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_3.1.2) Report on the geomorphological setting 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

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Contents

General overview

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 -2.5 to 5 m above m.s.l. (Figure 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 1230 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 (Faculty of Civil Engineering Split, 1996; “Nasa Neretva,” n.d.). 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 1). In this report, initial agricultural conditions of the regions Luke, Opuzen ušće and Vidrice are explained.

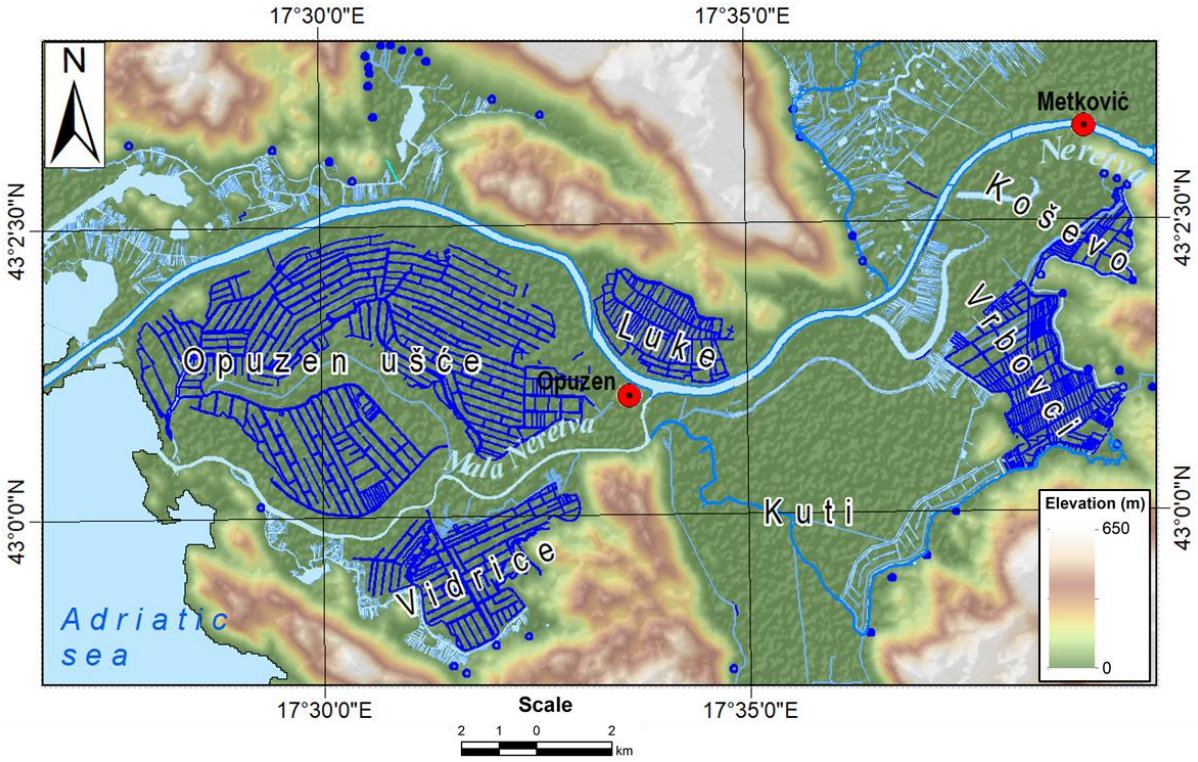

Figure 1 Geographical extent of the River Neretva Delta

Historical overview

The Neretva Valley is located in the southeast of the Republic Croatia on the coast of the Adriatic Sea (Figure 2). The Neretva Valley is surrounded by karst hills to the north, east and south, and by the sea to the west. The overall shoreline length between the rivers Neretva and Mala Neretva equals to 2200 m. The entire area is relatively flat with heights range from -2.00 up to 2.50 m a.s.l. and it lies on average below the mean sea level. In its present form, it covers about 5000 ha of agricultural land, making it the largest cultivated area on the Croatian coast ("Geografija,"

n.d.). The Neretva Valley can be divided into two major areas: Vidrice and Opuzen ušće, each of them representing a melioration subsystem. The Opuzen ušće area is located between the Neretva and Mala Neretva rivers, while the Vidrice area is located between the Mala Neretva river and the karst hills to the west, east and south (Figure 2). The Opuzen ušće area can be further divided into three specific sub-areas: Diga, Jasenska and Crepina.

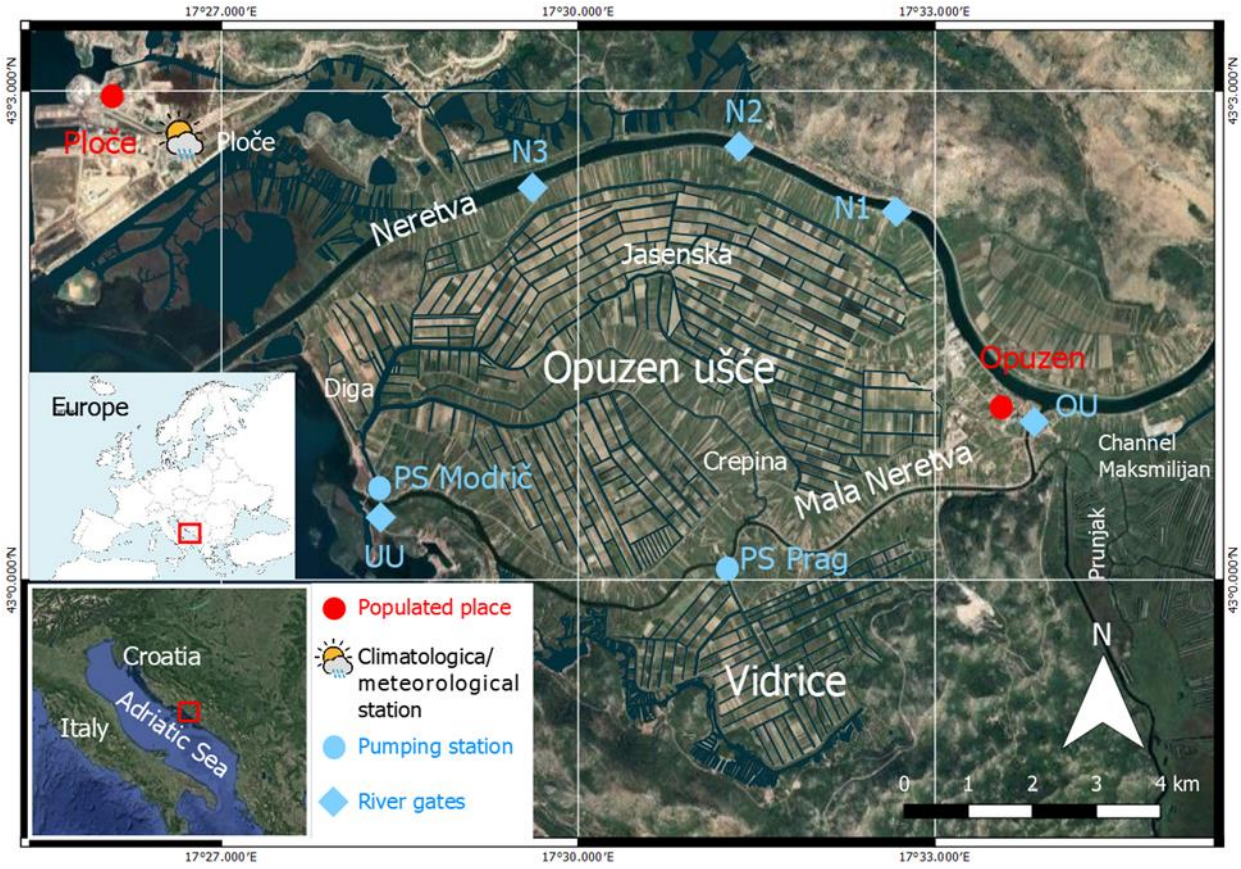

Figure 2 Location of the study area with definition of the operational infrastructure elements and climatological/meteorological station

Initial morphological conditions

The very first formal mapping of the area of interest has been made during the second military survey period 1851-1854 by Habsburg Empire (Figure 3). The insight to this source offers a fact about the presence of several lakes covering the area of interest. Due to the fact river Neretva delta is low laying area, the influence and the proximity of the Adriatic Sea lead towards significant influence of the seawater elevation in the definition of geomorphological settings of the area (Lovrinović et al., 2022, 2021). Largest lake was Modrič which was closest to the Adriatic Sea. More towards inland one founds lakes Mlaka, Dragača and Glog emphasizing the swamp conditions as found along the area. Apart from Opuzen ušće area, Vidrice area has been characterised by the lake Blato and river Matica.

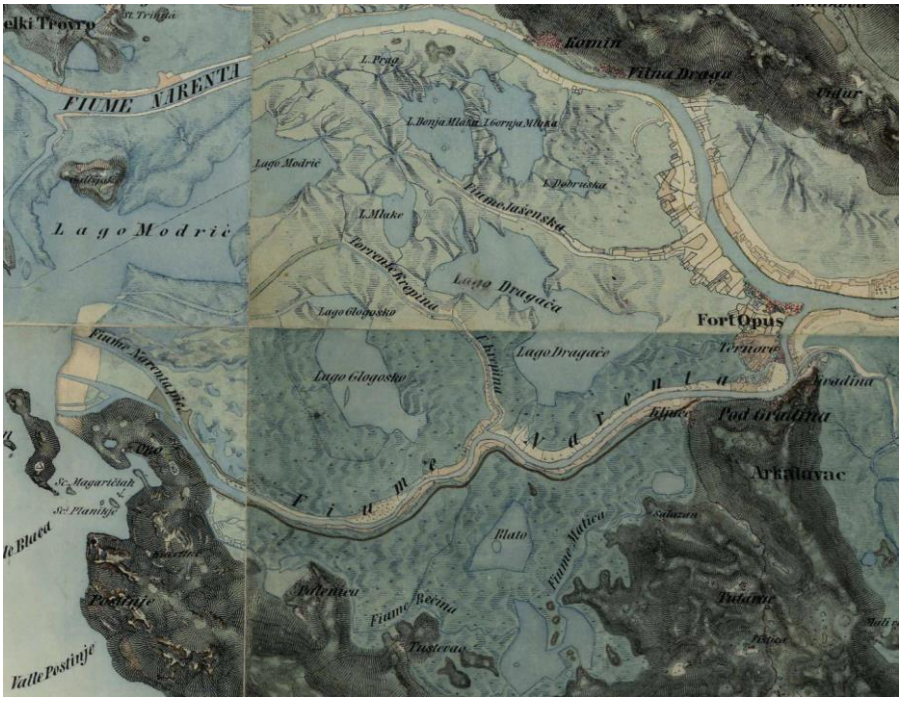

Figure 3 Dalmatia (1851–1854) - Second military survey of the Habsburg Empire – study area

20th century

First attempts to separate the valley from the Adriatic Sea and delineate water surface elevation has started during 1950's. First infrastructural point which lead towards significant change of local geomorphological conditions, was the construction of the Diga embankment between the mouth of river Neretva and mala Neretva. The general design has been planned as a 2 km earth fill embankment with twofold purpose: i) a solid border which will protect the area from the direct contact to the Adriatic Sea and ii) creation of controlled coastline which do not change significantly.

Figure 4 Vidrice area prior the melioration (mid of 20th century)

Figure 5 Diga construction (mid of 20th century) - view from the Mala Neretva

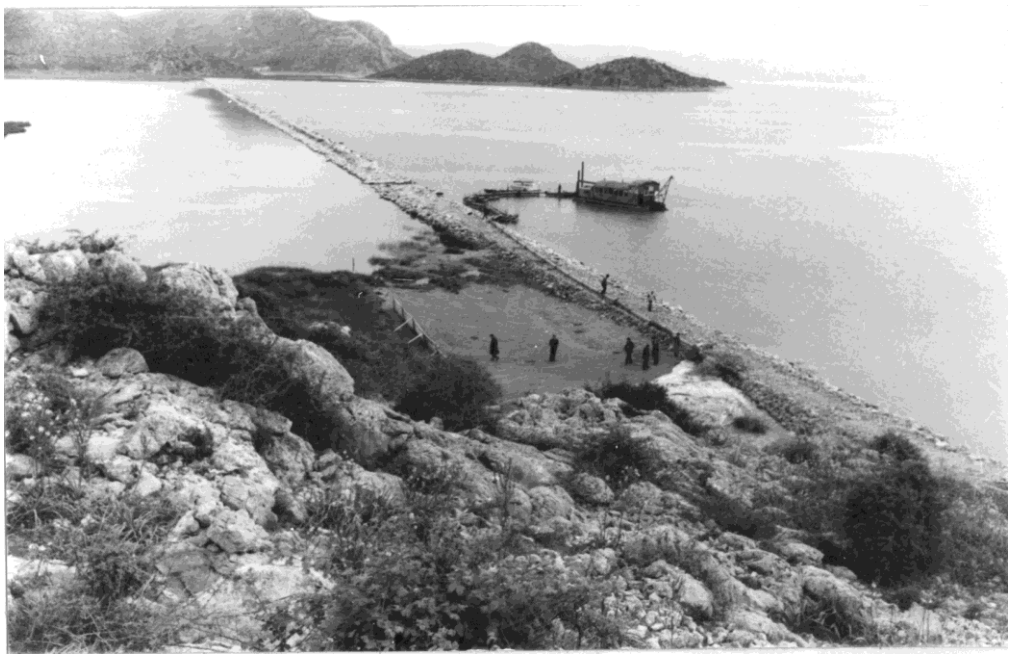

Figure 6 Diga construction (mid of 20th century) - view from the Galićak hill

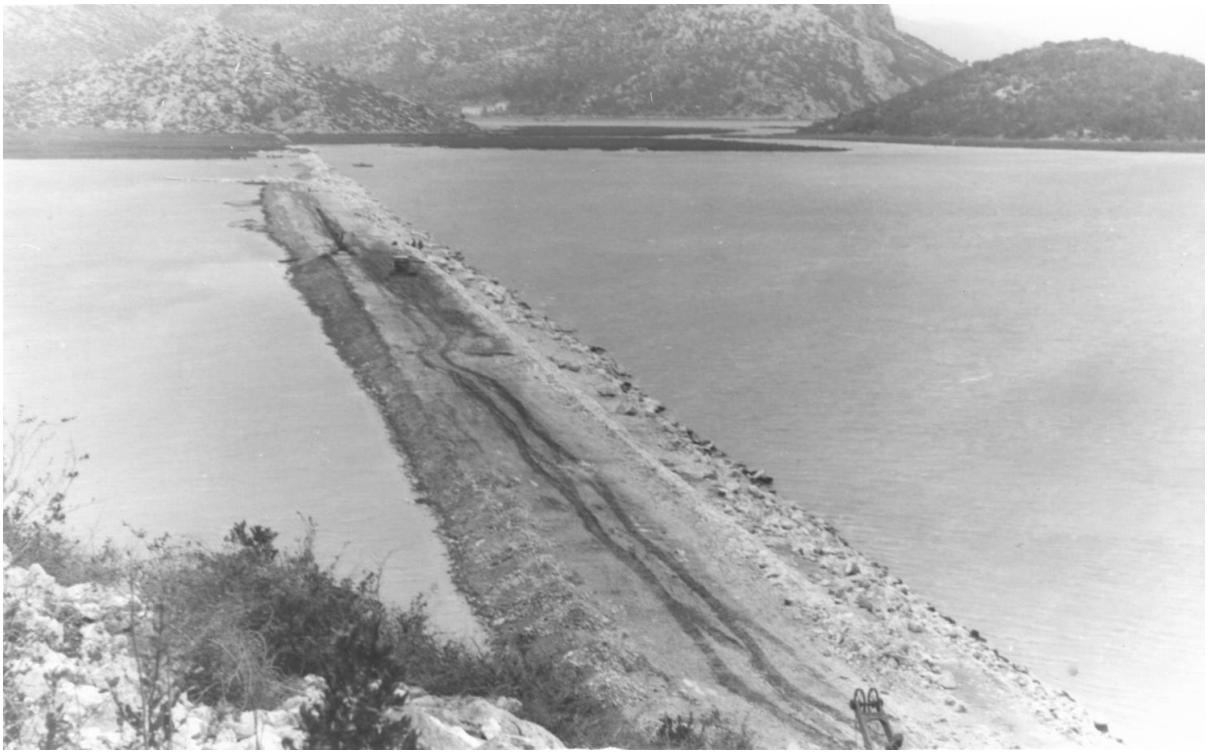

Figure 7 Diga construction sand refill (mid of 20th century) - view from the Galićak hill

Figure 4 - Figure 7 have been made on site during Diga construction and they offer only relevant information about the visual description of the Diga construction. This in line geotechnical object has been shown to be of great importance for the area since its presence and functionality up to date.

Operative regimes controlling local morphological conditions

As can be seen in Figure 1 Opuzen ušće is surrounded by the rivers Neretva and Mala Neretva, while the area of Vidrice is located between the Mala Neretva river and the karst hills to the south, east and west. The area of Vidrice represents a separate melioration subsystem in the Neretva Valley. The Vidrice area is fed with water from the coast upstream from Opuzen town.

The groundwater level in the Vidrice area is regulated by melioration channels driven by the operative regime of the pumping station Prag (PS Prag). The capacity of PS Prag is 6.5 $m^3 s^{-1}$ with general aim to pump water from the Vidrice area into the Mala Neretva river. Mala Neretva is a branch of the Neretva river separated from the Neretva river by river gates marked OU (Figure 8) and from the sea by river gates marked UU (Figure 1).

Figure 8 The OU river gates (Google Street View)

Originally, the Mala Neretva river was intended to receive excess discharge from the Neretva river for flood control. Due to anthropogenic interventions in the floodplain around the Mala Neretva, this system, originally intended for flood protection, no longer fulfils its original purpose. Therefore, the capacity of Mala Neretva to absorb excess water from the Neretva river is reduced only to the capacity of the riverbed without floodplain. Nowadays, the river is used as the main source of fresh water in the dry season, with water from the Mala Neretva being dispersed to the Neretva Valley for irrigation. The two gates on the Mala Neretva River (OU and UU) are

intended to prevent seawater from entering the Mala Neretva River from the Adriatic Sea and from the Neretva river. The OU gate consists of three separate gate segments with the same dimensions (12 x 4.5 m) and a ship lock. All segments are controlled and opened individually when necessary. The UU gates are similar to the OU gates with the addition of one more opening. The UU gates have openings with dimensions of 12 x 3.5 m and a ship lock identical to that of the OU gates. The operative regime of the UU and OU river gates is based on human experience and outdated standards from 1987. Both river gates are mainly closed during the year. The UU gates are opened when the water level near the UU gates is higher than sea level to remove excess water from the Mala Neretva and to ensure that no salt wedge reaches upstream. The OU gates are rarely opened, usually when the water level in the Mala Neretva is higher than in the Neretva, which happens during the receding part of the Neretva hydrograph after peak occurs. In this way, seawater from the Neretva riverbed is prevented from entering the Mala Neretva, which enables the water in the Mala Neretva system to be refreshed. Besides intermittent refreshment by the Neretva river, Mala Neretva is constantly fed with fresh water from the Maksimilian channel. The channel Maksimilian with its capacity of 7 $m^3 s^{-1}$ ensures that the Mala Neretva system is supplied with an adequate amount of freshwater during the dry period of the year. Freshwater from the Mala Neretva is further distributed through the Crepina channel and melioration/irrigation channels in the Opuzen ušće area.

The Opuzen ušće area is also refreshed in the dry season by the river gates marked N1-N3 on the left side of the Neretva river. They are usually open from April 1st to October 31st, unless the supervisory authority of the area decides otherwise due to meteorological and climatological conditions. The river gates (N1-N3) are designed to allow the entry of fresh water from the surface of the Neretva above the salt wedge. All gates are 3 m wide and 2.5 m high. Besides the N1-N3 gates, there are about twenty other smaller gates on the left bank of the Neretva. They

all have the same purpose as the N gates and the opening of these gates is coordinated with the same regulations as N1-N3, OU and UU gates (Skupština Općine Metković, 1987). The height of these smaller gates ranges from 0.8 m to 1.8 m and are all 1.2 m wide, but the depth of these gates is 0.3 m and is below the average water surface elevation of the Neretva River during the dry season.

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