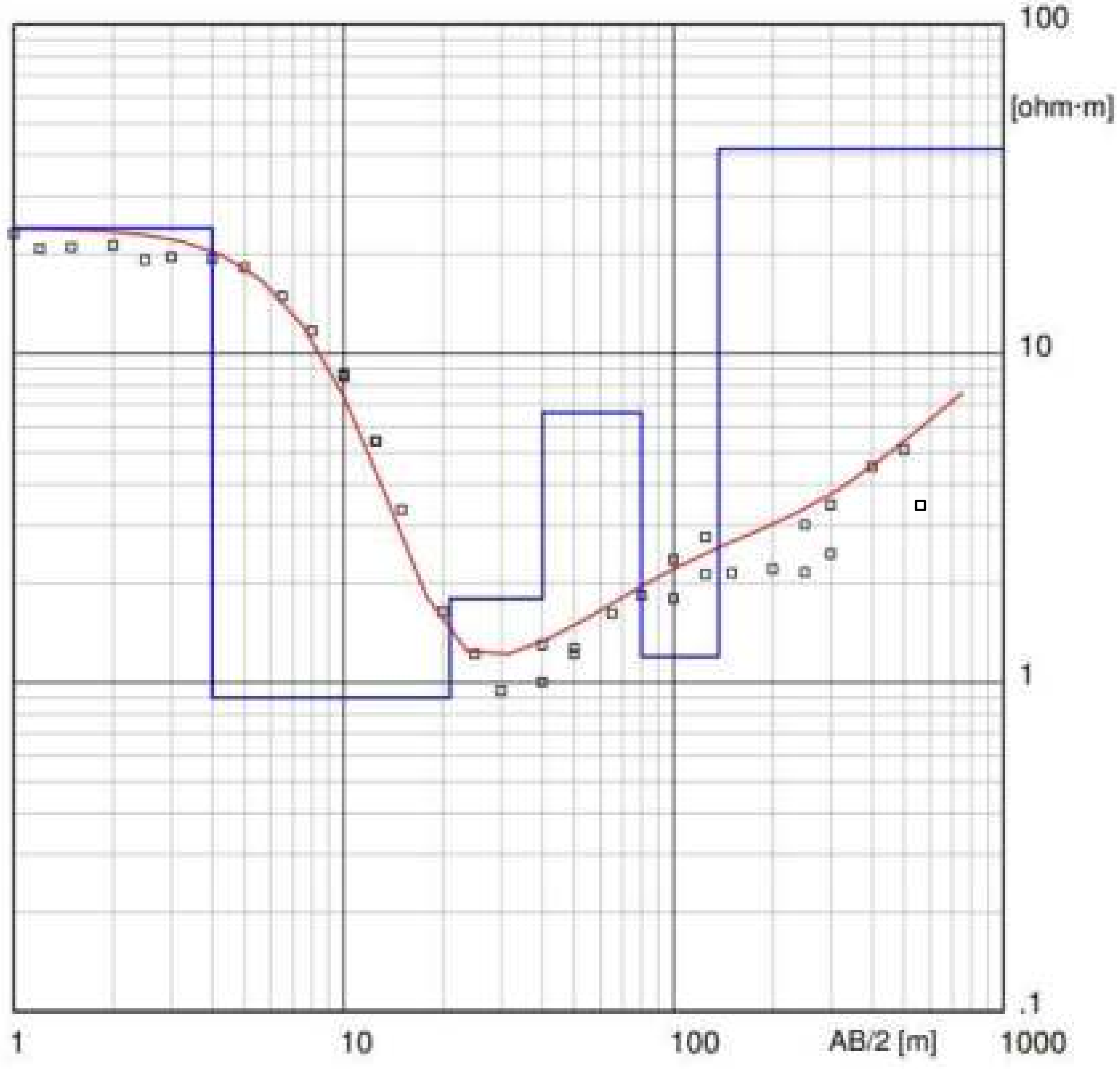
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	34	7.6	7.6
2	1.2	38	46
3	1.6	12	58
4	2.4	21	79
5	0.7	26	105
6	41	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2, 3	CLAY SATURATED WITH SALT WATER
4	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
5	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-8



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	24	4	4
2	0.9	17	21
3	1.8	19	40
4	6.6	40	80
5	1.2	57	137
6	42	–	–

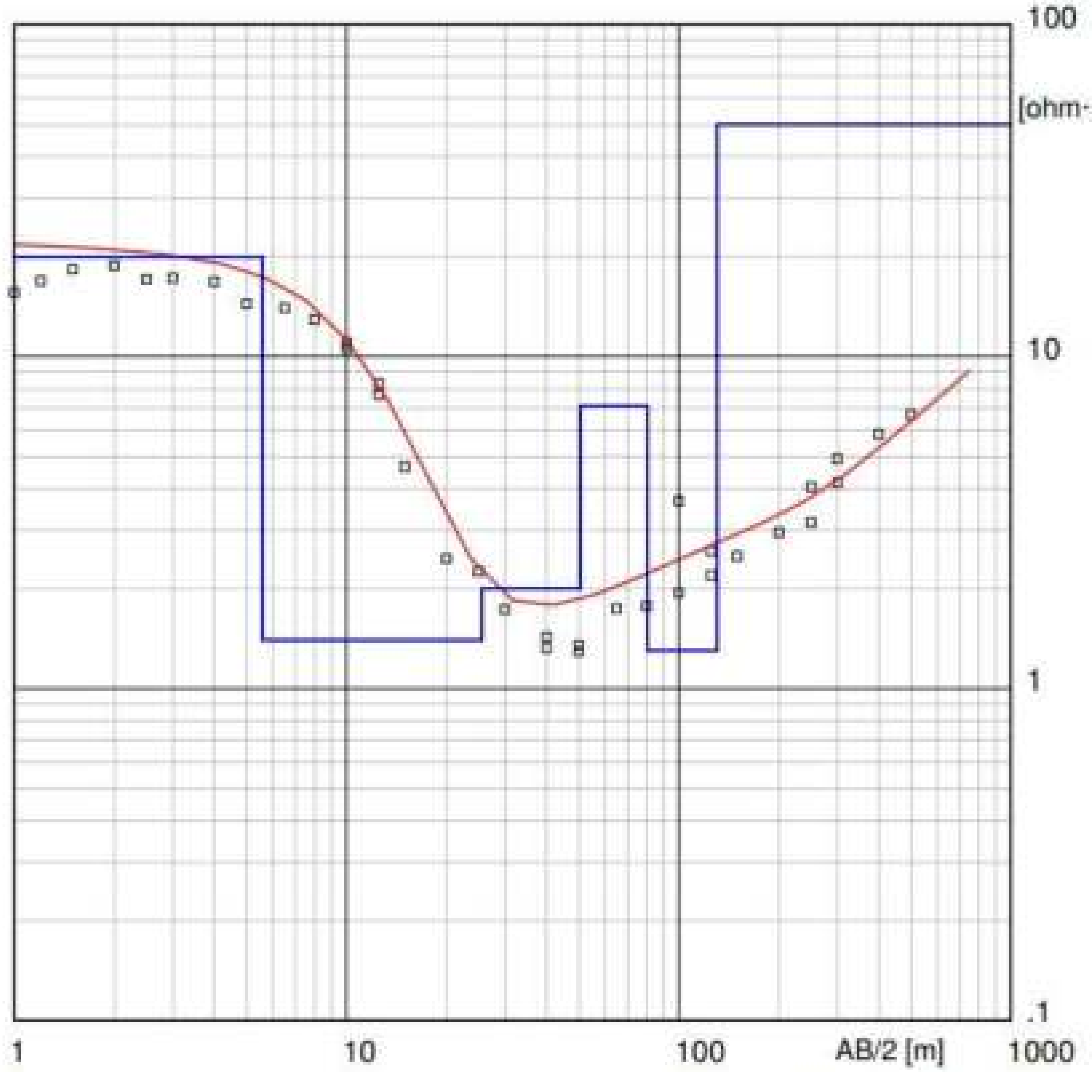
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2, 3	CLAY SATURATED WITH SALT WATER
4	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
5	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-200-9



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	22	0.9	0.9
2	20	4.7	5.6
3	1.4	20	26
4	2	25	51
5	7.1	30	81
6	1.3	50	131
7	50	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1, 2	SAND, CLAY (DRY ZONE)
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

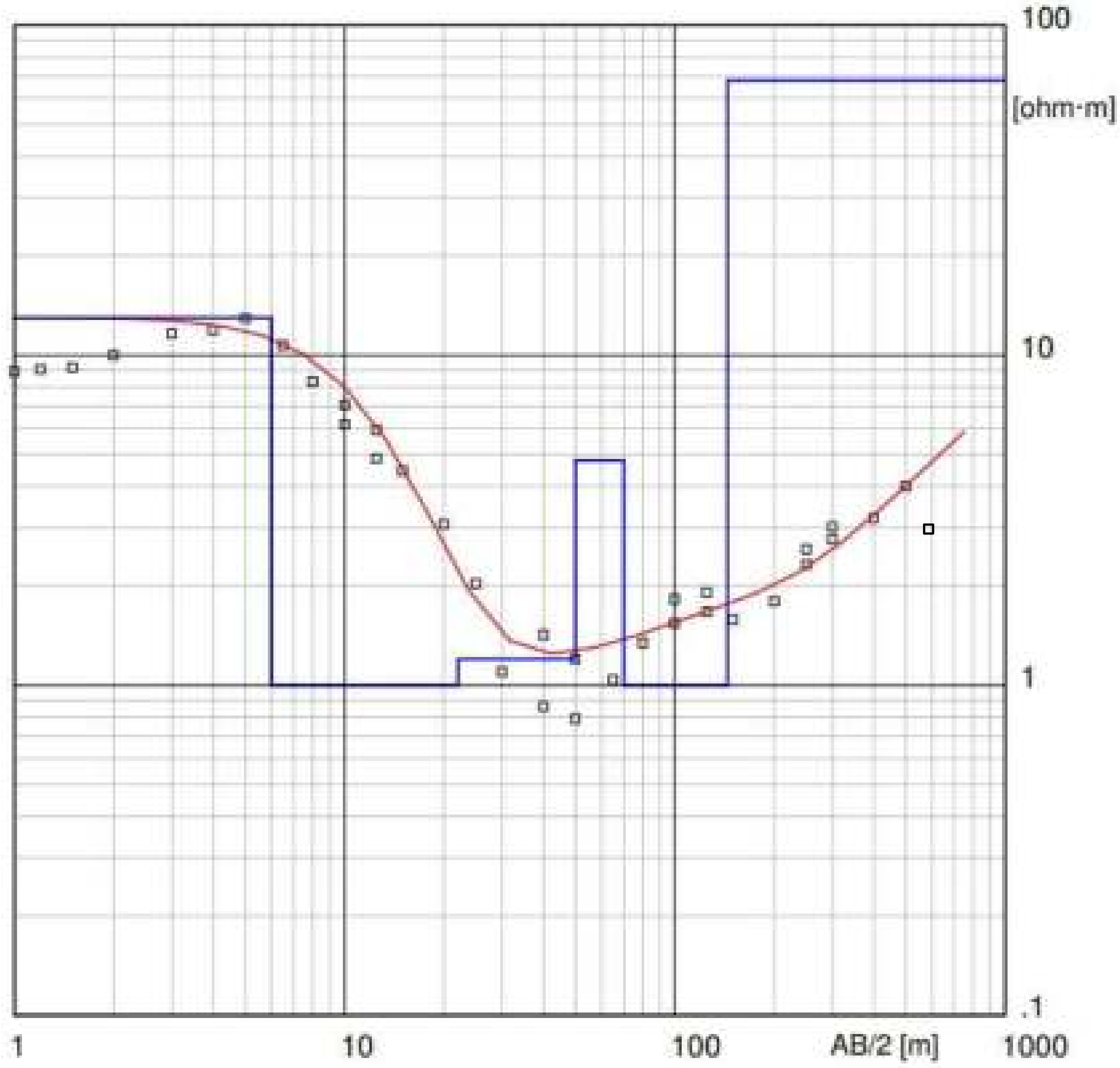
Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Appendix: 5.9

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-10



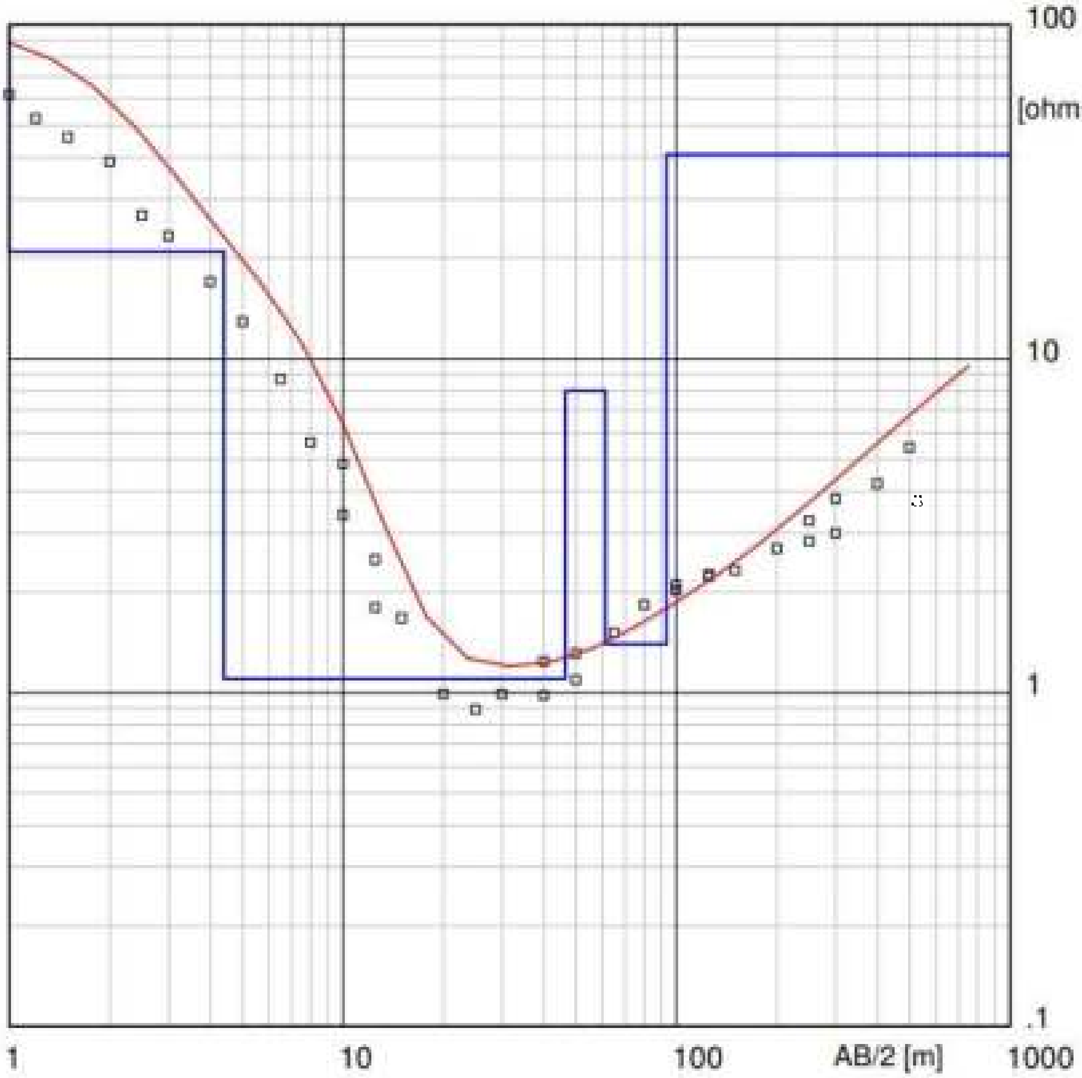
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	13	6	6
2	1	16	22
3	1.2	28	50
4	4.8	20	70
5	1	74	144
6	68	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2, 3	CLAY SATURATED WITH SALT WATER
4	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
5	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-11



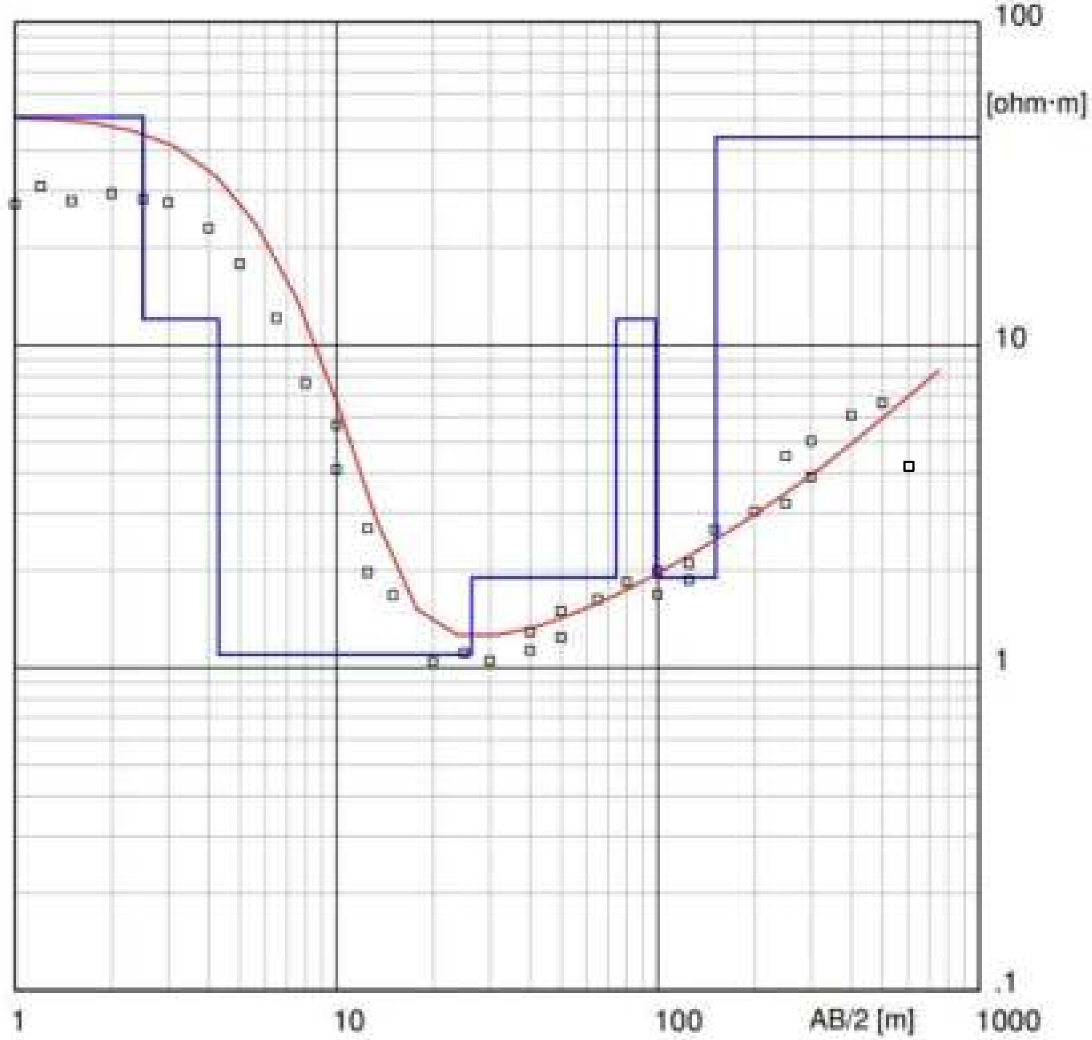
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	99	1	1
2	21	3.4	4.4
3	1.1	42	46
4	8	15	61
5	1.4	32	93
6	41	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1, 2	SAND, CLAY (DRY ZONE)
3	CLAY SATURATED WITH SALT WATER
4	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
5	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-12



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	51	2.5	2.5
2	12	1.8	4.3
3	1.1	22	26
4	1.9	48	74
5	12	24	98
6	1.9	53	151
7	44	–	–

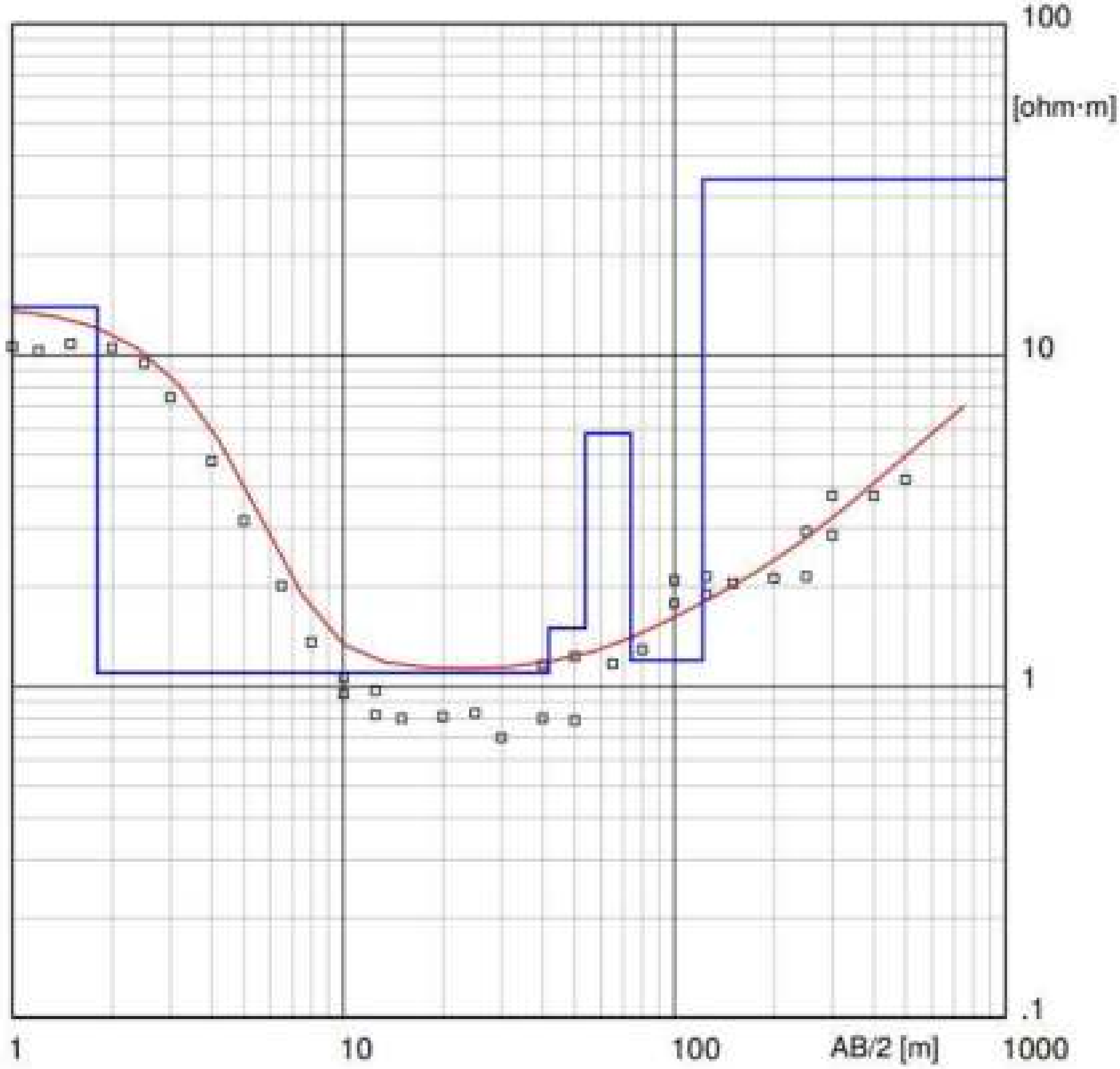
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-200-13



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	14	1.8	1.8
2	1.1	40	42
3	1.5	12	54
4	5.8	20	74
5	1.2	48	122
6	34	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2, 3	CLAY SATURATED WITH SALT WATER
4	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
5	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

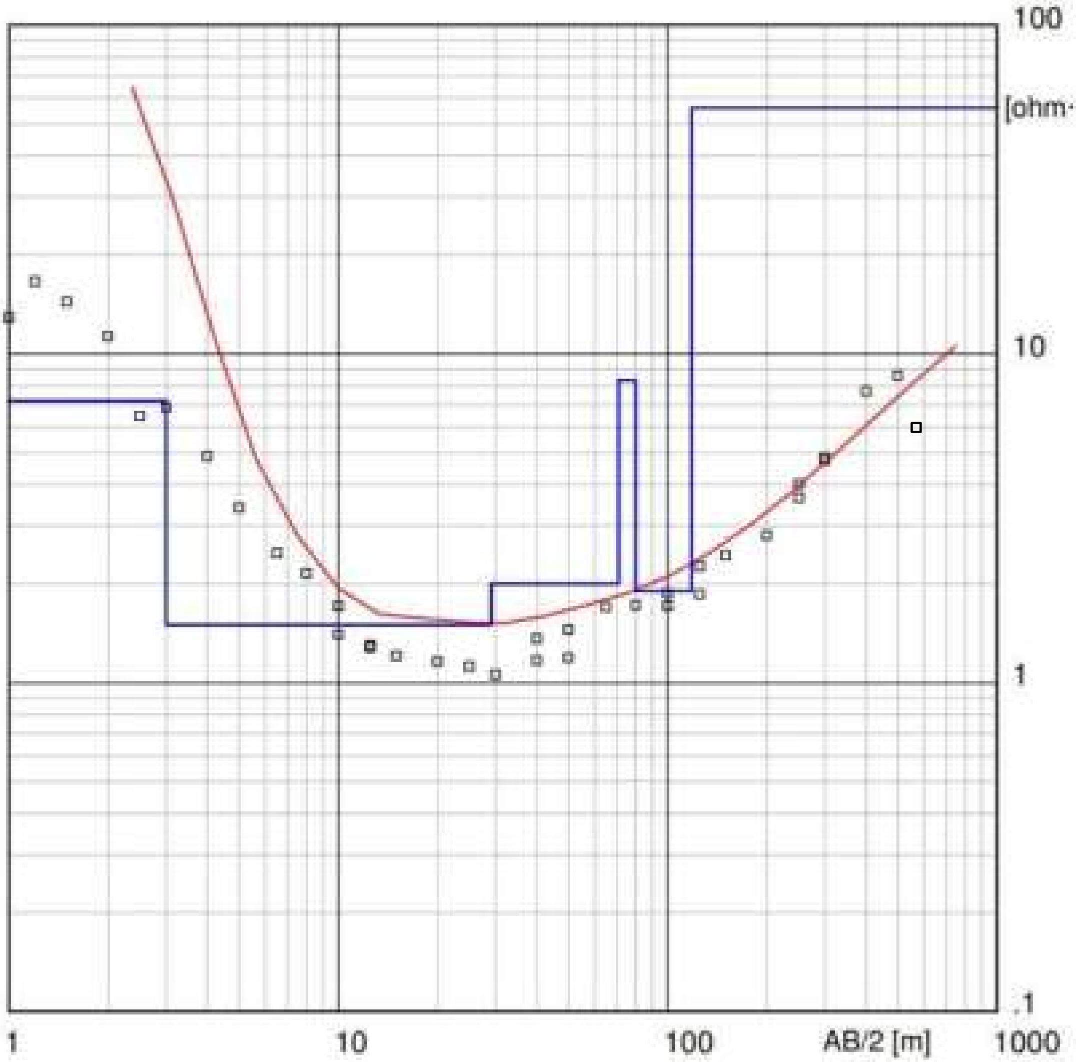
Appendix: 5.13

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-200-14



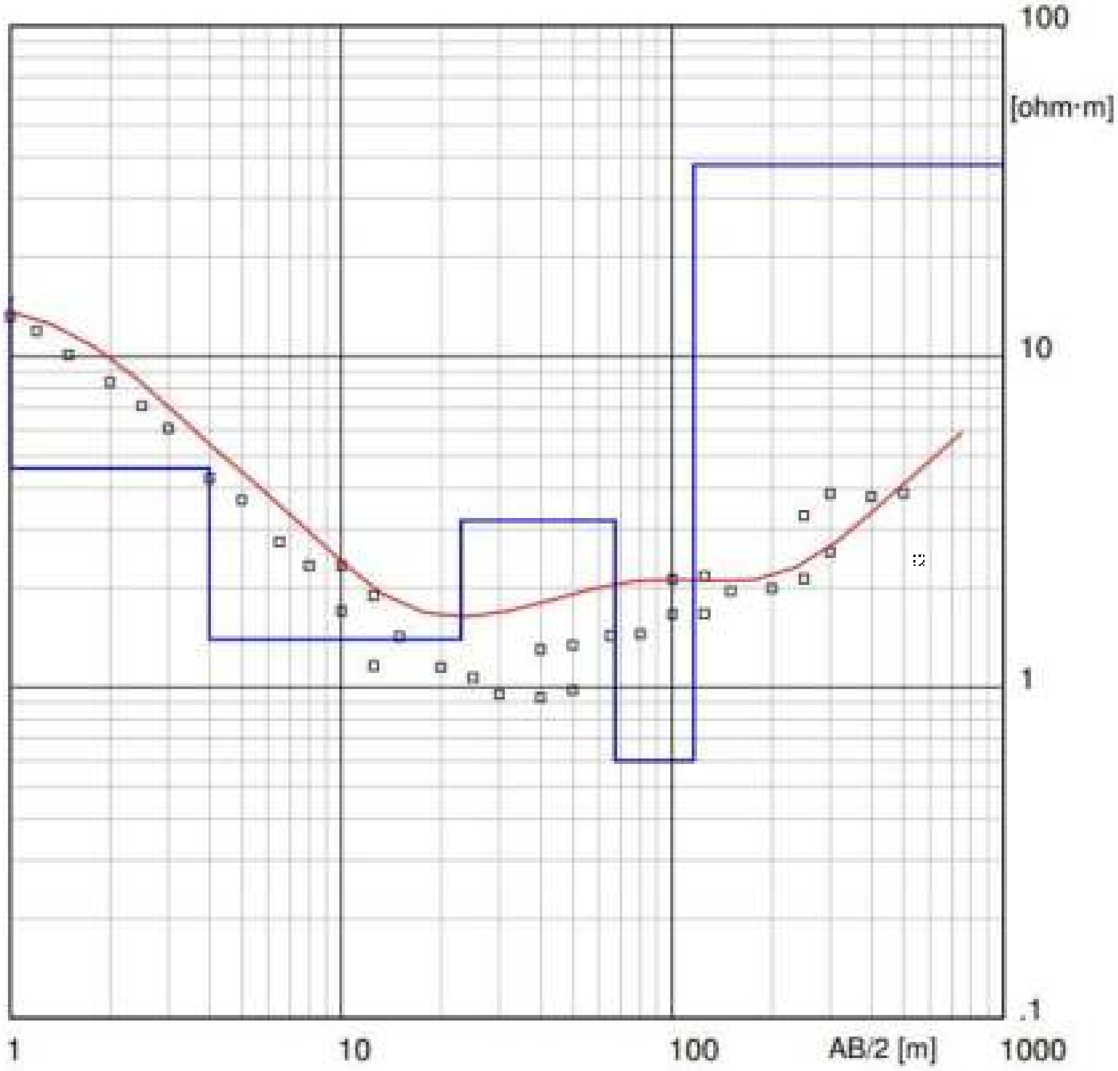
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	244	0.9	0.9
2	7.2	2.1	3
3	1.5	26	29
4	2	42	71
5	8.3	9	80
6	1.9	38	118
7	56	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-15



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	15	1	1
2	4.6	3	4
3	1.4	19	23
4	3.2	44	67
5	0.6	49	116
6	38	–	–

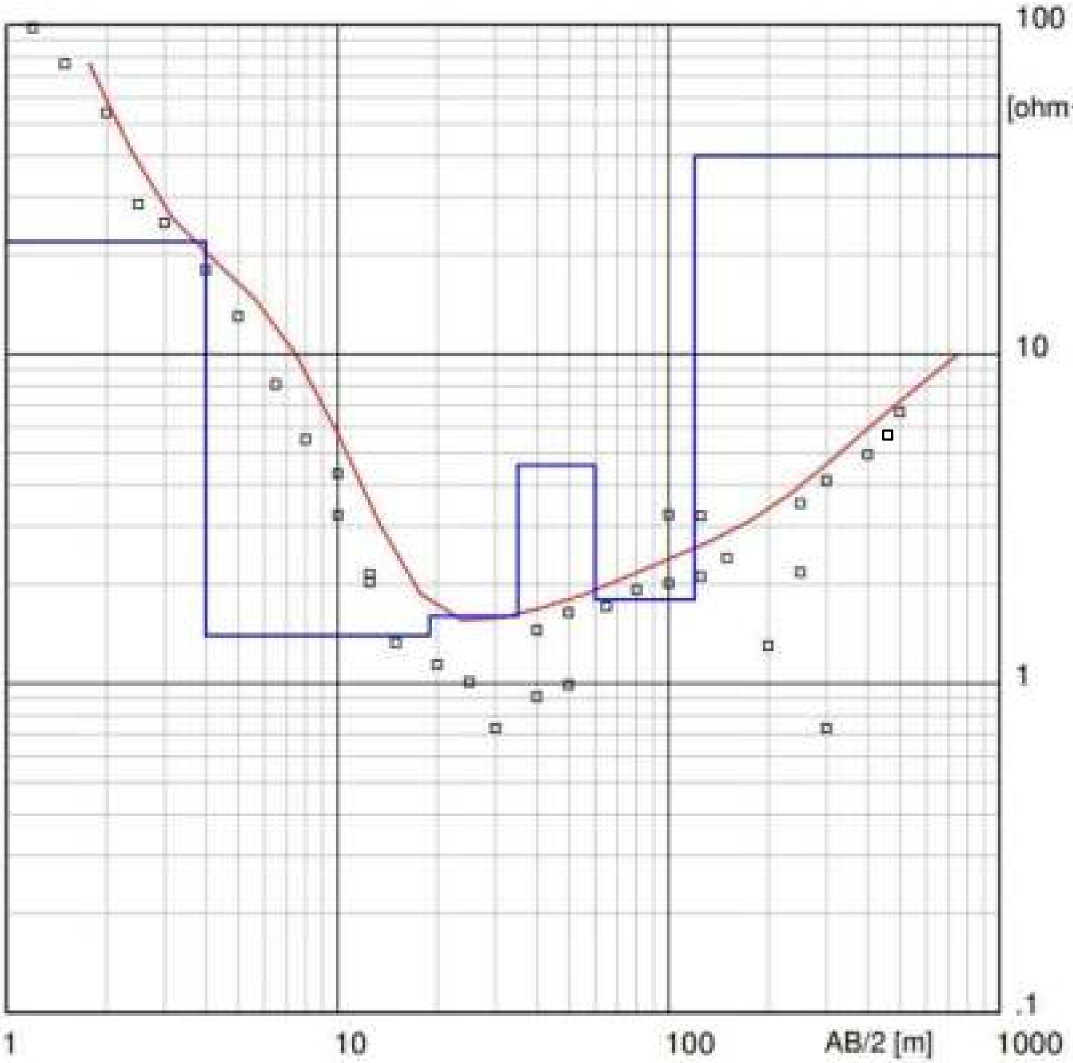
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3	CLAY SATURATED WITH SALT WATER
4	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
5	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-200-16



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	305	0.6	0.6
2	22	3.4	4
3	1.4	15	19
4	1.6	16	35
5	4.6	25	60
6	1.8	60	120
7	40	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1, 2	SAND, CLAY (DRY ZONE)
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

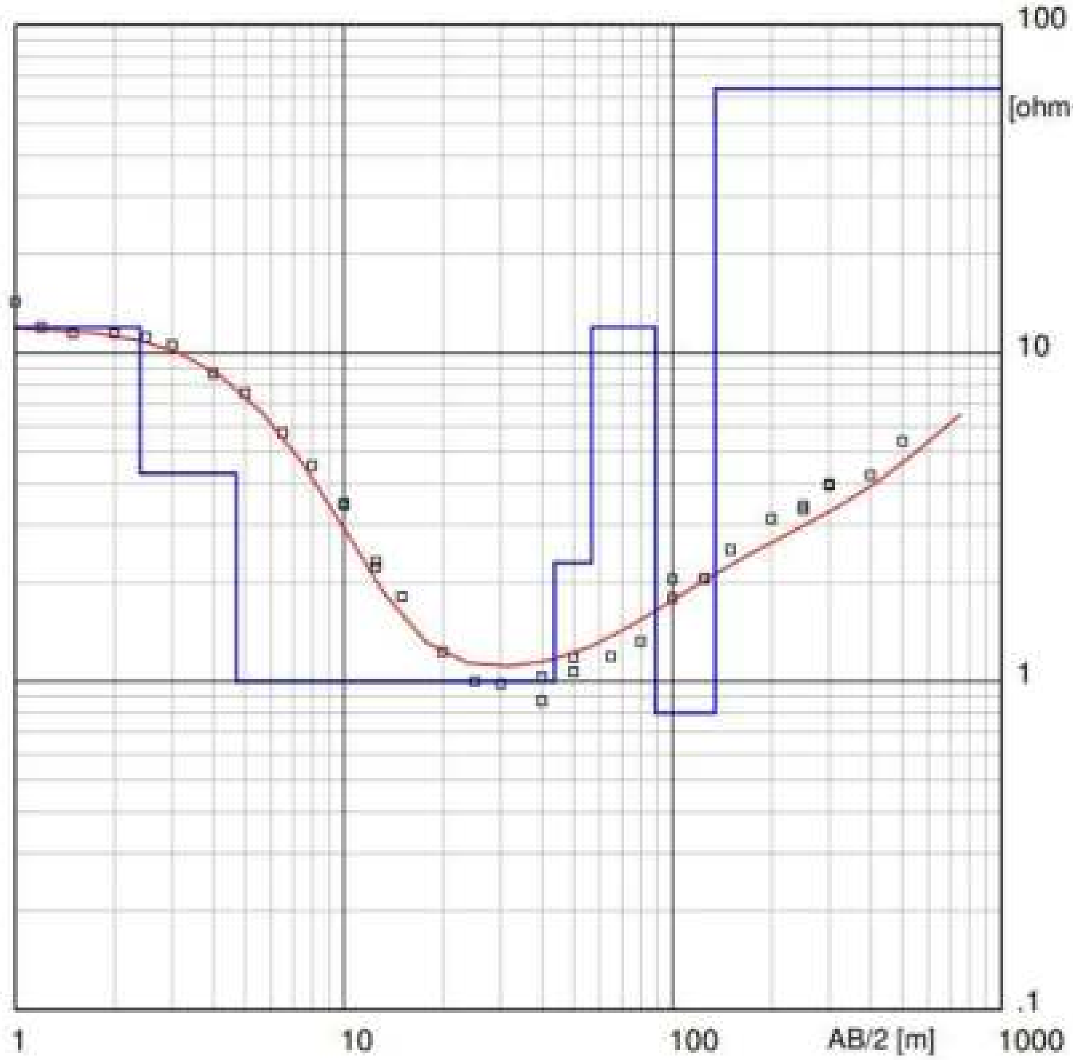
Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

TERRA COMPACTA

GEOELECTRICAL PROBE GS-200-17



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	12	2.4	2.4
2	4.3	2.3	4.7
3	1	39	44
4	2.3	13	57
5	12	32	89
6	0.8	46	135
7	64	–	–

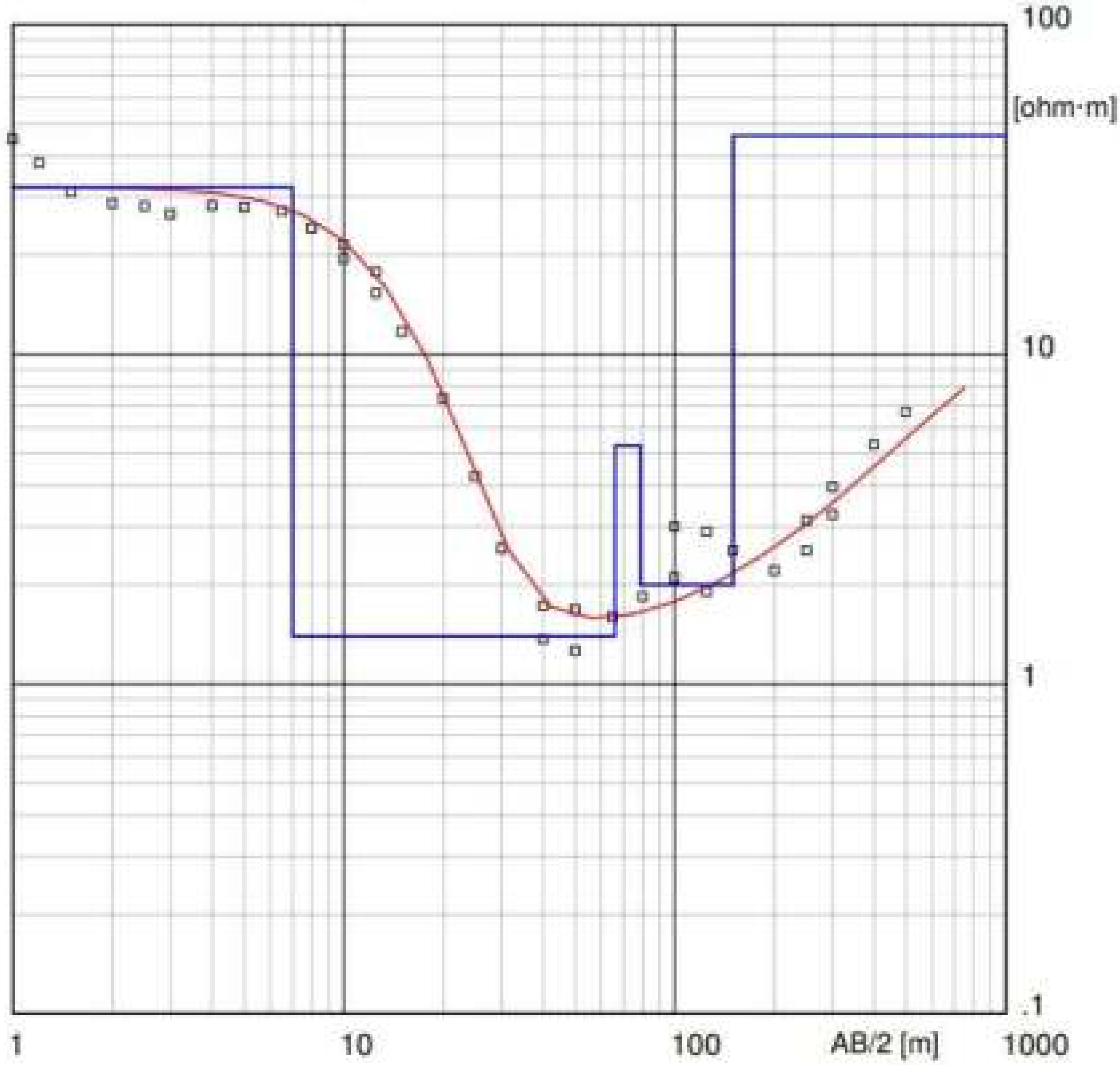
INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-18



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	32	7	7
2	1.4	59	66
3	5.3	13	79
4	2	71	150
5	46	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	CLAY SATURATED WITH SALT WATER
3	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
4	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
5	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

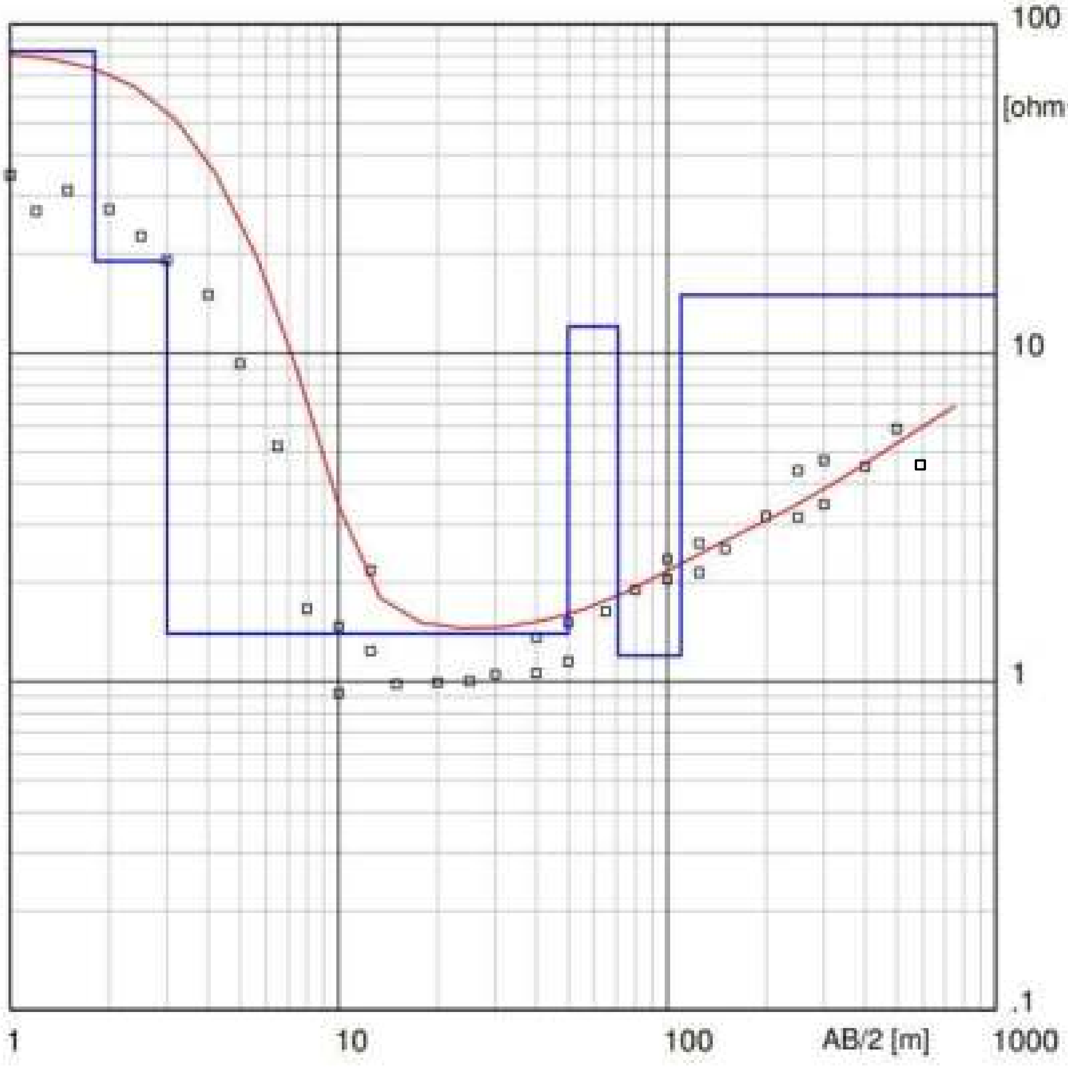
Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Appendix: 5.15

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-19



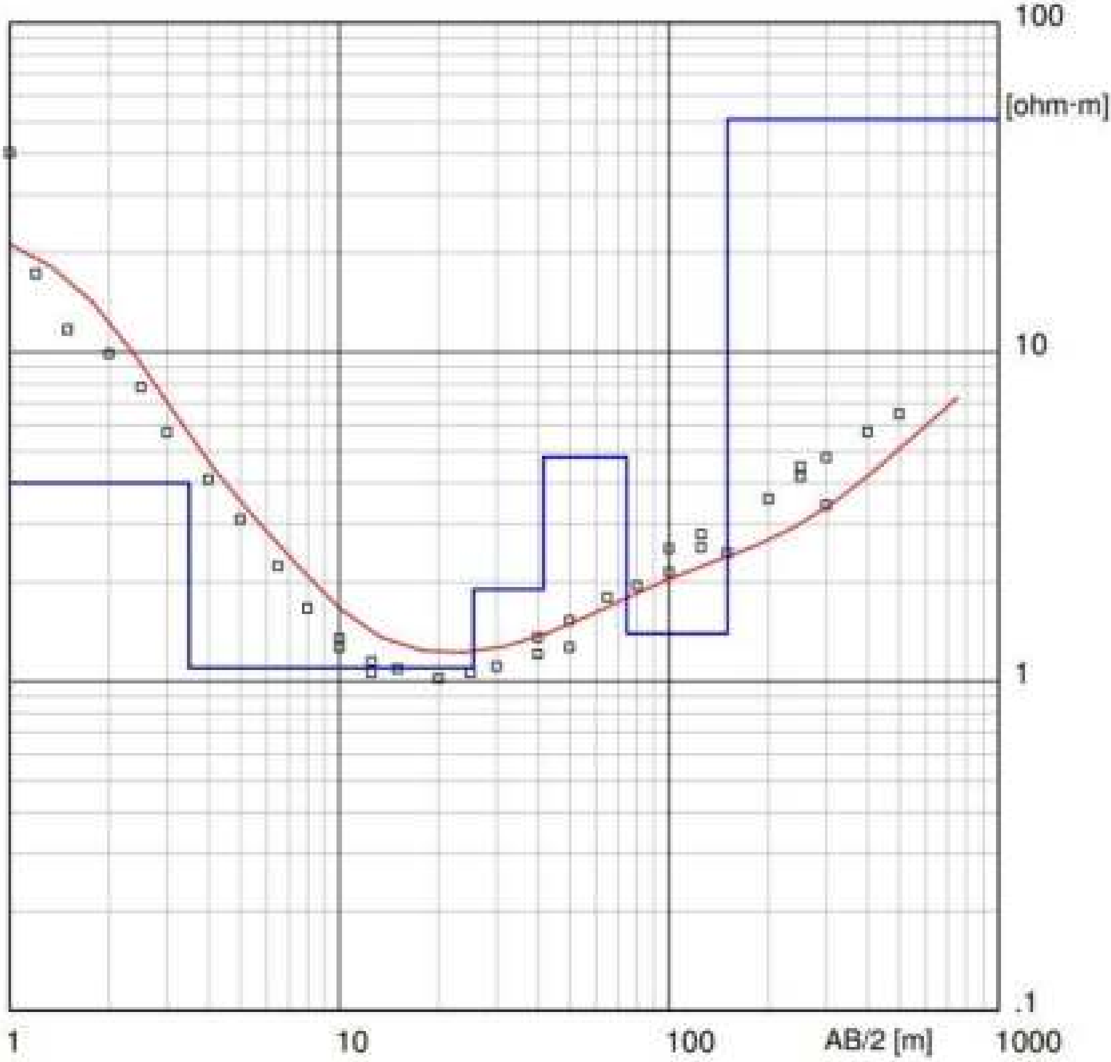
INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	83	1.8	1.8
2	19	1.2	3
3	1.4	47	50
4	12	21	71
5	1.2	39	110
6	15	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3	CLAY SATURATED WITH SALT WATER
4	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
5	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
6	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Location: Neretva Valley

GEOPHYSICAL INVESTIGATION
METHOD: GEOELECTRICAL SOUNDING
INTERPRETATION DEPTH: 200 m

GEOELECTRICAL PROBE GS-200-20



INTERVAL	RESISTANCE	THICKNESS	DEPTH
/	ohmm	m	m
1	25	0.9	0.9
2	4	2.6	3.5
3	1.1	22	26
4	1.9	16	42
5	4.8	33	75
6	1.4	76	151
7	51	–	–

INTERVAL	LITHOLOGICAL DETERMINATION
1	SAND, CLAY (DRY ZONE)
2	SANDY CLAY, SATURATED WITH SALT WATER
3, 4	CLAY SATURATED WITH SALT WATER
5	COARSE GRAVEL TO POORLY BONDED CONGLOMERATE SATURATED WITH SALT WATER
6	SMALL GRAIN GRAVEL TO SAND SATURATED WITH SALT WATER
7	LIMESTONE BEDROCK, DIFFERENTLY FRACTURED

Processing and interpretation: mr. sc. Božo Padovan, dipl.ing.fiz.

Appendix: 5.20