REPORT ON WATER AND SEDIMENT FLUXES IN THE PILOT AREAS

Activity 3.3

Task 3.3.1

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Activity:	3.3. Characterization of water and sediment fluxes from the mainland
Phase Leader:	Croatia
Deliverable:	3.3.1 Report on water and sediment fluxes in the Pilot Sites. This report will summarize all the information collected by the Activity, providing a basis for sediment budget and water quality assessment

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1. INTRODUCTION

This document has been produced within the framework of the INTERREG Italy – Croatia Project entitled: Climate cHallenges on coAstal and traNsitional chanGing arEas: WEaving a Cross-Adriatic Response (CHANGE WE CARE Project). The project examines climate risks faced by coastal and transition areas contributing to a better understanding of the impact of climate variability and change on water regimes, salt intrusion, tourism, biodiversity and agro-ecosystems affecting the cooperation area. The main goal of the project is to deliver integrated, ecosystem-based and shared planning options for different problems related to climate change (CC), together with adaptation measures for vulnerable areas to decision makers and coastal communities who may best benefit from it. Relevant information and updates of the Project can be found at: https://www.italy-croatia.eu/web/changewecare.

1.1. WP 3 and Activity 3.3

This WP characterizes ongoing natural processes and their recent trends also in the light of their interactions with the anthropogenic forcings, with the aim to identify and quantify the key driving factors for the processes affecting the marine and coastal areas in the cooperation zone and the selected Pilot Sites. The aim of Activity 3.3 is to characterize sediment and water fluxes from the mainland used as basic information for the better understanding of hydrological and ecological dynamics and geomorphological evolution. The first step is a collection of available data and research results from the catchment areas of Pilot Sites, based on information from both, direct observations and indirect inferences. To this aim, hydro-meteorological data, hydrological variables, non-point pollution sources, soil characteristics, plant growth, pesticides, and land management practices are presented and analyzed. The next step is measurements of water quality data by Smart Water Sensors and suspended sediment load concentration using Acoustic Profilers.

1.1.1. Organization of the document

This document is organized as a report on water and sediment fluxes in the Pilot Sites. It summarizes all the available information collected by the Activity 3.3, providing a basis for sediment budget and water quality assessment. For all Pilot Sites, a quantitative analysis of previously available and newly acquired hydrological and climatic datasets (runoff, sediment, and/or nutrient loads) is reviewed and interpreted. After the Introduction (this chapter), a general characteristic of the water, sediment, and nutrients discharge in the Adriatic is given, followed by status and trend of coastal evolution (chapter 2). Chapter 3 provides available data on water and sediment flux and quality data for each Pilot Site. The first of the main six subsections for each Pilot Site includes a general description of a site catchment, including brief summaries of meteorological and hydrological data, together with sediment and nutrient fluxes. The next three subsections present water quality data referring to non-point pollution sources such as excess of fertilizers, herbicides and pesticide usage, grease, oil, chemicals and salt input, and sediment as the water pollutants, all related to land management practices. The fifth subsection presents newly acquired data (if any) and analysis of recent trends related to water and sediment fluxes. Estimates of relevant flow, sediment, nutrients, and pesticide movements within the catchment area from available datasets for each Pilot Site is discussed in the final subsection, emphasizing main problems and potential solutions. A special attention was planned to be dedicated to the identification and assessment of the ecological quality state for each Pilot Site water catchment, by using Reliability–Resilience–Vulnerability (RRV) indicators. However, baseline performance analyses for Pilot Sites are not set and the failure thresholds to perform the RRV analysis are not determined, both mostly due to the incomplete datasets.

1.1.2. New data collection methodology

Concerning the newly acquired data of the water quality in Nature park Vransko lake Pilot Site, the Libelium Smart water sensors have been installed on the Vransko lake on 3 locations (P2, P4, P6). The sensors are measuring water salinity, conductivity, total dissolved solids, oxygen levels, and temperature since June 2020 (on P4 and P6) and since August 2020 (P2) (Figures 1.1, 1.2, 1.3). The measurements of ions (NO^{3-}, Cl^-) were also set up, but the sensors are still being calibrated, therefore the measurement results are not available at the moment of delivery of this report. All the data is being sampled in the hourly frequency. The delivery and installation of the equipment and thus the data measurements have been delayed due to COVID19 special measures and lockdown. A detailed analysis of the data will be a part of future reports in WP4 and WP5. For Banco Mula di Muggia Pilot site the acquisition of an acoustic Doppler current profiler (ADCP) and it set up in the Isonzo mouth was planned in this WP the purchase process is ongoing, but the Covid-19 lockdown slowed down the work. Monitoring activities are expected withing the project Change We Care to acquire new in-situ data along the main branches of the Po River PIlot site, with the aim of reconstructing the morphological changes occurred in these recent years. However, these experimental campaigns are still in progress.

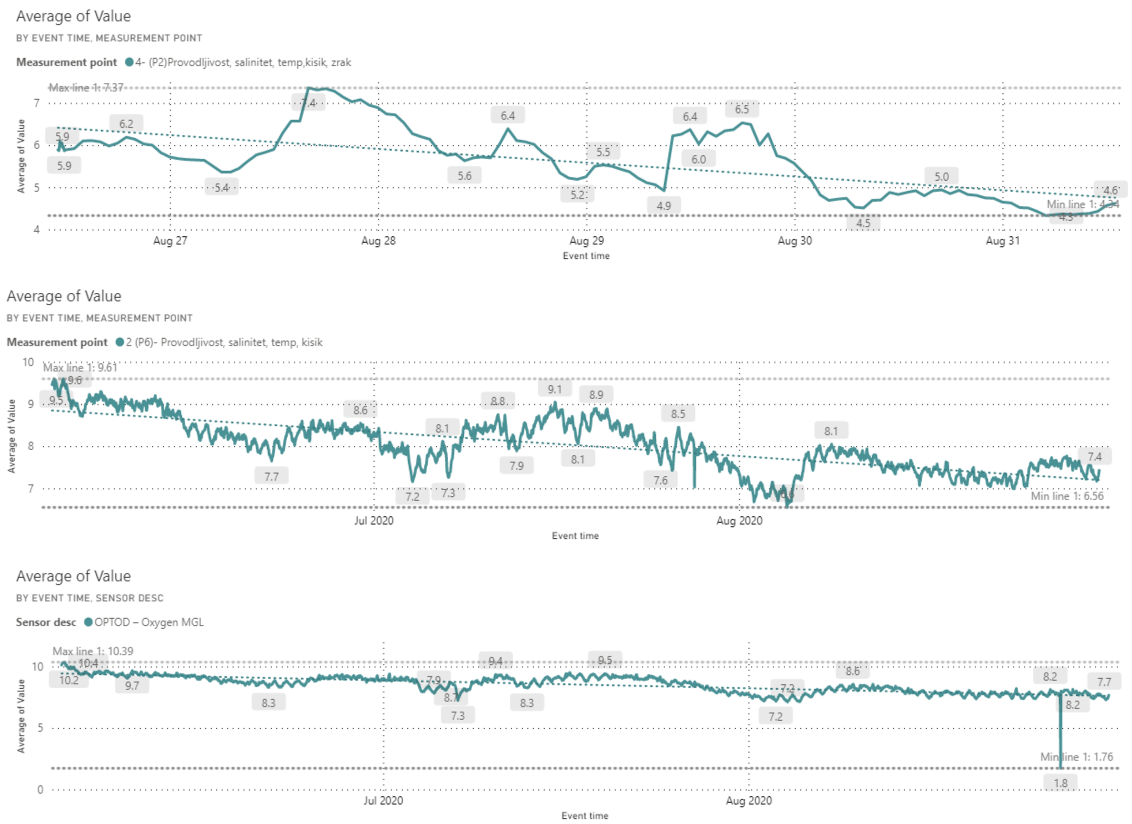

Figure 1.1. Oxygen levels measured on 3 measuring locations (P2, P4, P6) on the Vransko lake.

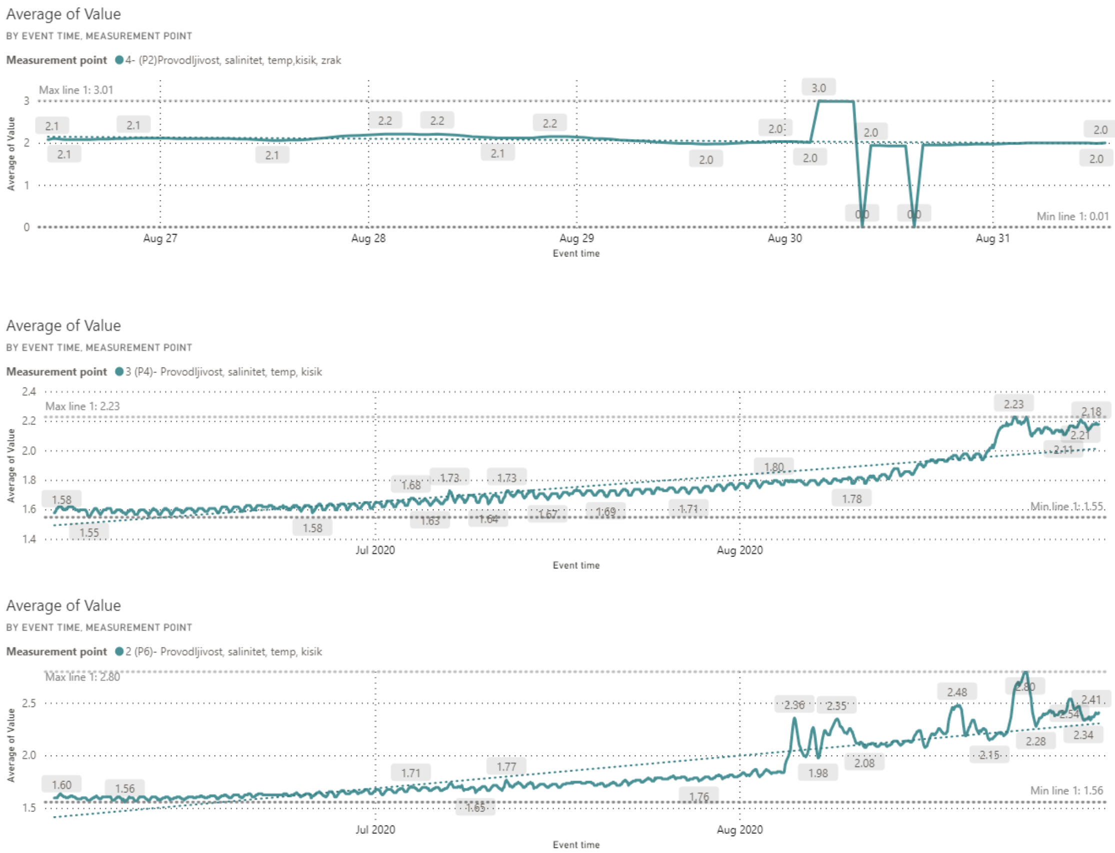

Figure 1.2. Salinity levels measured on 3 measuring locations (P2, P4, P6) on the Vransko lake.

Averege, Maximal, Minimal

BY SENSOR NAME, LOCATION NAME

Location name	Crkvine - P2			Prosika - P6			Sredina - P4			**Total**		
Sensor name	Averege	Maximal	Minimal	Averege	Maximal	Minimal	Averege	Maximal	Minimal	**Averege**	**Maximal**	**Minimal**
C4E – Conductivity	3,893.19	5,582.10	24.22	3,484.53	5,227.10	2,922.19	3,284.25	4,168.20	2,910.30	**3,399.42**	**5,582.10**	**24.22**
C4E – Salinity	2.08	3.01	0.01	1.86	2.80	1.56	1.76	2.23	1.55	**1.82**	**3.01**	**0.01**
C4E – Temperature	26.24	28.11	24.56	25.21	30.62	19.38	25.06	29.60	19.10	**25.17**	**30.62**	**19.10**
C4E – Total dissolved solids	2,250.99	3,227.60	12.22	2,014.74	3,022.30	1,689.59	1,898.93	2,410.00	1,682.70	**1,965.52**	**3,227.60**	**12.22**
OPTOD – Oxygen MGL	5.65	7.37	4.34	8.04	9.61	6.56	8.56	10.39	1.76	**8.22**	**10.39**	**1.76**
OPTOD – Oxygen PPM	5.65	7.37	4.34	8.04	9.61	6.56	8.56	10.39	1.76	**8.22**	**10.39**	**1.76**
OPTOD – Oxygen saturation	70.39	93.91	52.37	97.86	109.43	82.51	103.97	120.22	21.80	**100.01**	**120.22**	**21.80**
OPTOD – Temperature	26.37	28.17	24.60	25.35	30.89	19.59	25.23	29.95	19.26	**25.32**	**30.89**	**19.26**

Figure 1.3. Water quality parameters measured on 3 measuring locations (P2, P4, P6) on the Vransko lake for the period of 1st August – 31st August 2020..

2. GENERAL CHARACTERISTICS OF WATER AND SEDIMENT DISCHARGE IN THE ADRIATIC COASTAL SYSTEM

2.1. General description of water discharge in the Adriatic Sea

The Adriatic Sea is characterized by significant spatial inhomogeneities of precipitation. On average, maximum precipitation occurs during late autumn, while the minimum occurs during summer. Rainfall is significantly higher along the eastern coast due to the local cyclogeneses combined with coast backed by high coast-parallel mountains, with the maximum precipitation of 4600 mm/y in Montenegro (Bošković and Brajković, 2004). The western coasts of the basin record less precipitation, decreasing to the south (Poulain and Raichich, 2001) (Fig. 2.1). Generally decreasing precipitation is the recent trend over the Adriatic Basin, particularly along the northern coast of Italy (Philandras et al., 2011). Overall, this trend affects the freshwater discharge and consequently changes the input of sediment, nutrients, and potential contaminants as well.

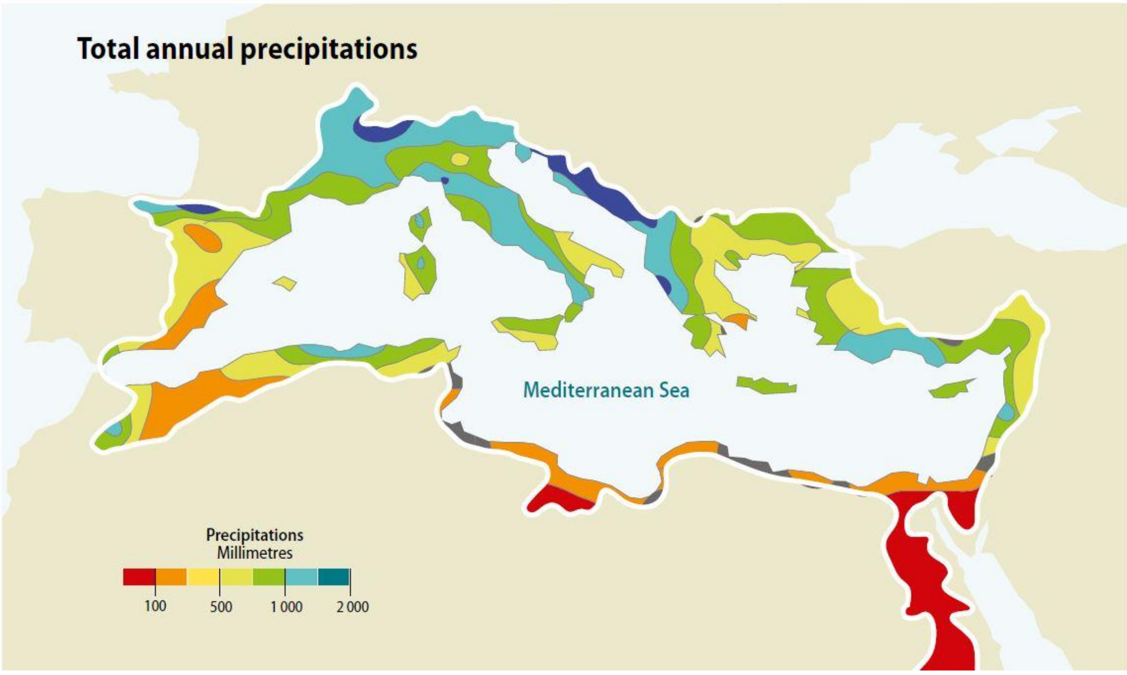

Figure 2.2. Total annual precipitations in the Mediterranean. Source: UNEP/MAP (2003).

As the northernmost landlocked basin of the Mediterranean, substantial freshwater enters the Adriatic Sea by rivers (approx. 2500 - 3700 on annual basis, according to Struglia et al. (2004) and Ludwig et al. (2009), respectively), mostly by the Po River and other Italian rivers (over 50%) (Fig. 2.2). Total discharge from the Croatian coast is estimated to 15-19%, including river, submarine, and groundwater discharge (Sekulić and Vertačnik, 1996; Gačić et al., 2001a; Orlić, 2001). Considerably lower water discharge from Po River was observed during the 20th century, in particular after the 1970ies together with lower sediment input largely due to hydropower and irrigation needs (Syvitsky and Kettner, 2007; Cozzi and Giani, 2011). Other Adriatic rivers show a similar trend of water discharge decrease in recent years (IOF, 2020).

Due to its carbonate lithology, Croatian rivers participate with only several percents in freshwater discharge, except the Neretva River, which is among the top ten freshwater contributing Mediterranean rivers (Ludwig et al., 2009). The very same carbonate lithology combined with karstified and tectonized bedrock simplifies groundwater discharge along the eastern coast, and yields considerable submarine freshwater discharge. It is estimated that approx. 2200 m^3/s of this overlooked freshwater load enters the Mediterranean (Zektser et al., 2006), prevalently along the eastern Adriatic coast. Both, submarine spring discharges and groundwater seepages play a critical role in fresh water-sea water balance in coastal aquifers and maintain coastal brackish and wetland habitats. Inadequate land use management in zones of groundwater drainage area may contribute to nutrients and contaminants load to the sea, while salt intrusions have opposite pathways in areas of over-exploited coastal aquifers.

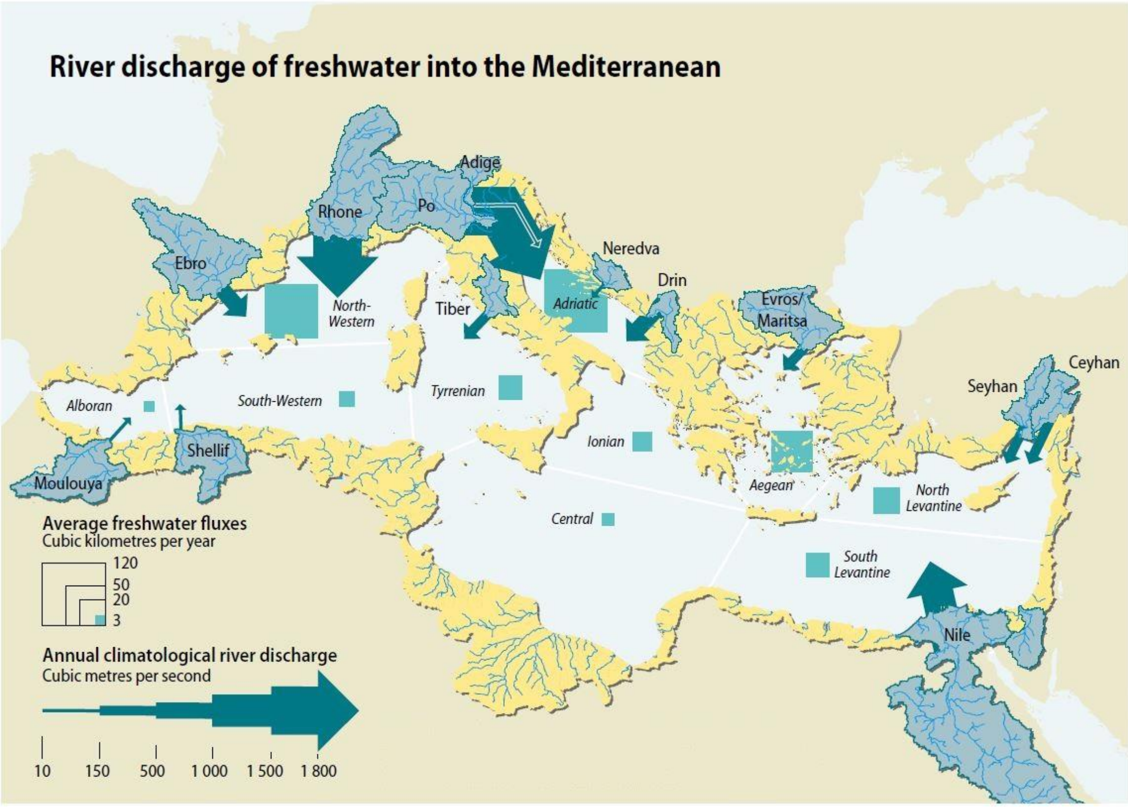

Figure 2.2. River freshwater discharge into the Mediterranean. Source: UNEP/MAP (2012).

2.2. General characteristics of sediment discharge and deposition in the Adriatic Sea

The main source of sediment material in the Adriatic Sea are rivers, and major directions of the terrigenous sediment supply are from the north-western Italian coast, and from its south-eastern part of the Albanian coast. Prior to dam construction, Albanian rivers contributed about 60% of the total sediment (approx. 85 Mt/y), while Italian rivers loaded approx. 56 Mt/y (Milliman et al., 2016, and references therein) (Fig. 2.3). Considering its carbonate lithology, only the Neretva river of all Croatian rivers yields a considerable amount of sediment– approx. 14 Mt/y (prior to dam construction). The main difference between the depositional area of sediment brought by Italian and Albanian rivers is the morphology of the Adriatic basin: sediment from Albania is deposited on its narrow shelf, backed by South Adriatic Pit, where much of the sediment has been deposited by turbidity flows (Milliman et al., 2016 and reference therein). On the contrary, the north-western shelf is wide and shallow and covered by thick Plio-Quaternary deposits in form of series of clinoforms (Trincardi et al., 1994; Correggiari et al., 2005; Ridente and Trincardi, 2005; Cattaneo et al., 2007). Under the present-day conditions of typical cyclonic circulation in the northern Adriatic, much of the discharged sediment remained in the narrow coastal belt along the Italian coast, after being distributed southward by the longshore drift driven by western Adriatic Current (Ravaioli et al., 2003; Steckler et al., 2007). Hence, the central section of the northern Adriatic shelf is sediment deprived and covered by relict sediment (Ravaioli et al., 2003; Steckler et al., 2007; Pikelj, 2010) (Fig. 2.4).

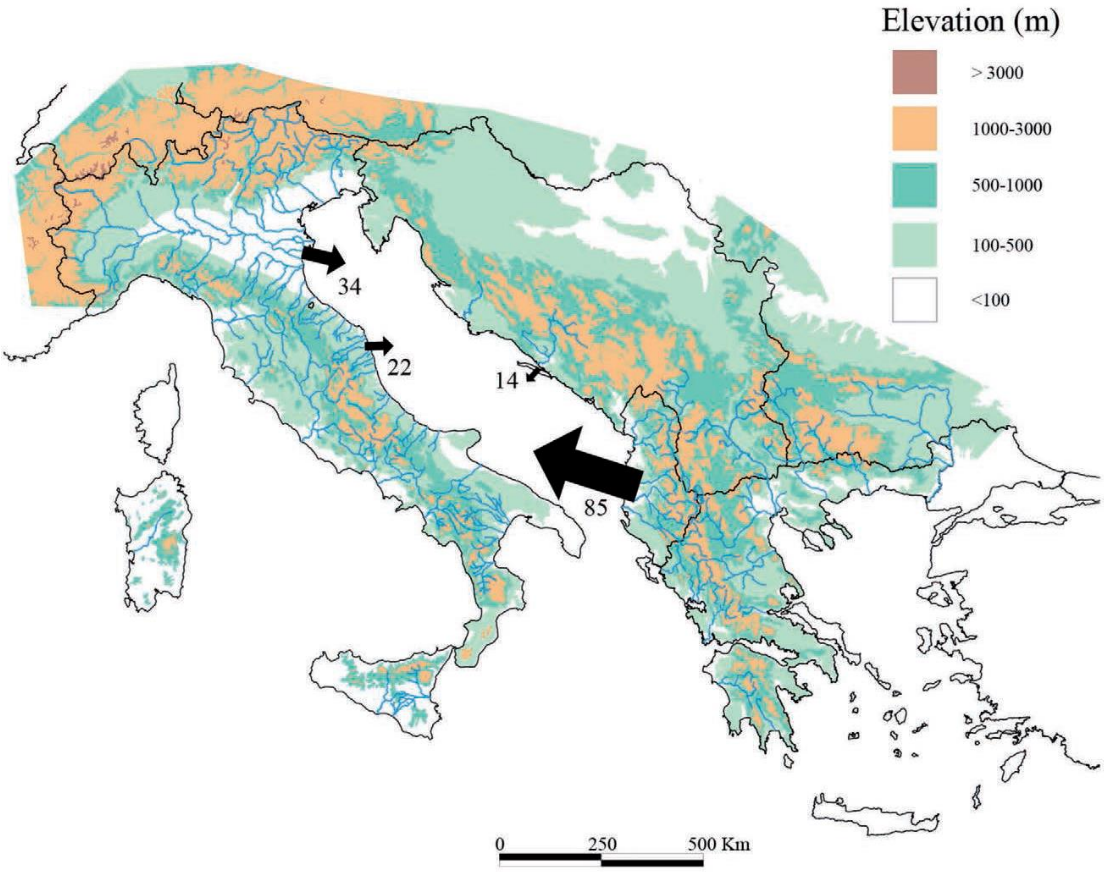

Figure 2.3. Mean annual sediment flux to the Adriatic Sea from 29 Italian, 1 Croatian and 5 Albanian rivers prior to dam construction in million tons per year. Source: Milliman et al. (2016).

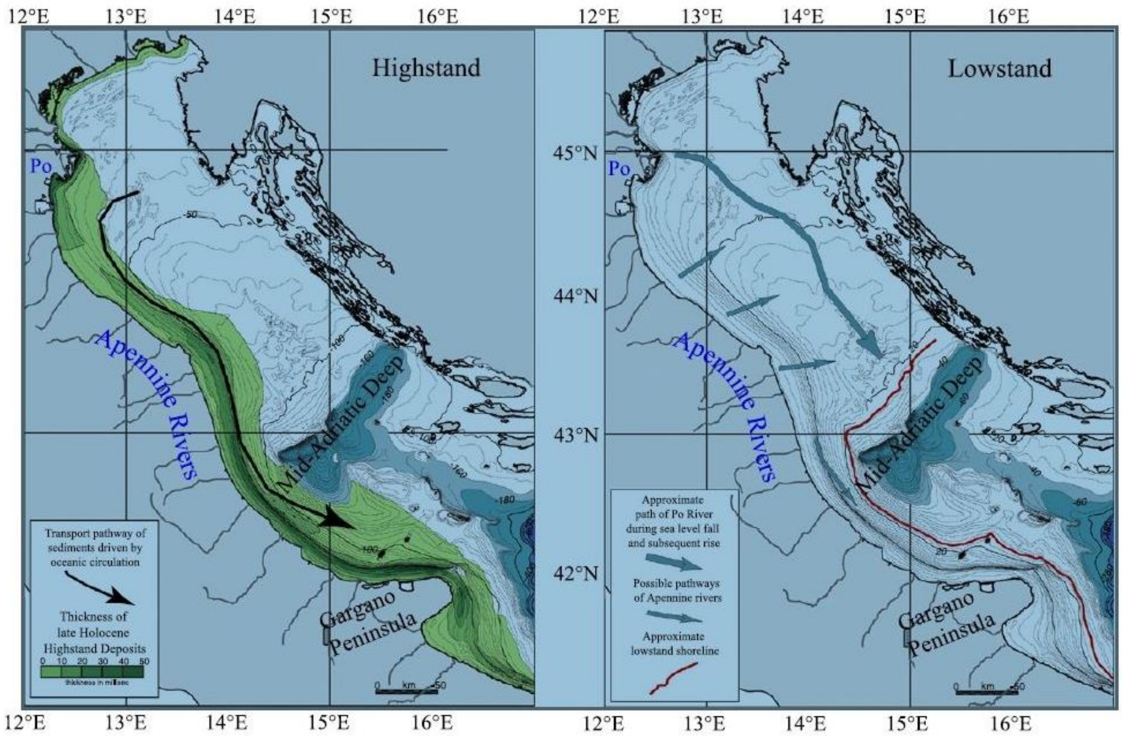

Figure 2.4. The difference in sediment pathways in the Adriatic Sea today during the high stand sonditions (left) and during the low stand conditions (right). Source: Steckler et al., (2007).

Due to its karstic nature, the eastern Adriatic coast and its hinterland are characterized by small or limited discharge of mostly karstic rivers, as previously mentioned. Due to their generally lower sediment load compared to non-karstic rivers, and the predominant direction of the eastern Adriatic Current, the eastern Adriatic shelf is sediment starved depositional environment under significant influence of biogenous carbonate production (Pikelj, 2010; Pikelj et al., 2016). Mixed terrigenous-carbonate or terrigenous sediment dominates in highly closed and protected bays, as well as in places where the terrigenous sediment input is higher, such as off the Neretva River delta (Jurina et al., 2013; Pikelj et al., 2016: Fiket et al., 2017) or in places of local weathering of non-carbonate coastal rocks (Pikelj and Juračić, 2013; Pikelj et al., 2018; Pikelj and Furčić, 2020) (Fig. 2.5). The eastern part of the Adriatic Sea is a highly folded and faulted karstic relief, partially submerged after the post-Holocene sea-level rise. Due to its developed morphology submergence of the eastern Adriatic Sea seabed led to numerous and diverse depositional environments.

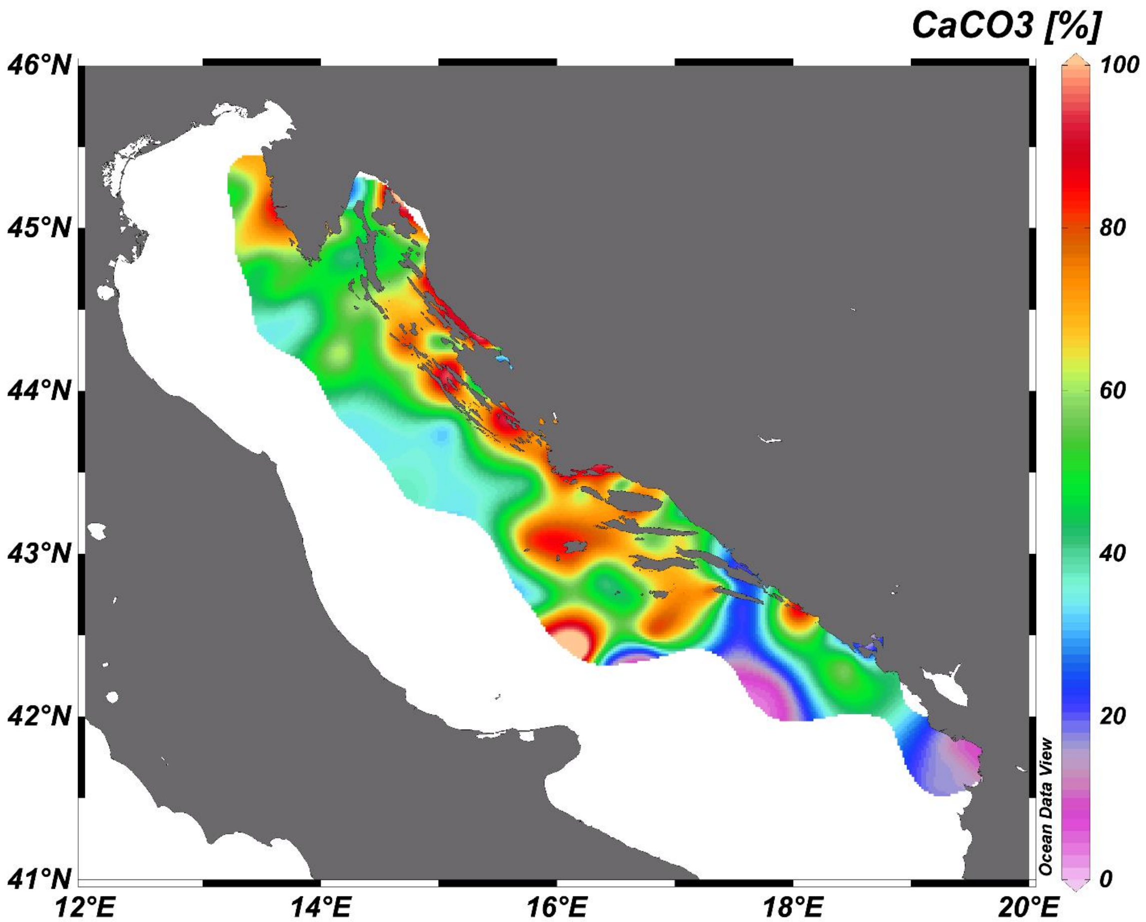

Figure 2.5. Carbonate content in the surface sediment of the eastern Adriatic shelf. Source: Pikelj, (2010).

3. WATER AND SEDIMENT FLUXES AT PILOT SITES

3.1. Neretva river delta

3.1.1. General description of site catchment

Neretva River is the longest river along the eastern Adriatic coast (Albanian rivers are excluded), flowing from Dinaric Mountains into the Adriatic Sea and it is located in the south-eastern part of the Adriatic coast (Fig. 3.1.1). It is a 225 km long river with a drainage area of over 13 000 km^2 (Klement et al., 2009). Over 97% of its drainage basin is in Bosnia and Herzegovina (Klement et al., 2009). The main course of the Neretva River in Croatia is only 22 km long (Juračić, 1998; Slišković, 2014). The Neretva River delta plain extends along the last 36 km of the Neretva River, downstream from the confluence of the Bregava and Trebižat rivers, covering approximately 170 km_2. The upper part of the deltaic plain belongs to Bosnia and Herzegovina. The actual appearance of the delta is clearly visible in the Croatian part of the deltaic plain, where the Neretva River branches in several directions. Main river courses in the Croatian part of the Delta are Neretva River and Mala (Small) Neretva, while minor tributaries entering the delta plain from the surrounding karstic area. Neretva River mouth is located near Ploče port, while other important settlements in the surrounding area are Opuzen and Metković (Fig. 3.1.1).

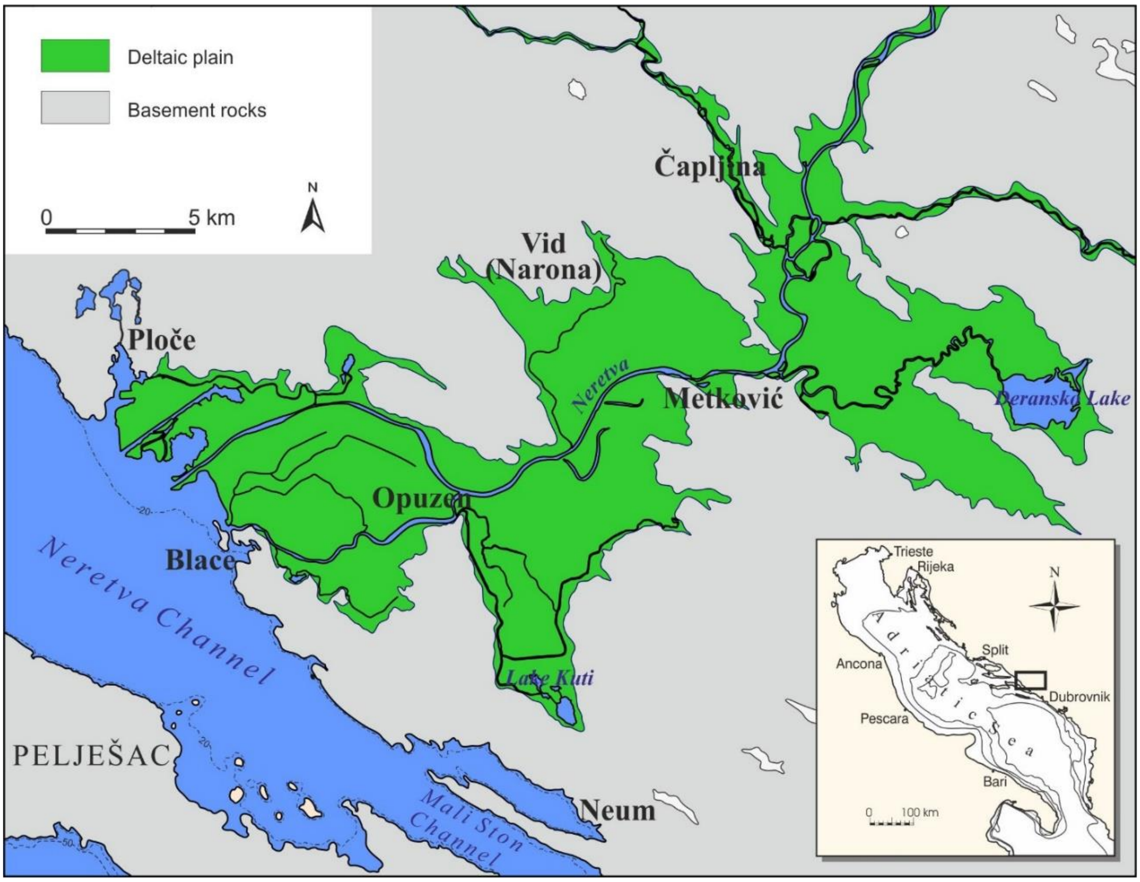

Figure 3.1.1. Location of the Neretva River Delta.

Originally, before the reclamation Neretva River branched into 12 directions, which was reduced to two main courses above-mentioned courses and several small ones. Ideas of reclamation occurred many times during the recent history (Fig. 3.1.2). Significant changes started during the 19th century (1881-1889) when most of the flow between Metković and Ploče was regulated, without reclamation of the surrounding land. Gradually, reclamation of the deltaic plain started using a technique called “jendečenje” or “jendek” making, meaning that existing channels were deepened, while the excavated material was used to build mounds that served as arable land (Fig. 3.1.3). During the process of reclamation, many wetlands were changed and/or disappeared. The most significant changes within the Neretva Delta occurred in the second half of the 20th century when a modern melioration was applied. The melioration included drying up of wetlands and remained river courses.

Figure 3.1.2. Neretva River Delta before reclamation activities (1851-1854). Source: Mapire.eu.

Figure 3.1.3. Jendeks in the Neretva River delta. Source: www.agroportal.hr.

3.1.1.1. Meteorological characteristics

The climate of the wider are of the Neretva River Delta is the Mediterranean climate, characterized by dry and hot summers and mild and wet winters. Most of the annual runoff is thus realized during the cold season, and this is also the truth for the entire Neretva River drainage basin: 60-70% of the runoff is collected between November and March (Klement et al., 2009). In order to characterize meteorological characteristics of the Croatian part of the Neretva River Delta, a set of average meteorological data for the period 1971-2000 from Dubrovnik meteorological station was used (Zaninović et al., 2008). Mean annual temperature for the given period was 16.3 ^oC, with a minimum of -5.2 and a maximum of 36.7 ^oC. Graphical temperature data is shown in Figure 3.1.4.

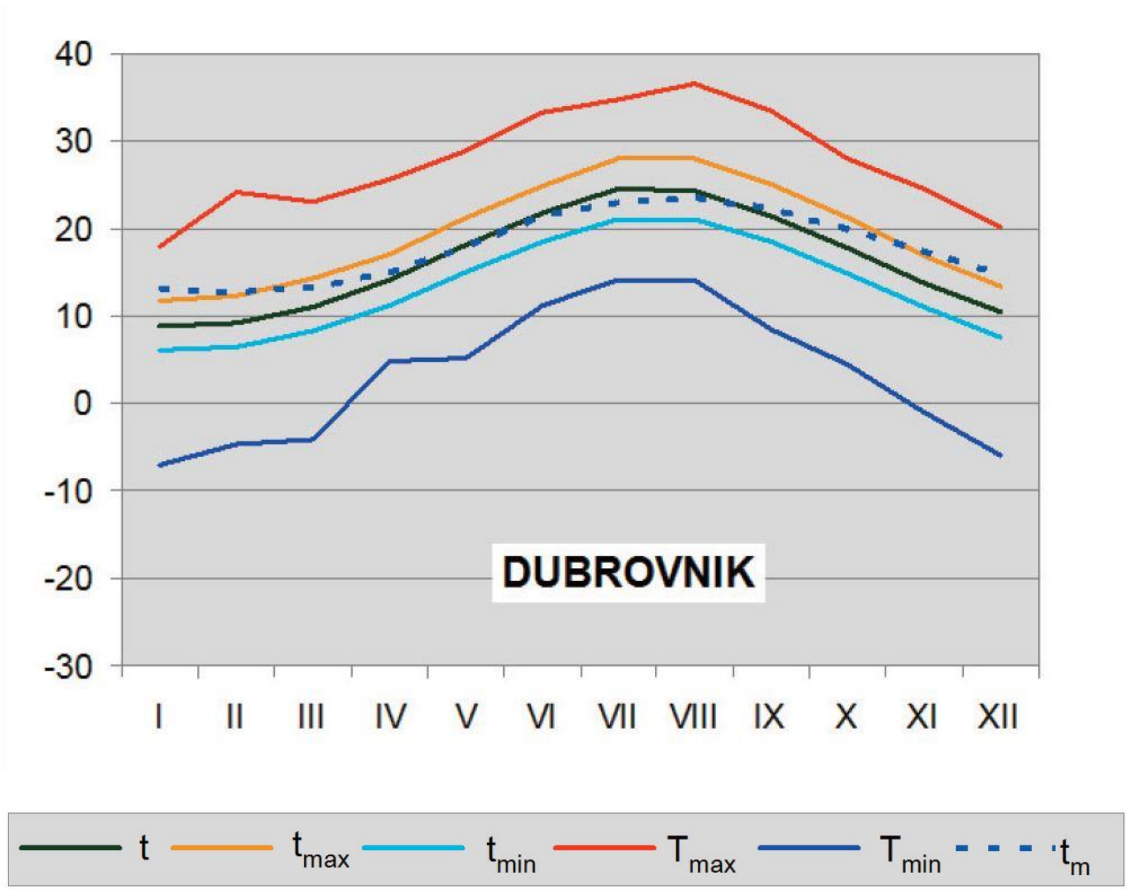

Figure 3.1.4. Temperature data (annual course in ^oC) for Dubrovnik during period 1971-2000. Legend: t – monthly mean; t_{max} – monthly maximum; t_{min} – monthly minimum; T_{max} – absolute maximum; T_{min} – absolute minimum; t_m – sea temperature. Source: Zaninović et al., 2008.

Most of the precipitation refers to rain. The mean annual rain precipitation for the given period was 1064 mm, with a minimum of 726.1 mm and the amaximum of 1480.5 mm. Snow is rare and snow day occurrence during the given period was 0.1 for S≥ 1 cm (Zaninović et al., 2008). Graphical data for precipitation is shown in Figure 3.1.5.

Trends of temperature changes during the last decade (2012-2020) are provided by Croatian Meteorological and Hydrological Service (DHMZ) through online data (https://meteo.hr/klima_e.php?section=klima_pracenje&param=srednja_temperatura) comparison of annual temperature changes (2012-2020) for Dubrovnik with 1961-1990 period (Fig. 3.1.6).

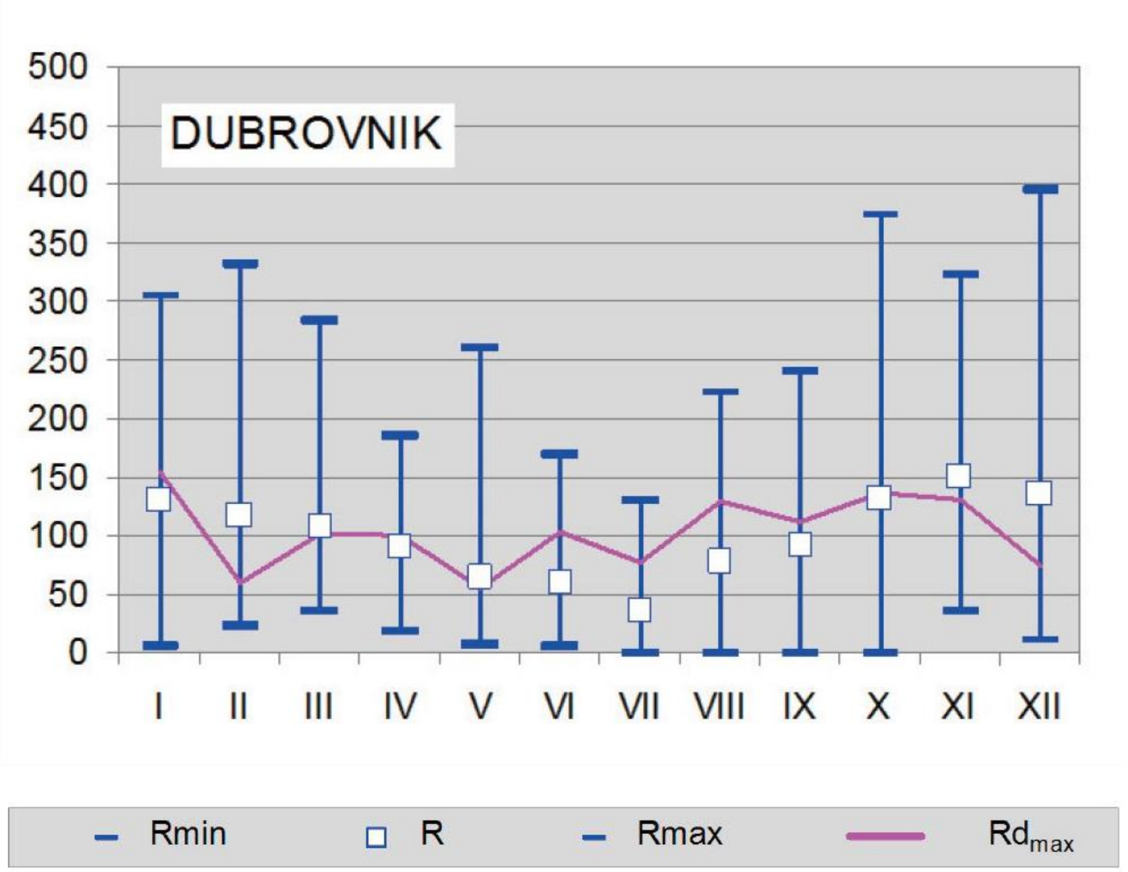

Figure 3.1.5. Precipitation data (monthly amounts in mm) for Dubrovnik during period 1971-2000. Legend: R_{max} – monthly maximum; R_{min} – monthly minimum; R – monthly mean; Rd_{max} – maximum daily precipitation. Source: Zaninović et al., 2008.

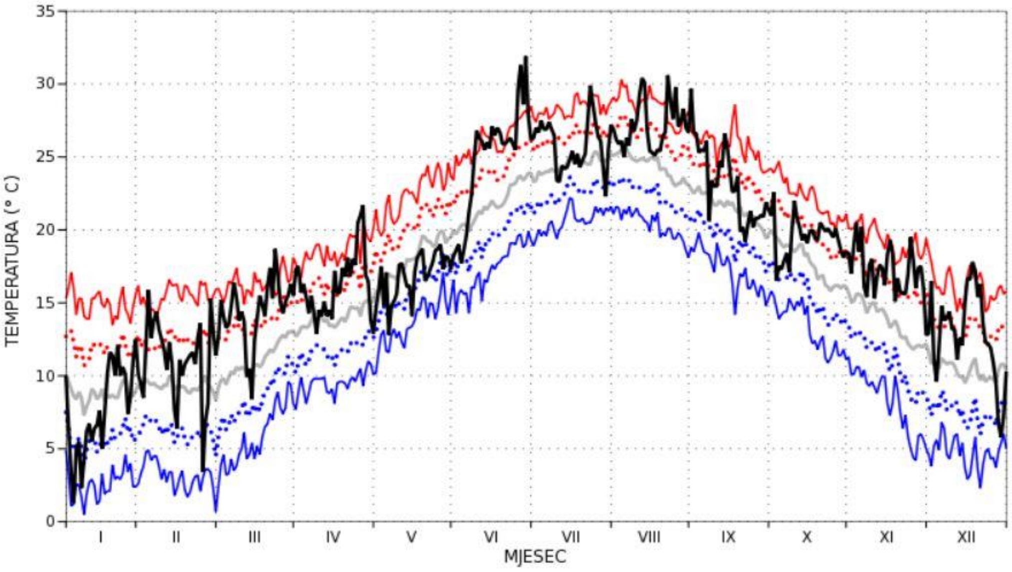

Figure 3.1.6. Comparison of Dubrovnik 2019 annual course of temperature to the average for the 1961-1990 period. Legend: black line – daily mean for 2019; red line – daily mean + 2δ; red dashed line – daily mean +1δ; grey line – daily mean; blue dashed line – daily mean -1δ; blue line – daily mean -2δ. Source: meteo.hr.

3.1.1.2. Hydrological characteristics

The quantity of water discharge is related to the drainage basin lithology and pattern of precipitation over the drainage basin. The lithology of the river drainage basin has a significant role in the hydrological characteristics of the Neretva River Delta. Unlike in the case of other Croatian coastal rivers, the upper reaches of the Neretva River flow through mountain areas in Bosnia and Hercegovina of mixed lithology: metamorphic, magmatic, and clastic sedimentary rocks. However, lower reaches flow through the karstic bedrock, composed mostly of carbonate rocks and less present clastic flysch (Raić et al., 1976; Mojićević and Laušević, 1973a, 1973b; Raić et al., 1980; Sofilj and Živanović, 1980; Mojićević and Tomić, 1982; Juračić, 1998). Therefore, the Neretva River is considered as an allogenic karst river, supplying more water compared to other autogenic karstic rivers along the eastern Adriatic coast. Hydrologic characteristics of the Neretva River Delta are rather complex due to the mixing of the freshwater, seawater and water supplied from karstic springs of highly variable water discharge. According to Orlić et al. (2006) and Klement et al. (2009) the annual average water discharge of the Neretva River is 332 and 380 m^3/s, respectively. Seasonal variation of Neretva River discharge is considered low, due to the relatively low snowmelt contribution and considerable karstic flow (approx. 26% of the runoff; Glamuzina et al., 2002). On other places, part of the water is lost in the underground when the river reaches carbonate terrain (Štambuk-Giljanović, 1999). The flow regime in the upper part of the drainage basin is nivo-pluvial. Water level fluctuations may reach 14 m in the Mostar area. In the deltaic plain these fluctuations are much lower due to the flood control measures and continued karstic input (Glamuzina et al., 2002). Obstructions of water flow in the upper part of the drainage basin resulted in lowered water discharge and in a modified hydrological regime downstream of artificial reservoirs. Water column of the main course, Neretva River, has been stratified, with the seawater intrusion extending upstream all the way to the town of Metković. Other watercourses are mainly freshwater courses (Jurina et al., 2013). One of the consequences of reduced water discharge is saltwater intrusion in many places over the deltaic plain, thereby degrading the quality of both, freshwater and soils in the area used for intensive agriculture.

3.1.1.3. Sediment fluxes

As mentioned in the previous section, there is a correlation between water discharge and drainage basin lithology. Due to the nivo-pluvial regime with an impermeable upper drainage basin, together with high relief ration, climatic variation, and scarce vegetation, Neretva River is considered to have a high sediment flux. Additional sediment load is due to the flysch bedrock in its lower drainage basin. As an allogenic karstic river, Neretva discharges a large quantity of particulate sediment into the Adriatic compared to other Croatian rivers. The valley in which the deltaic plain is situated was incised in the karstic relief during the lower sea-level stand. The valley was submerged during the last sea-level rise and an estuary was formed. Strong natural sediment supply and the negligible tidal and wave activity resulted in rapid delta growth. Sediment analyses of the 100 m long sediment core from the Mali Ston Channel showed that terrigenous and carbonaceous sedimentation alternated during the Pleistocene and Holocene delta growth, indicating occasional periods of significant terrigenous flux interchanged with normal carbonate sedimentation characteristic for the eastern Adriatic Sea (Felja et al., 2016).

However, sediment input is nowadays substantially reduced due to the sediment trapping in reservoirs behind large dams. In totally, 9 dams (including ones on the Neretva River tributaries) trap most of the particulate material in the part of the drainage basin upstream of Mostar, approximately 70 km away from the river mouth. The most complex dam is one on the Trebišnjica River which has a negative impact on the deltaic plain and the Neretva River: it significantly reduces water and sediment discharge, increasing thus riverbed erosion (Bonacci and Jelin, 2009). Additionally, uncontrolled sand and gravel mining additionally reduced sediment discharge. It is estimated that total excavated quantities of sediment are > 20 times higher than ones of natural replacement of the sediment material. Most of the sediment brought by the Neretva River deposits in the main river channel. Sediment cores presented by Vranješ et al. (2007) showed that muddy sediments prevail in the topmost horizons of the sediment sequences and it was correlated with the period after river damming and/or to the sea level rise. According to Jurina et al. (2015) Neretva River plume discharges its load over a wide area of the Neretva Channel, resulting in a relatively uniform depositional rate. Specific sediment transport is estimated to be 1093 t km^2/y (EUROSION, 2004). Long-term runoff decreases and retention of the sediment material in the upper part of the drainage basin led to the reduction of sediment fluxes, especially during the last 70 years. As a consequence, delta is no longer expanding or even decreases.

3.1.1.4. Nutrient fluxes

Due to its sedimentological characteristics (high terrigenous input) and the strong agricultural production, especially in its deltaic area, it is expected increased nutrient load within the Neretva River Delta, i.e. downstream increase. According to data presented by EIONET 2003-2005, water sampled near the Neretva River mouth are well oxygenated with an average 98 % of dissolved oxygen. Minimum of oxygen usually occurs during the summertime and it is associated with the lower water discharge and water temperature. Multi-year results of dissolved inorganic nitrogen measurement showed a range between 0.28-1,19 mg/l, meaning that the status of the Neretva River water in its deltaic area is of moderate status. Nitrates range 0.27-1.01 mg/l, defining its moderate status, while according to nitrite range of 2.5-20 µg/l, water in the Delta is of good status. The same is in the case of total ammonia, which ranges between 5 and 160 µg/l. However, the downstream increase of ammonia concentration within the total DIN has been recorded in general: concentration of 0.5 % has been recorded in Bosnia and Herzegovina, while 5.6% in Croatia. In terms of total phosphorus concentration, the water in the Neretva River Delta is considered of high quality (0.005-0.08 µg/l). However, total phosphorus shows opposite concentration behaviour: upstream increase, pointing to local points of pollution. Organic phosphorus tends to increase in its lower parts, and it is ascribed to the organic inputs in the upper parts of the drainage basin. General nutrient concentration may occur during dry periods, e.g. during the late 1990ies with a peak in 2001.

Phytoplankton growth is one of the indicators of nutrient input. According to Jasprica and Carić, 1994; Jasprica et al., 2012; Skejić et al., 2015; Viličić, 1989; Viličić et al., 1998, seawater in the Mali Ston Channel off the Neretva River mouth is considered as a moderate natural eutrophicated system, based on the nutrient concentration, and the quantity of the phytoplankton. Bužančić et al. (2016) reported on influence of eutrophication on phytoplankton in the same area. Oxygen saturation in this area ranged between 94 and 127%. The maximum surface concentration of orthosilicates was recorded in the same area during winter conditions 0.37-21.93 mmol/m3. Total inorganic nitrogen was most abundant at a depth of 5 m during autumn: 0.34-38.85 mmol/m3. Orthophosphate concentrations ranged between 0.01 to 0.11 mmol/m3, indicating a week anthropogenic influence. This is in accordance with the upstream increase of phosphorus in the Neretva River, as mentioned above.

3.1.2. Excess fertilizers, herbicides and pesticides usage

The use of the herbicides in the Neretva River basin due to intensive agriculture is wide-spread and sometimes may be uncontrolled. Đedibegović et al. (2010) presented a comprehensive study on pesticides present in the water between Ladanica and Gabela (BiH). Several types of organochlorine pesticides (OCP) were found in all places, together with DDT, being the major OCP contaminant. Total OCP concentration at the beginning of the deltaic plain was 140 pg/l, showing the not surprising downstream increase. Unpolluted freshwater contains usually 0.1-0.5 ng/l OCP, while polluted waters contain ten-fold higher concentrations. Thus, total OCP concentration at this particular Neretva River Delta site is low, as well as DDT. However, DDT is forbidden and its recent use has to be further investigated.

3.1.3. Grease, oil, chemicals and salt input (from energy production, mining activity, irrigation and urban runoff)

Data on grease, oil and chemical inputs along the Neretva River are generally scarce and only isolated reports and case studies may be found. Besides its use as an agricultural area, there are industrial facilities dispersed along the river, as well as urban areas. Mining and industrial activities impacting the Neretva River are generally located upstream in the neighbouring Bosnia and Herzegovina. An aluminum plant in Mostar is one of the prominent industries along the river and it is a source of polycyclic aromatic hydrocarbons (PAHs). Total PAHs concentration found at the Gabela site at the beginning of the Neretva River delta was 4000 pg/l, which is assumed to be related to upstream domestic and industrial discharge (Đeđibegović et al., 2010). Compared to the EU and United States Environmental Protection Agency (EPA) standard.

Hydroelectric powerplants located on both, Neretva River tributaries and the river itself, are the source of polychlorinated biphenyls (PCBs) since these chemicals are one of main constituents of transformer oils (Đeđibegović et al., 2010). Total PCBs concentration was 120 pg/l, which is above the EPA standard. Two polybrominated diphenylethers (PBDEs) are found in the Gabela site (Đeđibegović et al., 2010). Their sources are not known; however, they are usually result of the wastewater plant effluents, and may thus be related to industry and urban areas.

Due to the delta erosion recession and variable hydrological regime, largely changed by powerplant construction in the upstream part, the seawater intrusion is one of the main environmental and economic problems in the Neretva River Delta. Saline intrusions are controlled by the freshwater discharge, and thus, dry season and generally dry years may increase the possibility of saltwater intrusion (Margeta and Fistanić, 2000). A multiyear decrease of groundwater discharge from the Trebišnjica River is considered one of the major problems related to saltwater intrusions (Juračić, 1998). In the case of the Neretva River, saltwater wedge spreads over the riverbed deep into the deltaic plain up to Metković (Jurina et al., 2015), entering thus the underground water, increasing thus the salinity of the soil used in intensive agriculture. This process is usually facilitated by the freshwater pumping and used in agriculture.

3.1.4. Sediment as a pollutant

Deltas and estuaries are usually depositional basins for sediments, accumulating thus pollutants stored in soils and sediment from the upper drainage basins. For many pollutants alluvial plains and deltas may turn from sink to source under favourable chemical and physical conditions. Glyphosphate is one of widely used herbicide in the Neretva River Delta (Babić et sl., 2005) and one of its characteristics is low mobility (low solubility) in soils, especially ones of higher pH, such as are found in the Neretva River Delta region (Babić et al., 2005). However, increase of organic matter can lower pH in soils and increase solubility of the glyphosphate, bringing the soil to become source of this herbicide. Release of harmful contaminants from the soil may be increased due to the erosion and lowering of delta.

In case of sediments, one of widespread pollutant group are trace metals. As mention above, mining and industry along the Neretva River are possible source of trace metals. Recent study presented by Kralj et al. (2016) showed that the fate of trace metals may vary due to the considerable hydrological and sedimentological differences within this depositional environment, additionally superposed by various levels of anthropogenic activities. One of the main factors of trace metals dilution is sedimentation rate, which vary considerably over the Delta. Mineral and granulometric composition control the adsorption of trace metals in terms of presence of clayey fraction and clay minerals abundance. Elements such as Cu, Pb and Zn are main pollutants adsorbed on the sediment particles, and may thus be easily released back int the delta system. Among trace metals, Cu and Cd are of anthropogenic origin, mainly due to the agriculture and related activities. Changes of physical and chemical conditions in water and sediment of the Neretva River Delta my increase solubility of some trace metals. This is a case of Cd, which is more soluble in the presence of Cl introduced by saline water intrusions. This trace metal can further be absorbed by cultivated plants and reach human organism via vegetable consumption (Romić et al., 2012).

Ploče port situated within the deltaic plain is the second cargo port in Croatia. Its facilities contain several terminals and other port structures. Based on the main terminal purpose, including bulk cargo (coal, iron ore, phosphates…), liquid cargo (fuel), grain cargo, general cargo (cattle, food, industrial products…), alumina and petroleum terminal, cement terminal etc. it is expected that the sediment in the port is loaded by various contaminants. Data related to sediment contamination in the port are scarce. According to the Environmental assessment report (2006), sediment in the port is characterized as poor polluted sediment (class II), since the concentration of hazardous substances in sediment eluate is low. Sediment has been dredged occasionally and the dredged material is to be used in quay filling. In order to prevent negative impact of sediment and its pore water, sediment is kept in sedimentation basins for 24 h.

3.1.5. Acquisition of new in-situ data and analysis of recent trends of water and sediment fluxes

So far, there are no new in situ measurements of sediment, water or nutrient fluxes within the Change We Care project.

3.1.6. Conclusion

3.1.6.1. Results of the activities and discussion

Collected data compiled within this activity successfully described overall picture of sediment and water fluxes data within the Neretva River Delta. Many of data sets are still largely lacking, particularly those related to Ploče port sediment quality, composition and fate.

3.1.6.2. Problems and solutions

Collected data have shown that the Neretva River Delta is a complex area, with sediment and water supply from drainage basin of complex lithology. Its water discharge is considerably influenced by its karstic relief. Recognized anthropogenic influences are mainly related to dam construction with industrial and mining activities in its upper part and intensive agriculture in its deltaic part. The Delta itself has been dramatically changed since 19th century due to reclamation. Climate change with recognized warming trend may cause further decrease in sediment and water discharge, increased erosion over the deltaic plain and, as a consequence frequent occurrence of salt water intrusions. These changes in physical and chemical conditions within the Delta may be a trigger of harmful substances remobilization, causing thus their release within the deltaic system. This domino effect may threat the human population as well, largely depend on food production within the Delta.

3.1.6.3. Analysis of data quality

Due to the wide sources and general incompatibility of data, analysis of data quality was not performed to date within the Change we Care project.

3.2. Jadro river

3.2.1. General description of site catchment

The Jadro River starts as a karst overflow spring in the hilly karst area between the Kozjak and Mosor massifs at a height of about 33 m a.s.l. The Jadro River spring is part of the largest aquifer systems in Dalmatia (Fritz & Kapelj, 1998), and one of larger aquifer systems in Dinaric karst of Croatia (Bonacci, 1987). The present-day hydrological system of the Jadro river spring consists of topographic and groundwater catchment, both predominantly characterized by karstified carbonate rocks (Mesozoic limestone and dolomites) in the wider hinterland of the City of Split (Fig. 3.2.1). The length of the river is 4.41 km, while the average fall of the river bed is 7.48 ‰. According to various authors the groundwater catchment area of Jadro and nearby Žrnovnica springs is perceived as one and its size is approximated between 450 and 560 km^2 (Loborec et al., 2014; Bonacci, 1987; Kapelj et al., 2001). Due to the changed water regime and the increased water level of the nearby Cetina River, infiltration of its groundwater occasionally occurs (Fig. 3.2.2.). In comparison, its topographic catchment area is smaller covering about 28.2 km^2 and is characterized by a several smaller streams and two larger tributaries (Figure 3.2.3.). The upper part of the Jadro River is a typical karstic river, showing an uneven discharge during the year, ranging between 0.22 m3/s and approximately 78 m3/s (Table 3.2.1).

Table 3.2.1. Basic data for the Jadro River

Mark	**JKRN935013**	**Hydrology Station No. 7221- Majdan**	**Characteristic Flows**
Name	JADRO		
River basin district	Jadran	Data period 1984-2013	
Sub-basin	Jadro and Ozrnja	**Min flow**	0.219 m^3/s
Ecotype	T21B	**Max flow**	78.13 m^3/s
Topographic catchment area	28.2 km^2	**Ecological Min. monthly**	2.0 m^3/s
Total inner catchment area	130 km^2	**Ecological Min. daily**	1.8 m^3/s
Length	4.41 km	**Min.month.average-August**	2.83 m^3/s
Length of all streams	14.20 km	**Max.month.average-Decemb.**	14.64 m^3/s
Spring elevation	33 m a.s.l.	**Yearly average flow**	7.41 m^3/s
Average slope of river bad	7.48 ‰		

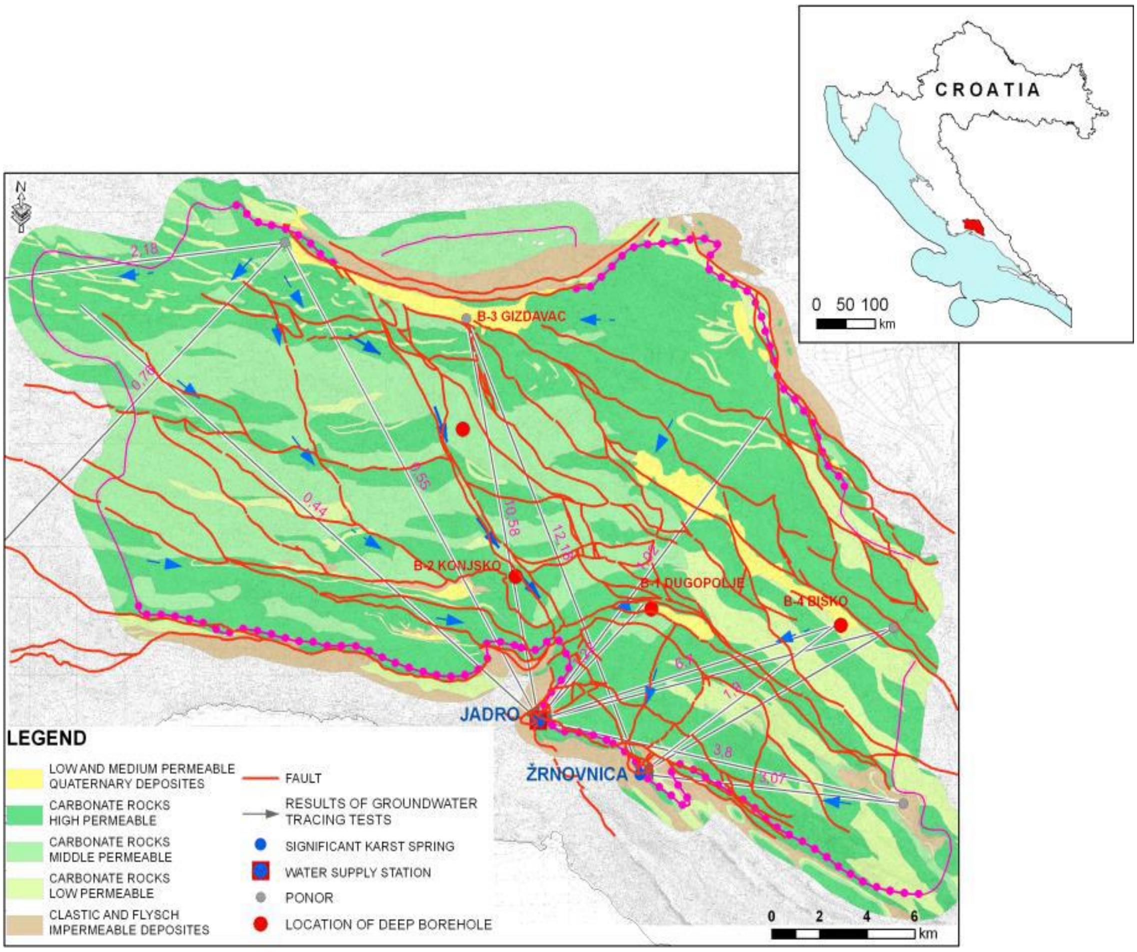

Figure 3.2.1. Hydrogeological map of the Jadro River catchment area. Inset: map of Croatia with the location of the study area (Loborec et al., 2014).

Figure 3.2.2. Map of the Jadro river spring catchment and its relation to the Cetina River

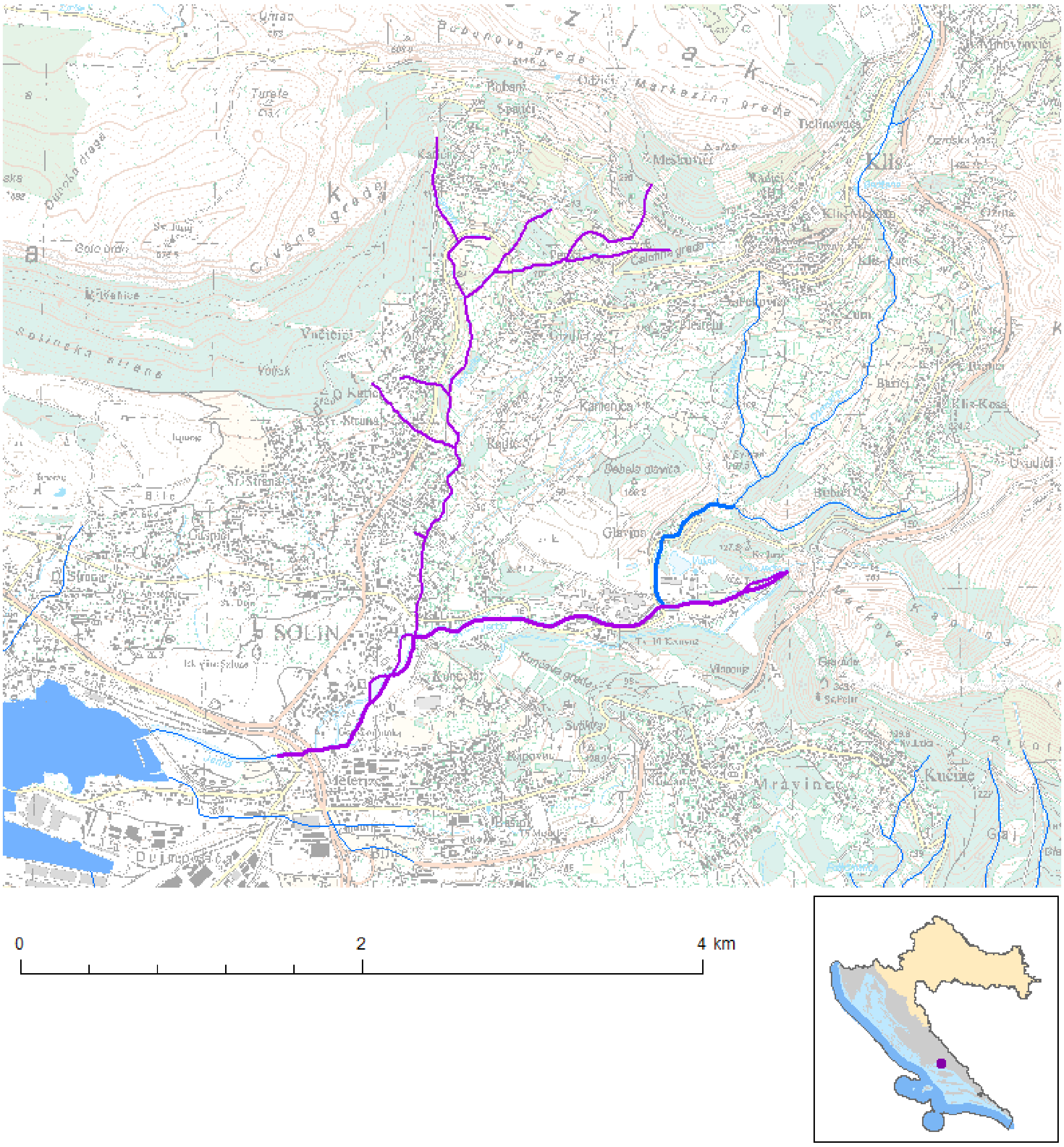

Figure 3.2.3. Topographic catchment area of Jadro River and its tributaries (source: Croatian Waters).

The Jadro River changes its character after the hydrological station Majdan: this is the point where the middle part of the stream begins, extending to the Gašpine mlinice within the Solin valley. In the past, rivers have expanded from this point into multiple parallel streams. Today, it is one regulated stream / riverbed length of L = 0.829 km. The average slope of the river bad at middle part of river is 9.6 ‰. After Gašpine mlinice the lower course of the river begins. The middle and particularly the lower parts of the course were regulated during the history, which is entirely channelized by stone and concrete (Fig. 3.2.4). Due to the railway and massive industry situated around, the river mouth itself was regulated as well. In whole, the lower part of the course was significantly isolated from natural geomorphological river processes since the river bottom has been largely covered by concrete and stone.

Figure 3.2.4. Middle part of the Jadro River

3.2.1.1. Meteorological characteristics

The Croatian Meteorological and Hydrological Service website (DHMZ) provides official meteorological information online. The Split-Marjan is the closest permanent automatized meteorological station situated 6 km SW of the Jadro River. The online access to basic meteorological data e.g., air temperature (Figure 3.2.5), precipitation, wind etc. is in open access (in Croatian) at:

https://meteo.hr/klima.php?section=klima_podaci&param=k1&Grad=split_marjan

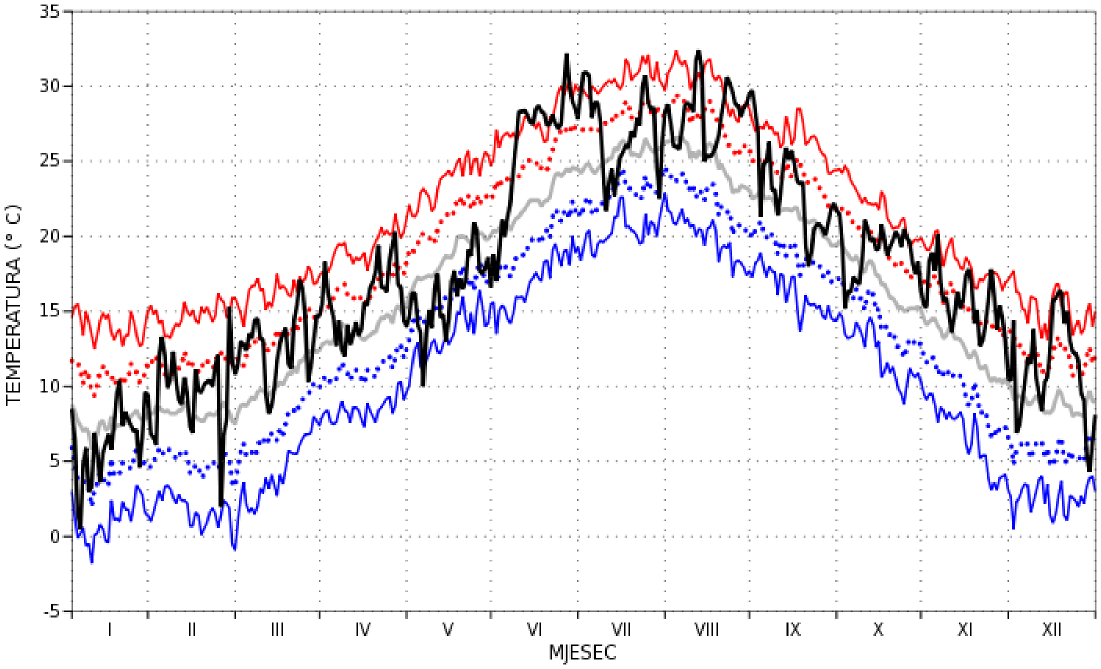

Figure 3.2.5. Mean daily (lower axis in months) air temperature on Split-Marjan meteorological station for 2019. (black curve) compared with the mean daily temperature for period 1961-1990. (grey curve), accompanied by two standard deviations (red and blue curves). Source: DHMZ

The precipitation per month in mm for Split-Marjan station (DHMZ-climate) can be accessed on: https://klima.hr/k2/gggg/oborina_gggg.xml (gggg = 2011 - 2020). For example, in extremely rainy and warm 2014 there was in total 1208.9 mm/year, whereas the lowest precipitation was in October (11.3 mm), and the highest in September (180.7 mm).

During 1948-2018 period mean air temperature was the lowest in January (7.9 °C) and the highest in July (26.0 °C). Rainfall in the same period was the lowest in July (27.3 mm) and the highest in November (112.6 mm).

The CHANGEWECARE (CWC) project partner Institute for Oceanography and Fisheries (IOF, 2020) reported the annual time series of air temperature at 2 m and precipitation that are extracted for the area of Jadro River site from the AdriSC climate simulation (1987-2017), within the CWC Activity 3.1 for Jadro River. Annual values of air temperature range from 13.0 to 14.5 °C, where the last value is reached in 2014. Clear temperature trend can be seen in the series, while annual temperatures can change for about 1 °C between years. The warming trend may be seen in all seasons, while being lowest during winter. Mean temperatures range between 7 and 10 °C during winter, while summer mean temperatures span from 19 to 21 °C. The precipitation rate is changing between 1 and 3 mm/day, i.e. between 400 and 1100 mm per year. The precipitation rate is maximal during autumn, when it might reach 5 mm/day, while the minimum precipitation rate is achieved during summer, when it might go down to 0.5 mm/day, or about 50 mm per season (IOF, 2020).

3.2.1.2. Hydrological characteristics

The Croatian Meteorological and Hydrological Service website (DHMZ) provides an easy procedure to access weather, climate and hydrological data in Croatia, whether they are needed for private or business purposes. The most commonly sought information is that concerned with the weather conditions (including weather forecast) and climatological data, and can be obtained in the textual or graphical form (tables, graphs etc) or in a form of your choice. The information provided must be paid according to the current price-list of the Croatian Meteorological and Hydrological Service. The price-list is provided with the offer (e-mail: usluge@cirus.dhz.hr). Besides, online data for period 1983-2018 on the Majdan station (see Act. 3.2.1. Report for Jadro River for location) is available free of charge (Figure 3.2.6).

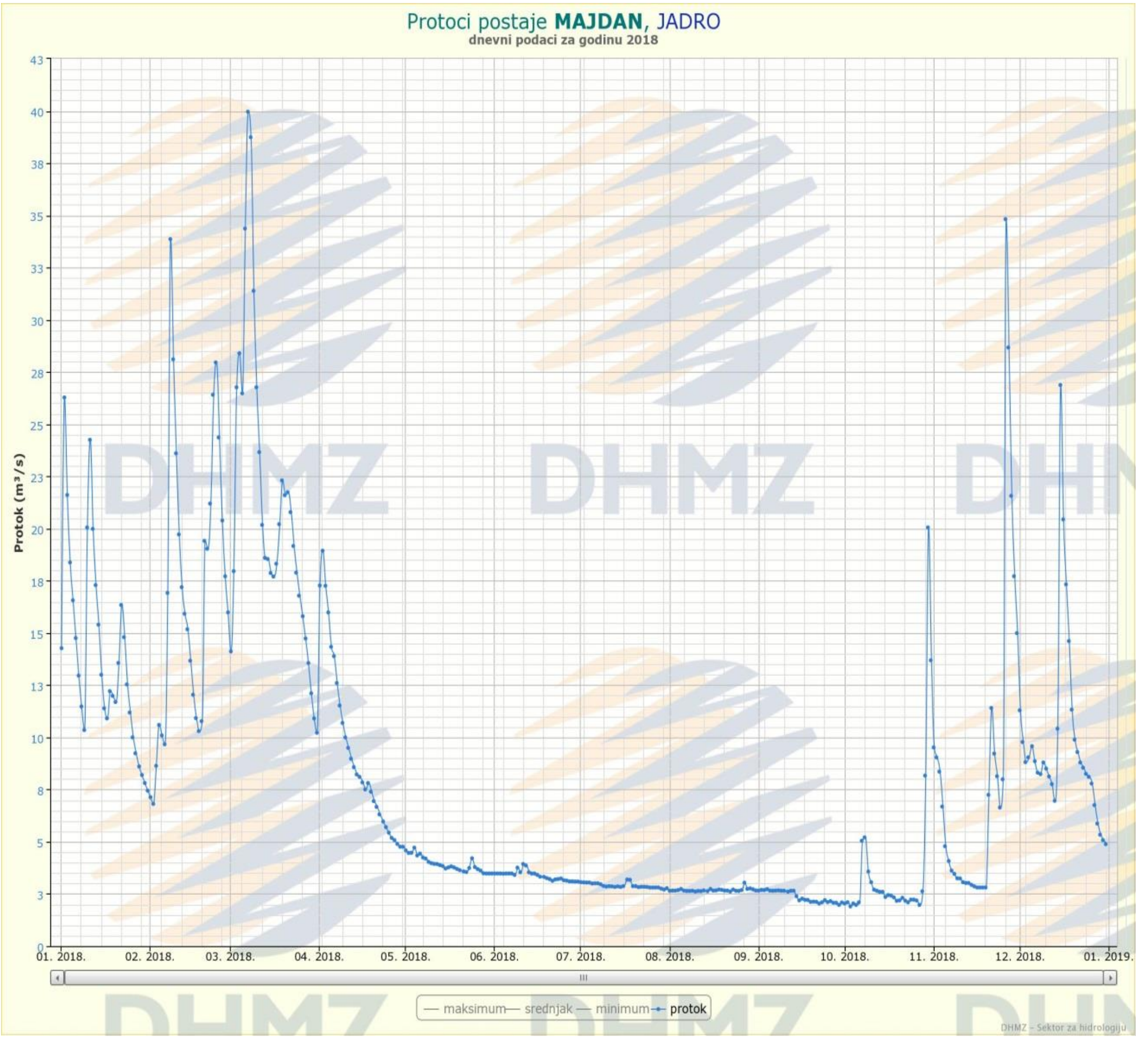

Figure 3.2.6. Jadro river daily discharge at Majdan station for 2018.

Jukić and Denić-Jukić (2009) estimated an average catchment area of 396 km^2 using the average monthly effective rainfalls and the average monthly groundwater recharges (Figure 3.2.7). The calculated groundwater balance shows that the Jadro Spring aquifer contains a significant storage capacity in the vadose and phreatic zones. During the year, the aquifer may accumulate up to 140 million m^3 of potable water.

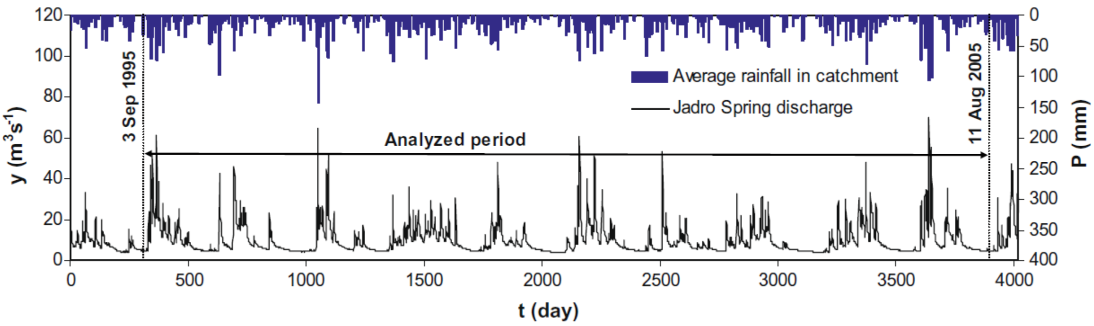

Figure 3.2.7. Daily average rainfalls in catchment (P) and daily discharges from the Jadro Spring (y) for the period of 10 hydrological years from 3 September 1995 to 11 August 2005 (Jukić and Denić-Jukić, 2009).

Bonacci (2012) analyzed hydrological data collected in the period from 1 January 1995 to 31 December 2009. Critical situations occur during dry summer months, particularly in July and August, when the natural discharges of the Jadro spring are low, water and air temperatures are high and water demands increase. In these months, sometimes also in September, more than 50 % of the natural discharge is taken from the spring, which is unacceptable from the viewpoint of sustainable management of this water resource. Of particular concern is the strong trend of increase in minimum annual discharges taken from the Jadro spring. Bonacci (2012) highlighted excessive water drainage from the Jadro spring and also alarming trend of increase in water drainage in the past 15 years. The relation between low discharges remaining in the Jadro river bed and high air temperatures was analyzed, and it indicates that there is a real danger of their coincidence and impact on the sustainable development of already very endangered karst environment.

According to LJubenkov (2015), the average annual discharge of the Jadro River measured at the Majdan station (Fig.3.2.8), is 7.9 $m^3 s^{-1}$ (1961–2010), the highest mean annual flow being 12.8 $m^3 s^{-1}$ (1970) and the minimum 5.1 $m^3 s^{-1}$ (1983). Within a year there is a considerable variation of the flow. Thus, the largest flows occur from November to March, with averages larger than 10 $m^3 s^{-1}$. The minimum mean monthly flows are observed in summer (July, August and September) and attain values of 3.3 $m^3 s^{-1}$, 2.9 $m^3 s^{-1}$ and 3.7 $m^3 s^{-1}$, respectively. It should be noted that even during the winter months relatively small flow rates can occur with monthly averages less than 4 $m^3 s^{-1}$.

Mihelčić and Lalić (2004) reported on general water characteristics at Jadro river spring. Mean annual temperature is 12.6 ^oC (10-15 ^oC), PH 7.7-8.2, chlorides are 13-22 mg l^{-1} and sediment over $8,2^oSiO_2$ only 13.2 days per year during extreme precipitation, and rarely is $>40^oSiO_2$ during short extreme rainfall.

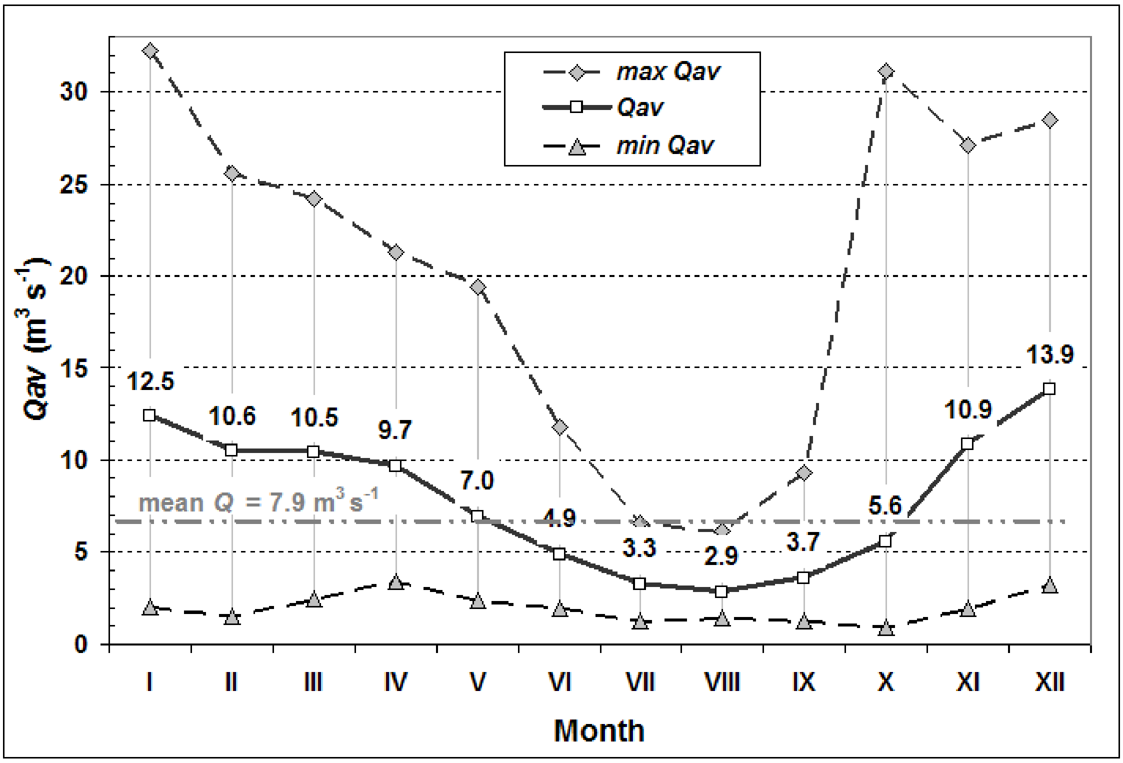

Figure 3.2.8. Monthly discharges of the Jadro River at gauging station Majdan (in the period 1961–2010). Qav is average discharge, maxQav is maximum mean monthly discharge and minQav is minimum mean monthly discharge (LJubenkov, 2015).

One larger tributary is situated downstream Majdan measuring site (western one on Fig.3.2.3), and thus contribute to the flowing discharge. However, the tributaries have in general a torrential character and, hence, feed the river occasionally, during the rainy season. In the summer period the streams are mostly dry (Ljubenkov, 2015).

Jukić and Denić-Jukić (2015) reported on time series of rainfall and Jadro karst-spring discharge that is influenced by various space-time-variant processes involved in the transfer of water in hydrological cycle. The analysed daily time series are the air temperature, relative humidity, spring discharge, and rainfall at seven rain-gauges over a period of 19 years, from 1995 to 2013. The application results show that the effects of spatial and temporal variations of hydrological time series and the space-time-variant behaviours of the karst system can be separated from the correlation functions. The main quantitative results obtained for the Jadro Spring show that the quick-flow duration is 14 days, the intermediate-flow duration is 80 days, and the pure base flow starts after 80 days. The base flow consists of an inter-catchment groundwater flow. The system memory of the spring is 80 days.

Kadić et al (2019) suggested that a preliminary detection of complex hydrological relations in karst systems can be carried out through analysing precipitation and discharge time-series, with an emphasis on the importance i.e. recommendation for implementing higher-order partial cross-correlation function. The analysis was based on available hourly values of meteorological data (precipitation, temperature and relative air humidity) and hydrological data (discharges) from the stations in the basins of the spring Jadro. It was proven that the time-series of temperatures, relative humidity and discharges have a significant influence on the precipitation-discharge correlation of dry and wet periods.

3.2.1.3. Sediment fluxes

There are no published data on sediment fluxes by the Jadro river stream. The water discharged by the Jadro spring is largely used for water supply since Roman times. Concentration of the sediment supplied by the groundwater is generally low and mostly fine-grained. Thus, it is generally considered that sediment brought by the spring does not contribute significantly to the sediment discharge. However, general observations of the orthophoto images imply a potential contribution of the fine-grained sediment derived from erosion of flysch marls exposed in a quarry situated close to the Jadro River upper stream (Fig. 3.2.9). Besides, construction works in marginal urbanized areas of the town of Solin as well as agricultural activities on the southern slopes of Klis could also contribute to enhanced erosion of the flysch marls and the residual soil developed on the marls. Thus, an occasional increase of the fine-grained sediment fluxes from the topographic catchment to Jadro River is expected.

Figure 3.2.9. Orthophoto image of Jadro River upper stream (2017). Note a quarry located close to Jadro river upper stream, the agricultural land of Klis area north of the upper stream and marginal urbanized area of town of Solin on the west. Source: DGU (https://geoportal.dgu.hr/).

Higher sediment fluxes are expected during rainy seasons, and especially during storms characterized by extreme rainfall (20-40 days per year), when water turbidity increases > 10 NTU. However, direct periodical measurements of both suspended and the bed-load sediment in the Jadro River lower stream and the estuary is missing.

As previously mentioned, middle and lower part of the Jadro River has been significantly hydro-morphologically changed and natural geomorphological processes here have been ceased. During several fieldworks in Solin town (K. Pikelj personal observations) it has been noticed that some parts of the channelized riverbed are covered by coarse-grained bedload, however, its origin is not easy to determine due to the massive anthropogenic changes. Furthermore, usually clear river water in the town centre and the fact that most of it is groundwater additionally corroborates the fact that fine-grained sediment transported by the Jadro River originates from flysch during periods of heavy rains, and mostly due to its tendency for mechanical weathering.

3.2.1.4. Nutrient fluxes

According to study of Štambuk-Giljanović (2006) performed with the aim to estimate the nitrogen and phosphorus loads in the Jadro River spring and its stream flow by calculating the load in kg/day or tons/year and to compare this with the load for the maximum allowed concentrations (MAC) for drinking water (Official Bulletin, No 46/94) expressed in kg/day or tons/year. Daily pollution loads at the Jadro River spring for total N ranged from 0 to 304 kg, for NH3-N from 0 to 38 kg, for NO3-N from 0–1321 kg and for PO4-P from 0–92 kg in the period from September 1993 to September 2003. When compared with MAC loads the results prove that the Jadro River spring is not polluted by nitrogen compounds and phosphorus. The average annual load for total N ranged from 10 to 33 t, for NH3-N from 0.25 to 5.15 t, for NO3-N from 40 to 190 t, and for PO4-P from 0.3 to 11.5 t. The nitrogen compounds and phosphorus loads vary from one year to another without any constant decreasing or increasing trends. The annual average loads compared with the average annual MAC loads (especially for NH3-N and PO4-P) show that there were no threats of constant pollution of the spring. The loads for total N and PO4-P along the Jadro River flow from the spring to the fishpond entrance were monitored over a five-year period from September 1999 to September 2004. The results show no regularities. The highest annual total nitrogen load of 45 t was recorded at the entrance to the fishpond (situated in the upper stream) during the 2002/2003 period. The highest annual PO4-P load of 10 t was measured at the Vidović Bridge during the 2003/2004 period; however, the concentrations of N and P did not exceed the MAC concentrations which are prescribed for drinking water. Štambuk-Giljanović (2006) concluded that the Jadro River spring and its streamflow are not polluted by nitrogen and phosphorus.

However, the lower stream is under the influence of urbanized area of the town of Solin. According to BULJAC et al. (2016 and refernces therein), the monitoring program of sanitary quality of sea in Kaštela

Bay (October 2008 - May 2009) indicates a significant improvement in the sanitary quality of sea Vranjic after years of extremely high concentrations of faecal pollution indicators in this area as a result of the successful Integral Project of Kaštela Bay Protection – ECO Kaštela Project. Thus, nutrients derived from the urbanized areas surrounding Jadro River are probably low.

Loborec et al. (2015) analysed the trend of typical spring-water pollution indicators. Water quality is estimated, and anthropogenic impact is assessed based on the COST 620 procedure, through analysis of hazards threatening to pollute water in this drainage area. It could be concluded that the nutrient levels at the Jadro River spring are within the allowed quantities.

3.2.2. Excess fertilizers, herbicides and pesticides usage

The whole topographic catchment of the Jadro is relatively small and covers about 28 km^2, while the agricultural land is generally half of it (Fig. 3.2.9). Agricultural land owned by local inhabitants is situated north of the Jadro River upper stream (Fig. 3.2.3). These are mostly oil tree yards, implying that fertilizers, herbicides and pesticides usage is probably not extensive. Thus, several smaller streams and two larger tributaries probably carry some amounts of pesticides from the agricultural land to the Jadro River stream. Vinceković et al. (2013) reported on occurrence of Persistant Organic Pollutants (POPs), where POPs pesticides were emphasized. According to the same source, a concentration of PCBs in the Jadro River was 3-13 ng/l in water and 2-507 ng/l in sediment in sampling period 1993/1994. During the same sampling period DDT-type compound concentration in the Jadro River was 20 ng/l and it was subsequently reduced to 2 ng/l.

3.2.3. Grease, oil, chemicals and salt input (from energy production, mining activity, irrigation and urban runoff)

Grease, oil or chemical input into the Jadro River is possible from the nearby highway in case of an extreme incident. Besides, there are pump stations and industry in the catchment area, and, considering the typical karst system, possible incidental pollution could reach Jadro as well.

Local boat harbor is situated in Jadro estuary and thus incidental or leaking engine oil and lubricants should be expected.

The Integral Project of Kaštela Bay Protection – ECO Kaštela Project probably significantly decrease the urban runoff related to Jadro River.

The Jadro River estuary area extends 1150 m upstream. This river segment can be significantly influenced by seawater, especially during summer dry periods, when sea intrusion into coastal aquifer may be expected in places.

3.2.4. Sediment as pollutant

Possible occasional extraordinary increase of the fine-grained sediment from the topographic catchment to Jadro River (see 3.2.1.3) and further to the river mouth in the Vranjic Bay could be considered as sediment pollution. Fluxes of the fine-grained sediment derived from erosion of flysch marls are expected from the Jadro River upper stream as well as from tributaries during extreme rainfall.

3.2.5. Acquisition of new in-situ data and analysis of recent trends of water and sediment fluxes

At the moment of the delivery of the report there were no new in situ measurements organized within the Change We Care project.

Divić et al (2020) presented an innovative low-cost measurement system for surface water properties at Jadro river mouth. Nine probes were released from the river mouth point, indicated as “source” in Fig. 3.2.10, and they were then collected after almost completely stopping, usually before reaching 500 m from the source. The results from the vertical profiles clearly show the salt wedge stratification, which typically occurs in similar estuaries in Croatia, and was previously detected in the River Jadro by other researchers. Such behavior causes the freshwater to be mostly contained in the upper layer that is consistently decreasing in thickness as one goes downstream, e.g., freshwater layer reaches up to a 1 m depth at the river mouth (vertical profile 1 in Fig. 3.2.11) as opposed to only 20–30 cm at the farthest vertical profile (vertical profile 4 in Fig. 3.2.11).

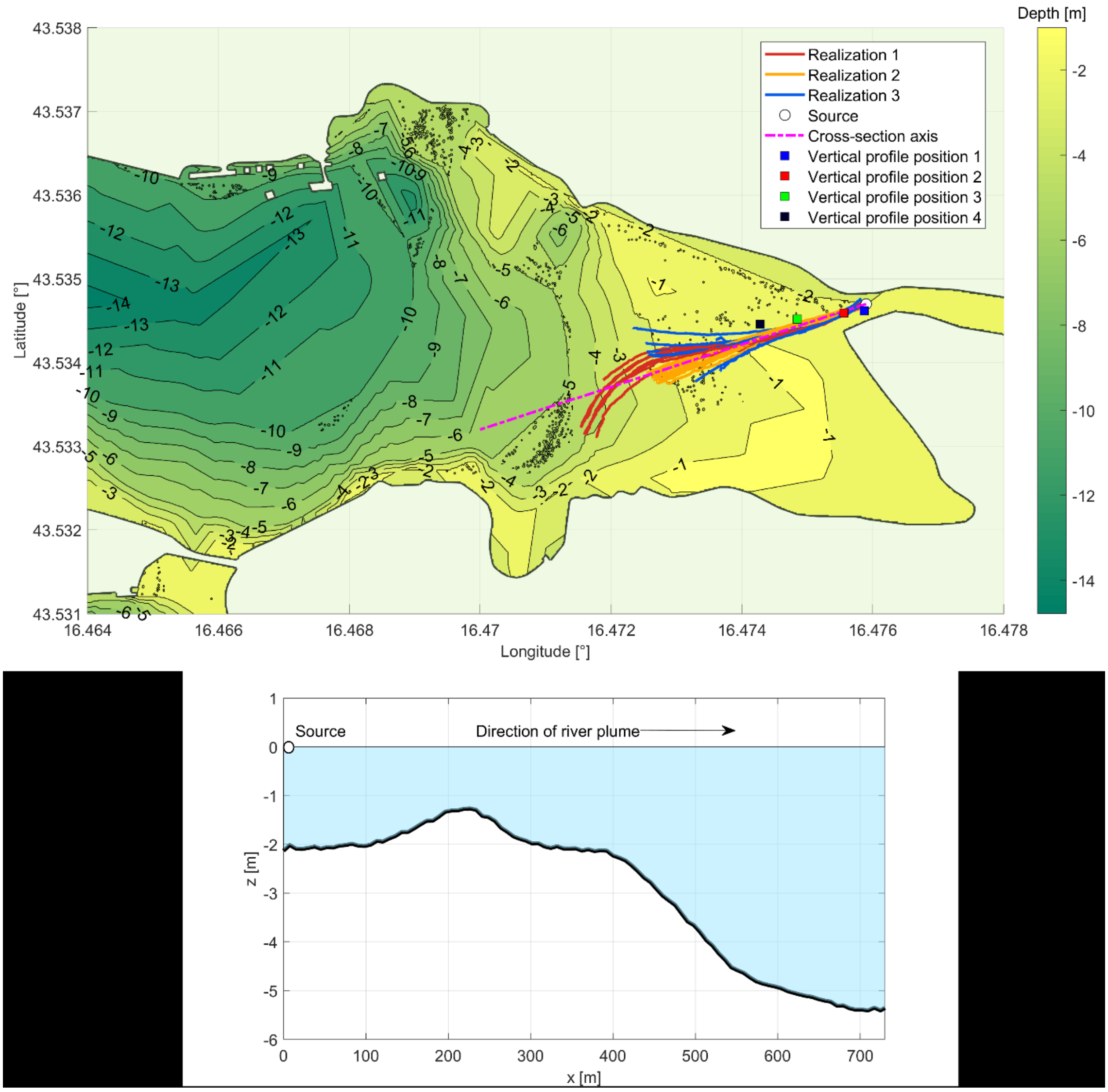

Figure 3.2.10. A map and a profile of the surface probes of the stream velocity, salinity and electrical conductivity at the Jadro River mouth (Divić et al., 2020).

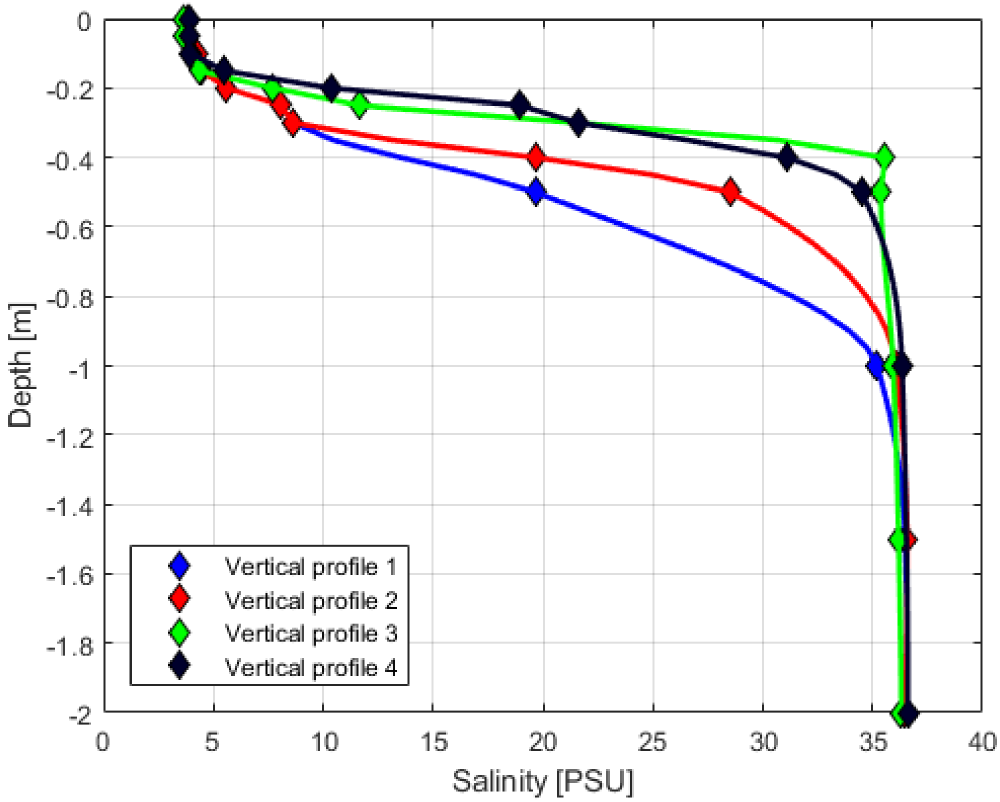

Figure 3.2.11. Vertical salinity profiles indicating the presence of the salt wedge stratification (Divić et al., 2020)

Velocities were calculated from the GPS data and were below 0.5 ms-1 on at first 300 m from the river mouth. For the first 100 m from the source point, most of the probes of Divić et al (2020) recorded a consistent river surface temperature in the range of 15–16 °C that are consistent with some of the previous measurements for the River Jadro during summer (Ljubenkov, 2015). Afterward, temperature slowly started to fluctuate as the sea water influence increases (at 150 m from source), finally reaching the ambient sea temperature of around 21–22 °C, in Kaštela Bay. The electrical conductivity was in range from 0.2 S7m close to river mouth up to 2 S/m at 300 m from the mouth.

3.2.6. Conclusion

3.2.6.1. Results of the activities and discussion

Jadro River spring is used as a major source of potable water for the wider area of the City of Split (more than 350.000 inhabitants), and thus is under a permanent control of the water supply authorities.

It can be generally concluded that any significant climate change can strongly influence Jadro River flow rates.

Nutrient supply from the spring is minor and under permanent monitoring of the water authorities.

Extreme rainfall could increase flysch marls erosion and fine-grained sediment supply to the river mouth, and consequently the sedimentation rate in the estuary and further in the Vranjic (Kaštela) Bay (see Act. 3.2.2 Report for Jadro River pilot site).

The successful Integral Project of Kaštela Bay Protection (ECO Kaštela Project) implemented during the beginning of the century significantly contributed to a decrease of the overall pollution of the water in the wider area of Jadro River and its mouth (Vranjic Bay).

3.2.6.2. Problems and solutions

Recent data presented by Margeta (2019) showed that climate change will affect discharge quantities and thus, water quality and sediment flux within the Jadro River and its estuary. The changes expected here are related to longer dry periods and shorter periods of higher precipitation and possible heavy rains. Furthermore, total precipitation is expected to be lower which together with sea-level rise may change water dynamics between the river and the sea. Permanent monitoring and correlations of precipitation, temperature, discharge and water usage is needed. The data can be used for climate modelling and the climate change predictions.

3.2.6.3. Analysis of data quality

At the moment of the delivery of this report, there are no analyses of the presented data quality.

3.3. Nature park Vransko Jezero

3.3.1. General description of site catchment

When compared with other pilot sites considered within the CHANGE WE CARE Interreg Project, it is obvious that Nature park Vransko jezero (Vransko Lake) differs largely since it does not represent river-sea connected system: it comprises a shallow lake situated in the immediate vicinity of the coast and a part of its catchment area. In order to understand the water and sediment fluxes of the Park itself, a wider catchment area (outside of the Park) will be considered here as well. More detailed geomorphological characteristics of the Vransko Lake has been described within 3.3 Project activities, however, some features will be repeated here in order to understand the water and sediment flux.

The Lake was formed within a well-recognized Dalmatian type of the coast, where both, concave and convex relief coastal features are elongated in the same direction and parallel to the coastline (Kelletat, 2005). Being the lowest point of the anticlines-synclines system of the Ravni Kotari region, Vransko Lake was formed after changes in freshwater-saltwater interface within the karst aquifer during postglacial sea-level rise (Katalinić et al., 2008; Ožanić and Rubinić, 2003). Basically, Vransko Lake is a submerged part of the karstic Vrana Polje. Poljes or valleys in this area are synclines mostly covered by impermeable Eocene flysch assemblage associated with younger (Quaternary) sediments and soils. Over the time, selective erosion of flysch assemblage led to the massive denudation of this Eocene deposits, revealing barren Cretaceous carbonates. Younger corrosive processes in its marginal parts widened the Vrana polje on the account of carbonates.

The Lake covers about 30 km^2, while the its catchment area is estimated to cover between 470 and 485 km^2 (Fritz, 1984; Stroj, 2012). Much of the catchment area is composed of Cretaceous and Eocene limestones (Mamužić and Nedela-Devide, 1968; Mamužić & Nedela-Devide, 1973; Mamužić, 1971; Mamužić, 1975). A combination of the alternating higher surrounding carbonate ridges and lower flysch valleys resulted in numerous karstic springs within the Lake catchment area, supplying it directly with groundwater (Figs. 3.3.1 and 3.3.2).

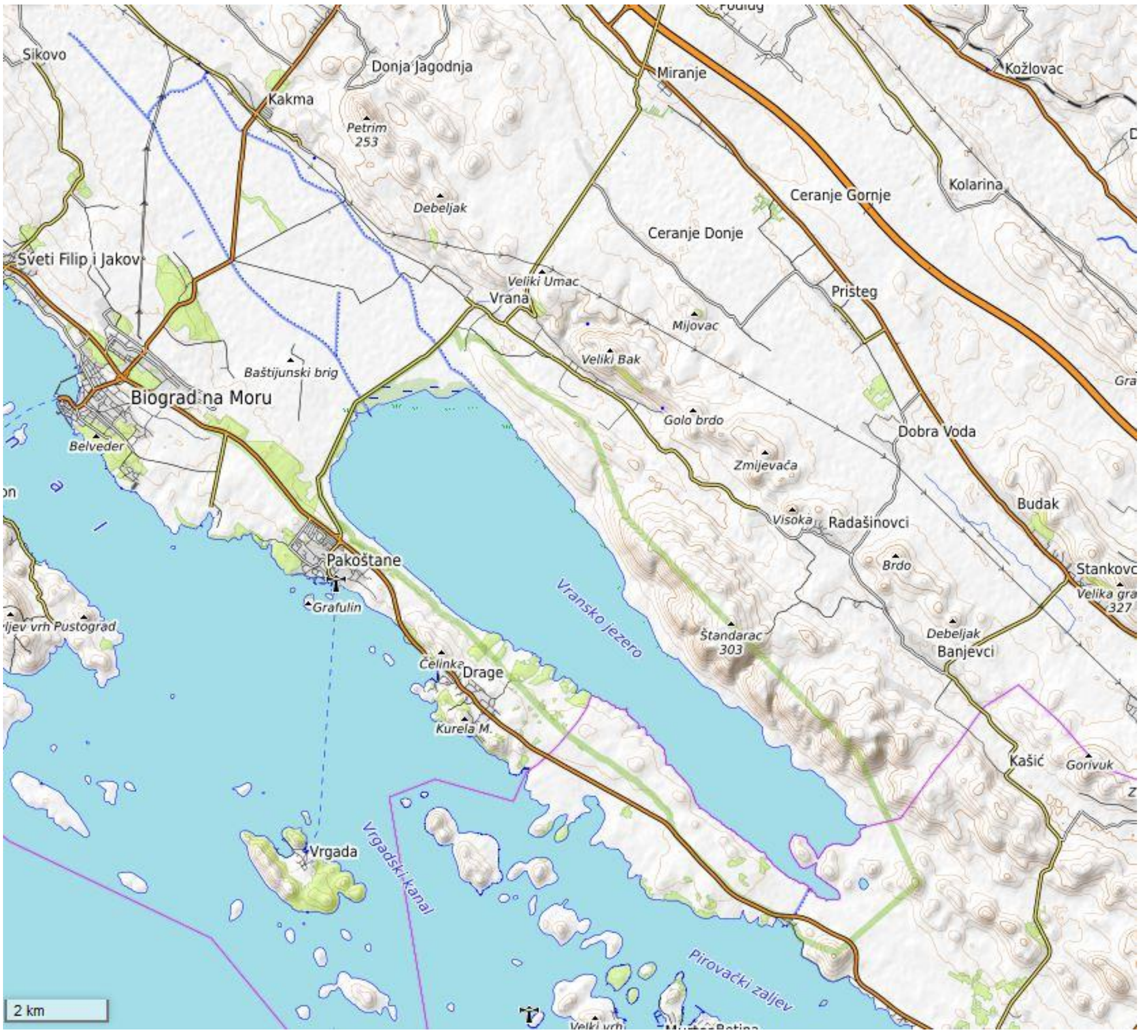

Figure 3.3.1. Topography of the Nature Park Vransko Jezero (bordered by green line) and its surrounding area (Source: Opentopomap)

Surface runoff formed by the combination of spring water and precipitation is the second source of the fresh water entering the Lake. It reaches the Lake via drainage channels from the subaerial part of the Vrana polje (Fig. 3.3.2). Surface streams network is developed in the north-western part, where the remnants of the former Mud of Vrana - a vast marsh – once existed (Figs. 3.3.2 and 3.3.3). In order to dry the marsh land, create agricultural area, prevent floods and marsh related diseases (e.g. malaria), 0.8 km long Prosika channel was built during the 18th century in its south-eastern part (Katalinić et al., 2008). Drying out enabled intensive agricultural activities within the Vrana polje. Besides the artificial channel, communication between the Lake and the sea is enabled through karstified underground, particularly in its south-western part, where brackish springs occur together with estavelle (Fig. 3.3.2). Accordingly, present Vrana Polje is partly covered with older lake sediments, indicating that the lake size varied during the recent geological past (Ilijanić, 2014).

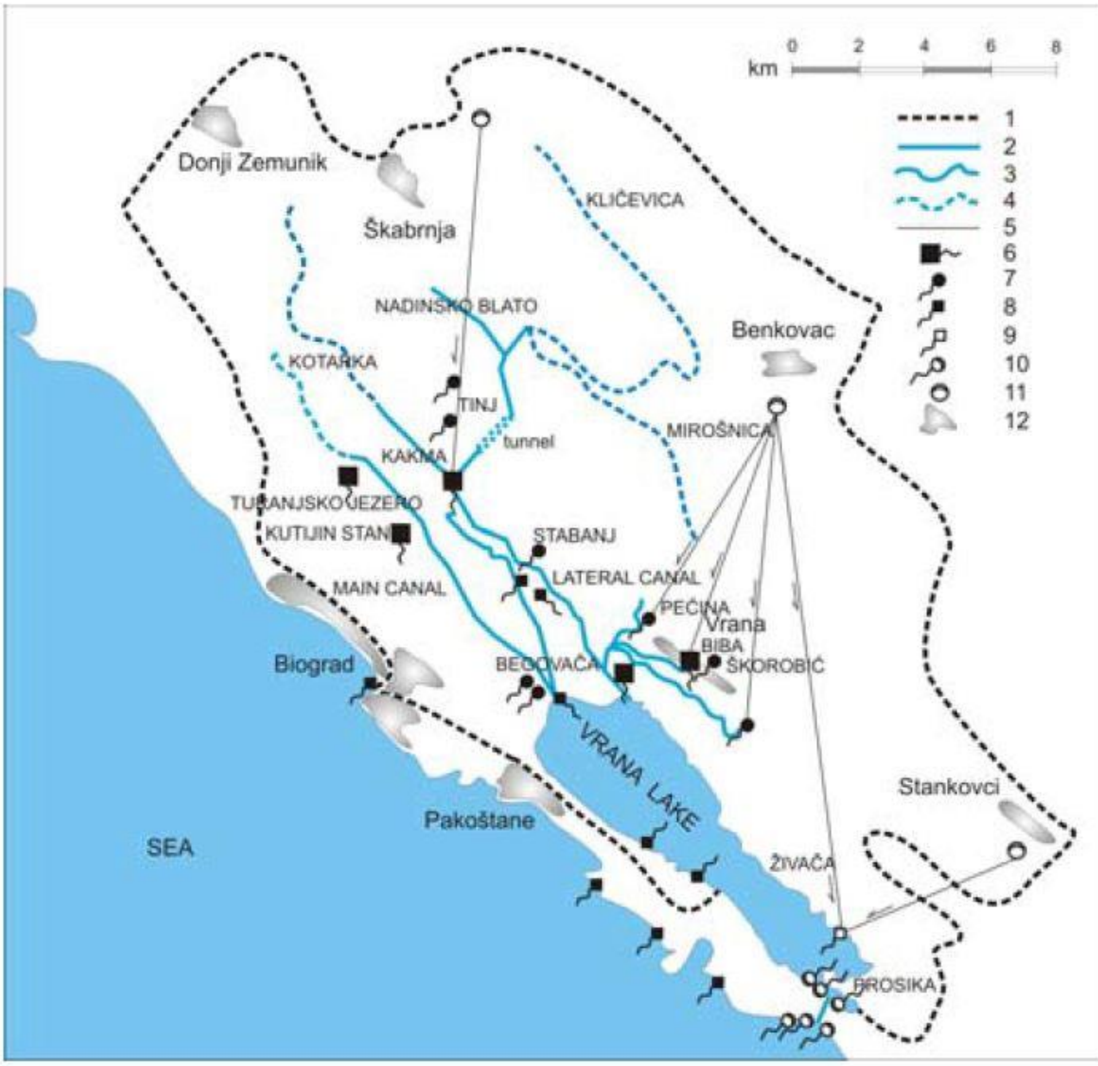

Figure 3.3.2. Schematic overview of the Vrana Lake catchment area. Legend: 1 – hydrogeological catchment boundary; 2 – regulation channel; 3 – permanent natural courses; 4 – intermittent natural courses; 5 – underground hydrological connection; 6 – water intake for water supply; 7 – affluent natural spring; 8 – brackish spring; 9 – vrulja; 10 – estavelle; 11 – ponor; 12 – settlement. (Source: Rubinić et al., 2010)

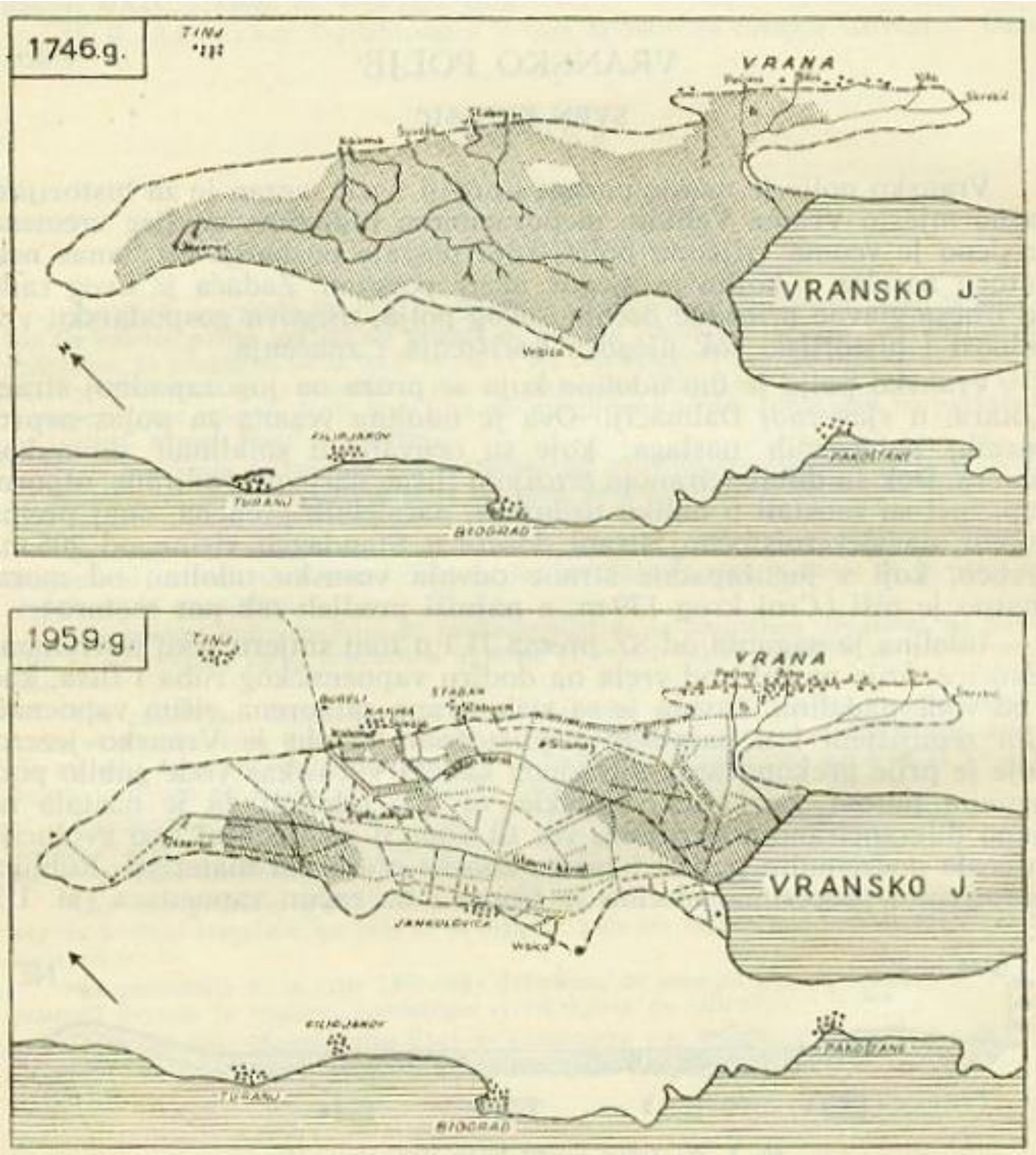

Figure 3.3.3. Natural surface flows and the extension of marsh (grey area western of the Lake 1746 (Upper sketch) and channelized area and reduced marsh (grey area western of the Lake) 1959 (Lower sketch) (Source: Kulušić, 1961)

3.3.1.1. Meteorological characteristics

The climate at the Nature Park is the mild Mediterranean climate, known by mild and wet winters and hot and dry summers. Much of the meteorological (and other) data presented here was collected The

Croatian meteorological and Hydrological Service (DHMZ). According to the climatological station in Biograd (1961–2012), the mean annual air temperature in the area is 14.7 °C. Monthly average summer and winter temperatures are 20°C and 9.4°C, respectively (Rubinić, 2014). According to climatological atlas of the Republic of Croatia for periods 1961-1990 and 1971-2000, the number of cold days (t_{min} <0°C) around the Lake slightly differs: most of the Park in its north-western part have 20-40 cold days, while this number ranges between 10 and 20 in its south-eastern part. In a similar way, number of hot days (t_{max} ≥ 25°C) is 100-120 and 110-120, respectively (Zaninović et al., 2008). Comparison of 2019 annual course of temperature to the average for the nearest meteorological station Zadar to the average for the 1961-1990 period is shown in the Fig. 3.3.4 and can be used as a trend for the Vransko Lake area. As it can be seen, temperature in 2019 was extremely high, approx. 1.5 °C above the average for the given period (grey line).

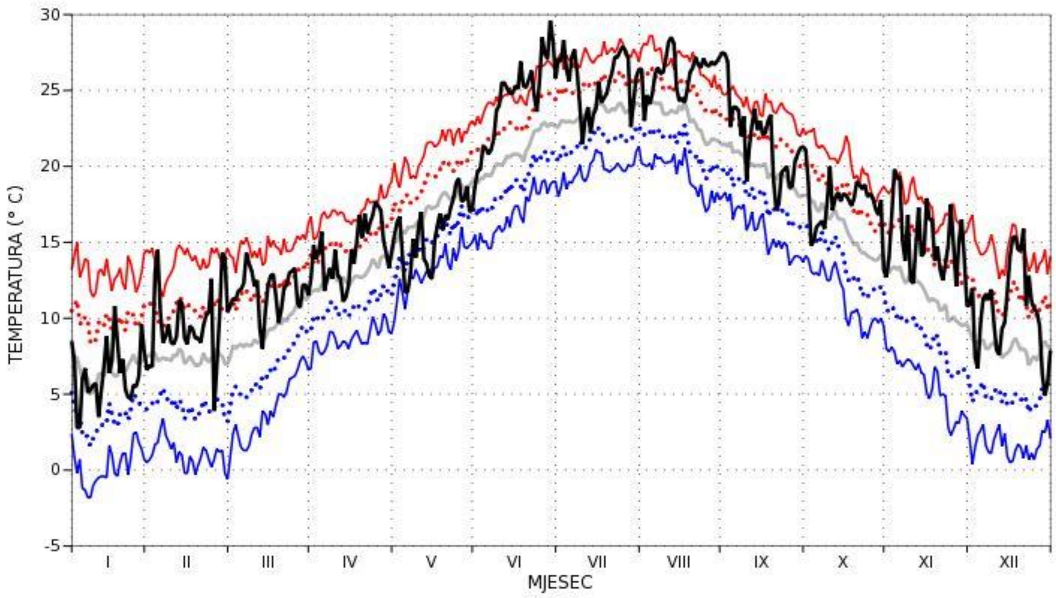

Figure 3.3.4: Comparison of Zadar 2019 annual course of temperature to the average for the 1961-1990 period. Legend: black line – daily mean for 2019; red line – daily mean + 2δ; red dashed line – daily mean +1δ; grey line – daily mean; blue dashed line – daily mean -1δ; blue line – daily mean -2δ. Source: meteo.hr.

Mean annual precipitation ranges between 800 and 900 mm, and the most of the precipitation is rain, since the number of snow day occurrence was < 5 for S≥ 1 cm (Zaninović et al., 2008). Mean annual insolation duration around the Lake is 2400-2500 h, while estimated evapotranspiration is estimated to 1660 mm/y (Zaninović et al., 2008; Katalinić et al., 2008).

3.3.1.2. Hydrological characteristics

Hydrological characteristics of the Vransko Lake are rather complex and are result of combination of dominant carbonate lithology combined with impermeable flysch, Mediterranean climate and location in the coastal karstic region of the Mediterranean where coastal aquifers are in contact with the sea. Hydrologically, the existence of the fresh water lake within the narrow coastal zone of the karstic Mediterranean is a rare phenomenon. Due to its complexity such a system is usually more prone to negative influences caused by climate change and human interventions. One of a key factors of water abundancy in case of the Vransko Lake is lithology. Hydrogeologically, the area is characterized by highly permeable Cretaceous limestones serving as a collector of the underground water. Dolomites in alteration with karstified limestones may represent a barrier for the groundwater flow, awhile the true impermeable rock assemblage is Eocene flysch. Besides flysch, the existence of the lake is due to the younger (Quaternary) lake sediments and proluvial deposits (Mamužić and Nedela-Devide, 1968; Mamužić & Nedela-Devide, 1973; Mamužić, 1971; Mamužić, 1975; Kapelj et al. 2008). The Lake is the lowest point of the Vrana area and thus a collector of surface water (Fig 3.3.5).

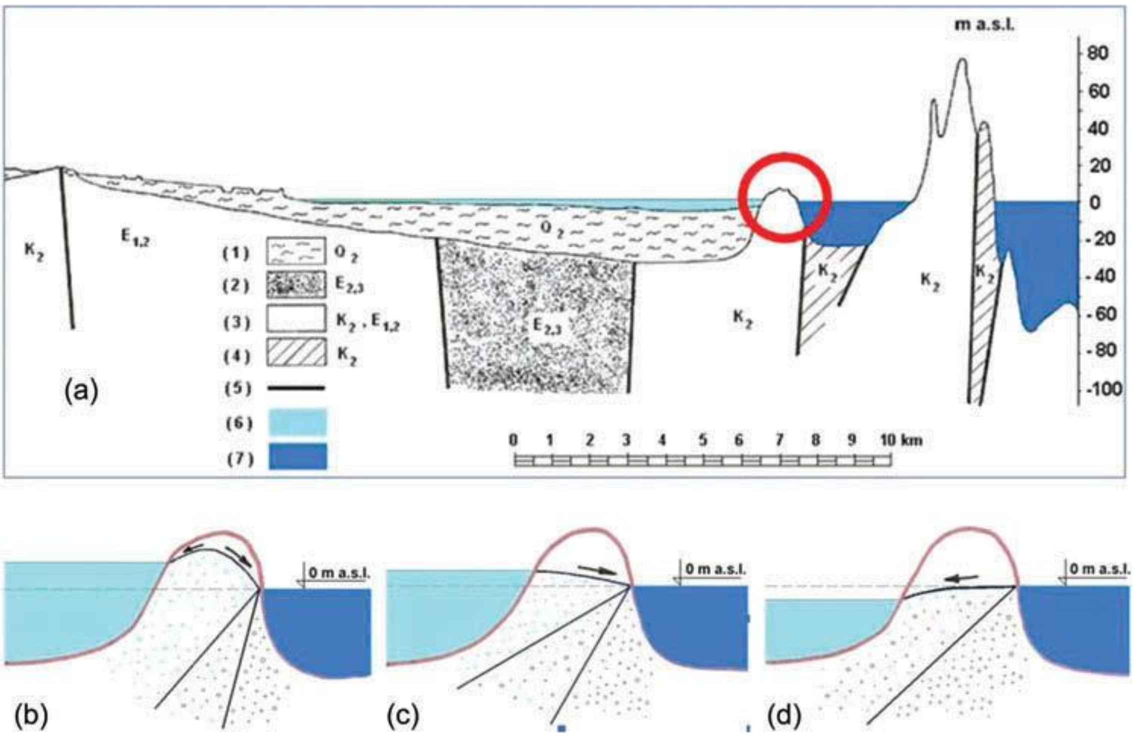

Figure 3.3.5: Hydrogeological characteristics of the Vransko Lake: a) longitudinal section of Vrana Lake basin with marked carbonate ridge that enables communication between lake and sea, (b) high water levels in lake during wet hydrological period, (c) high water levels in lake during dry hydrological period, and (d) low water levels in lake during dry hydrological period. (Source: Rubinić and Katalinić, 2014)

The Lake is a shallow cryptodepression with its bottom at 3.5 m below the sea level, while lake water level varies between 0.03 and 2.25 m a.s.l. Accordingly, considering its surface area of about 30 km^2, the volume of the lake varies between 50 000 and 120 000 m^3 (Rubinić and Katalinić, 2014). Drying out of the surrounding marsh area during the last 200 years indicates that the Vransko Lake is naturally rich in water, which is the actual phenomenon, a previously mentioned.

Due to its shallowness and the water loss, the Lake water level are highly variable depending on precipitation and the related surface runoff in the region. Average water level in the Lake for the period 1947-2019 is 0,79 m a.s.l. Regional decrease in precipitation and increase of average air temperature evapotranspiration underwent two episodes (2007/2008 and 2011/2012) of extremely dry periods and low water level (< 0,5 m a.s.l.) since 1999 according to Katalinić et al. (2017). As it shown on the Figs. 3.3.6 and 3.3.7, increasing water level is recorded within the 1947-2019 period, following the rising sea-level and indicating the obvious mixing of both waters within the karstic aquifer. Water level in the Lake are minimal during the summer-autumn period, when the sea-level tend to be the highest. During this period circulation in the sea-lake direction is thus aided.

The catchment area of the Lake includes supply by surface drainage of mostly regulated channels and by groundwater in form of springs. Surface inflow is considerably influenced by the seasonal precipitation (Rubinić and Katalinić, 2014). Hydrological disbalance between precipitation (approx. 800 mm) and evapotranspiration (> 1500 mm) can cause lowering of the Lake water level and intrusion of the sea water through both, karstified underground and artificial Prosika channel (Katalinić, 2008; Rubinić and Katalinić, 2014). Strong seasonal and even diurnial (Fig. 3.3.6) variations of lake-sea levels induces intensive flows in both directions and mixing of both water within the underground.

Interesting example of extremely dry and wet years, 2008 and 2010, respectively is shown in the Figure 3.3.8. During higher precipitation Lake water discharged into the sea through the Prosika channel. Conversely, during the dry period Lake level may lower bellow the sea level. In that case inflow of the sea water occurred (Rubinić, 2010). In order to prevent massive intrusion of the seawater, water level fluctuations of the Lake should be maintained and for this purpose a step within the Prosika channel height was constructed in 2009 (Rubinić and Katalinić, 2014). For this maintenance there are three key water level stations in the Park: on the Kotarka channel (NW part of the Park), on the lake-side of the Prosika channel, and the third on the sea-side of the same channel.

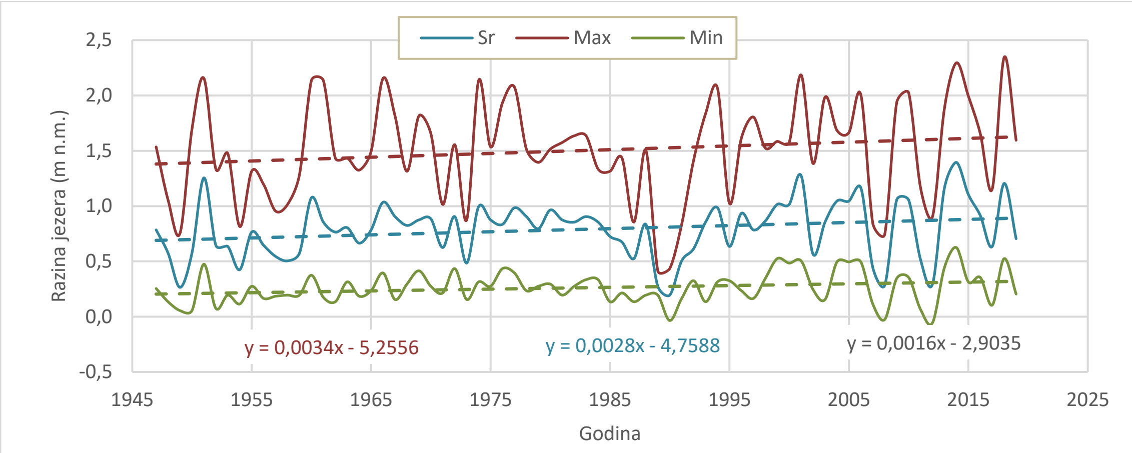

Figure 3.3.6. Course of characteristic annual water level (Kotarka station) in the Lake in the period 1947-2019. (Sr = average). Data compiled by Josip Rubinić (2020).

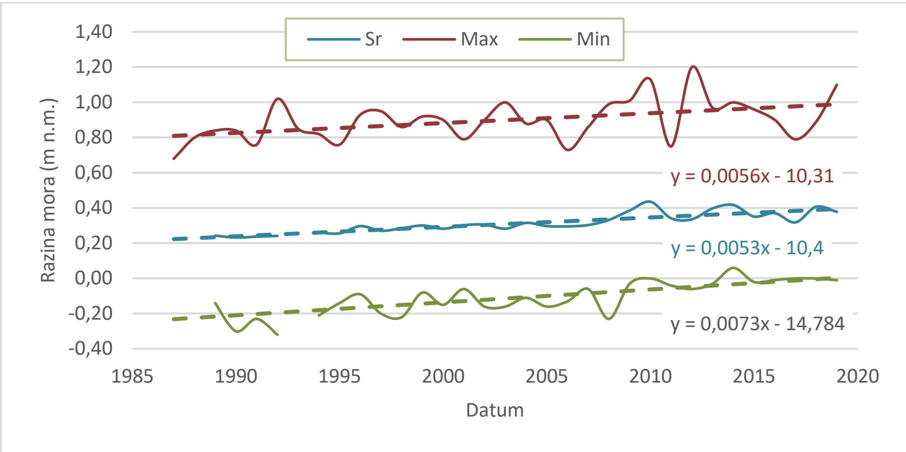

Figure 3.3.7. Course of characteristic annual sea- level on the Prosika station in the period 1947-2019. (Sr = average). Data compiled by Josip Rubinić (2020).

The quantification of the water inflow and loss in case of the Vransko Lake is still not possible due to the high complexity of its hydrological characteristics, but also irregular or absent hydrological monitoring in the past. Rubinić and Katalinić (2014) proposed a method for water flow calculation based on the annual precipitation and air temperature data. Modelled surface runoff for the period 1961-1990 was calculated to be 7,16 l/s km^2, while the annual discharge from the catchment was almost 3.5 m^3/s. Projections for the period 2021-2050 is decrease in annual discharge between 8 and 14%, while this decrease may reach 30-60% by 2100 (Rubinić and Katalinić, 2014).

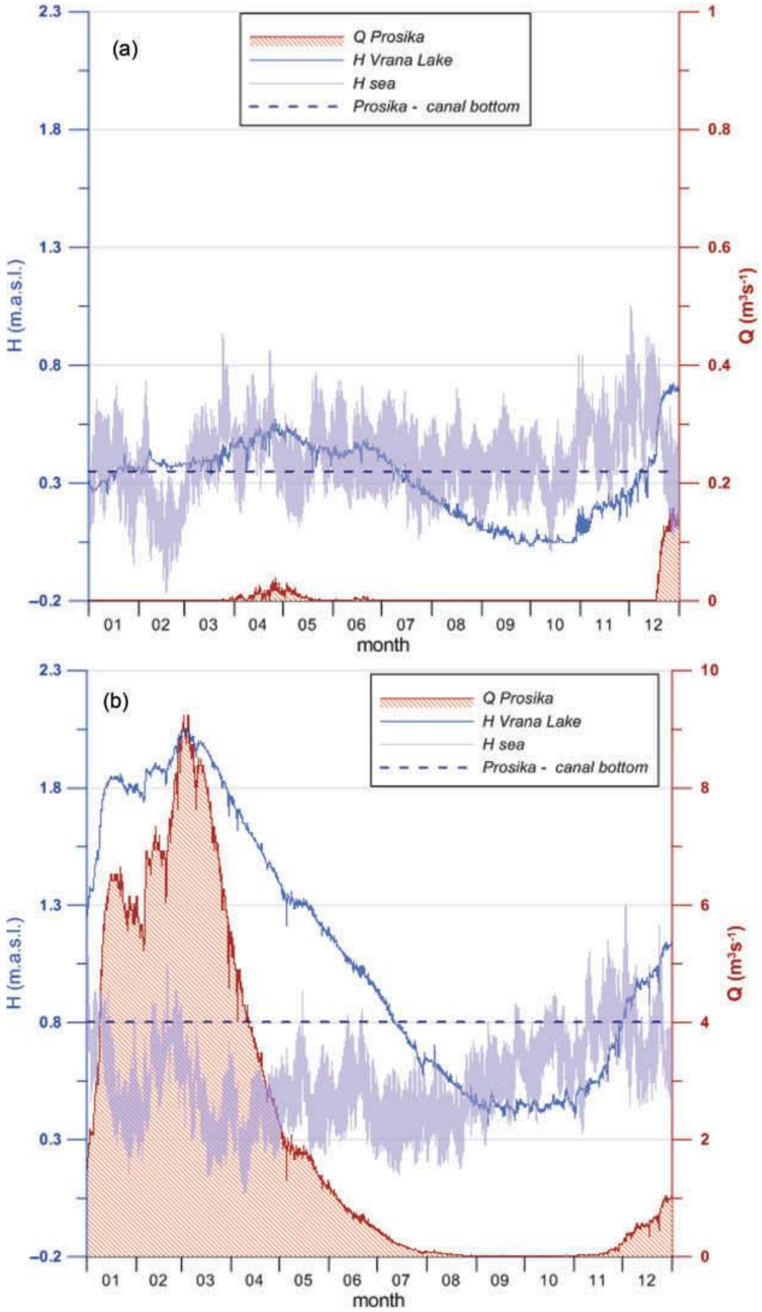

Figure 3.3.8. Hourly water levels in Vrana Lake and the Adriatic Sea showing the minimum elevation of the canal bed: (a) during 2008 before reconstruction of the canal bed, and (b) in 2010 after reconstruction. (Source: Rubinić and Katalinić, 2014).

3.3.1.3. Sediment fluxes

In line with the above described functioning of the Vransko Lake it is clear that sediment flux in case of Vransko Lake is still unknown, mostly due to the natural complexity of the lake water-sediment system functioning and the superposed human interventions within the Lake drainage area during the last 250 years. However, it is well known that the Lake itself together with the Vrana polje are covered by Quaternary deposits of Holocene age (Mamužić and Nedela-Devide, 1968; Mamužić & Nedela-Devide, 1973; Mamužić, 1971; Mamužić, 1975; Fritz, 1984; Ilijanić, 2014). Recent sedimentation within the Lake decrease water exchange with the sea: deposited material can close communication channels in the karstified carbonate aquifer. Based on the 29m long sediment core taken from the centre of the lake, Fritz (1984) showed that lake sedimentation started after the Pleistocene-Holocene sea-level rise and that it was mostly uniform during the last 9000 years. Thickness of Holocene sediments reached almost 30 m in the central part of the Lake, indicating contemporary sea-level rise and land subsidence. Studied Holocene sediment is mostly composed of clay and silt, while the lowermost clay deposits contain pebbles (Fritz, 1983; Fritz, 1984). Surface sediments in the Lake are dominated by carbonates, however, siliciclastic component is present as well. This composition indicates carbonate nature of lacustrine sediments with occasional influence of surrounding flysch (Fajković et al., 2014; Ilijanić, 2014). Higher amounts of siliciclastic component within the Lake sediment in the past indicates periods of possible intensive land use in the Vrana area (Ilijanić, 2014). Fajković et al. (2014) estimated sedimentation rates for the Vransko Lake: 8-10 mm/y in period 1954-1964; 2.3-4.1 mm/y for period 1964-1986 and 2,5-5 mm/y for period 1986-2010. Using the average sedimentation rate of 4,45 mm/y, it is calculated that average annual amount of deposited material within the Lake is 140 000 m^3 (data calculated by Josip Rubinić). In general, this decrease of sedimentation rate after 1964 can be related with decreased water discharge calculated by Rubinić and Katalinić (2014) for the same period, both indicating a general increase in dryness of the area.

Permanent monitoring of the sediment concentration does not exist, however, some estimates showed that 78 000 to 98 000 m^3/y may enter the Lake from the catchment area. Isolated monitoring campaigns of sediment load were done during 1996 and 1997. Average concentration of sediment entered the Lake was 6,23 g/m^3. Higher concentrations of the sediment load were related with periods of intensive precipitation within the drainage area.

3.3.1.4. Nutrient fluxes

Water quality monitoring has a long tradition within the Vransko Lake area, however, frequent changes of monitoring stations, sampling methodology, analysed water quality parameters etc. resulted in poorly highly dispersed data sets. All water quality monitoring campaign usually include water temperature, pH, conductivity, suspended load, alkalinity and total Ca-hardness. Further more oxygen regime is being monitored as well (dissolved oxygen, oxygen saturation), nutrient concentrations, various ions (calcium, magnesium, chlorides, silicates, sulphates), some biological indicators and metals with organic matter. The Vransko Lake is one of the most vulnerable water resources of high biodiversity (Mrakovčić et al., 2003). It is polymictic type of the lake (Gligora et al., 2007) which according to the total phosphorus, chlorophyll composition and biomass of the microzooplankton can be classified as mesotrophic lake (Peroš – Pucar, 2006). It is slightly brackish lake with highly changeable concentration of main seawater macroconstituents (chloride, sulphate, magnesium).

Nutrient load within the Lake is considerable due to the intensive agriculture in the wider area. Concentrations of the supplied nutrients vary significantly. When combined with water stratification and increased temperature, the lake is fluctuating between oligotprophy and eutrophy, leading sometimes to anoxic events. Such events occurred in 2017 and 2019.

Average concentrations of nitrates for period 2002-2019 were given in the Table 3.3.1.

Table 3.3.1. Average nutrient concentrations for period 2002-2019 on Mote, Kotarka and Prosika stations

Station		**Motel**	**Kotarka**	**Prosika**
Nitrates (mgN/L)	Av	0,915	2,54	0,662
	Max	6,6	14,0	2,54
	Min	0,010	0,010	0,010
Total N (mgN/L)	Av	1,45	3,23	1,22
	Max	7,02	14,0	3,66
	Min	0,136	0,406	0,226
Total P (mgP/L)	Av	0,037	0,031	0,035
	Max	0,276	0,315	0,304
	Min	0,005	0,004	0

Nutrient concentrations (nitrate, ammonia, chloride, phosphate and sulphate) in Vrana polje soils, spring water and drainage channel water were studied by Marković et al. (2006). Obtained results (Fig. 3.3.9) showed that their concentration in soils varies spatially, as a consequence of various practices of use of agricultural surfaces. Springwater concentrations are low, while Kotarka channel water, which drains arable surfaces showed higher nutrient load.

Depth, cm	Organic matter (%)	pH_V	pH_{KCl}	PO_4^{3-}, mg/kg	SO_4^{2-}, mg/kg	Cl^-, mg/kg	NO_3–N, mg/kg	NH_3–N, mg/kg	Depth, cm	Organic matter (%)	pH_V	pH_{KCl}	PO_4^{3-}, mg/kg	SO_4^{2-}, mg/kg	Cl^-, mg/kg	NO_3–N, mg/kg	NH_3–N, mg/kg
TJ-1/0-15	7.9	6.91	6.24	5.50	90.00	17.00	9.25	6.25	TJ-3/0-20	8.6	7.55	6.22	45.24	35.00	9.03	14.50	21.00
TJ-1/15-20	8.8	7.11	6.30	3.90	122.50	45.25	8.25	6.25	TJ-3/20-40	12.9	7.66	6.33	26.52	27.50	7.98	2.00	23.75
TJ-1/20-30	8.5	7.22	6.44	3.25	92.50	15.25	5.25	6.25	TJ-3/40-60	12.3	7.79	6.42	26.52	17.50	9.03	0.75	13.75
TJ-1/30-50	7	7.28	6.58	1.75	70.00	12.50	6.25	10.25	TJ-3/60-80	13.8	7.91	6.41	14.04	20.00	16.17	12.75	20.50
TJ-1/50-65	5.5	7.79	6.82	0.75	47.50	10.75	5.50	3.25	TJ-3/80-100	11.5	7.88	6.37	7.80	35.00	23.73	0.50	19.00
TJ-1/65-85	5.4	7.93	6.94	1.25	42.50	13.75	6.50	3.12	TJ-3/100-120	11.3	7.86	6.44	6.24	15.00	48.09	0.50	23.00
TJ-1/85-100	5.1	8.04	7.06	0.50	27.50	18.00	6.00	2.75	TJ-3/120-150	10.3	7.95	6.62	<0.01	47.50	24.78	0.50	37.50
TJ-1/100-115	4.8	8.20	7.10	0.88	22.50	16.25	5.25	10.00	TJ-4/0-20	11.1	8.04	6.70	46.80	45.00	6.51	2.00	12.50
TJ-1/115-130	5.7	8.18	7.04	0.63	47.50	12.75	6.25	13.25	TJ-4/20-40	10.1	8.05	6.93	15.60	40.00	7.56	1.50	12.25
TJ-1/130-150	6.3	8.12	6.90	1.00	25.00	11.25	9.50	2.38	TJ-4/40-60	9.2	8.00	6.99	6.24	42.50	12.81	5.50	13.00
TJ-2/0-15	9.5	7.96	6.62	37.50	45.00	14.00	10.50	13.00	TJ-4/60-80	9.8	7.90	7.00	14.04	45.00	22.47	4.00	10.00
TJ-2/15-30	9.8	7.90	6.61	31.25	22.50	15.75	8.25	12.50	TJ-4/80-100	10	7.89	7.01	17.16	50.00	15.96	5.25	11.00
TJ-2/30-50	11.3	7.82	6.43	14.13	22.50	16.25	7.75	12.25	TJ-5/0-20	13.5	7.92	6.96	<0.01	22.50	5.67	8.00	9.50
TJ-2/50-65	9.3	7.88	6.55	12.25	20.00	12.00	16.50	8.00	TJ-5/20-40	14.2	7.97	6.94	1.56	25.00	7.98	14.25	23.00
TJ-2/80-100	7.5	7.95	6.75	11.00	7.50	8.00	7.50	11.25	TJ-5/40-60	12.4	8.02	6.94	<0.01	55.00	15.12	0.75	10.25
TJ-2/100-120	5.9	8.06	6.77	11.00	10.00	11.50	4.50	10.00	TJ-5/60-80	15.9	8.01	6.90	<0.01	20.00	13.86	11.75	13.00
TJ-2/120-135	6.2	8.04	6.79	17.25	27.50	11.25	3.25	12.00	TJ-5/80-100	14.1	8.12	6.93	<0.01	25.00	13.65	<0.01	26.50
TJ-2/135-150	6.2	8.08	6.82	6.25	25.00	8.25	3.50	8.50									

Figure 3.3.9. Concentrations of organic matter, nitrates, sulphates and phosphates in soil samples collected in arable area.

Water drained by natural surface flows and drainage channels, such as studied Kotarka channel (Marković et al., 2006), eventually end in the Lake. Thus, there is a possibility that higher nutrient supply to the Lake may induce and/or change plant biomass growth. Gligora et al. (2007) showed that the annual changes in phytoplankton biomass and species diversity occured due to the nutrient availability, particularly nitrogen. Concentration of phosphorus were reported to be relatively low. This was assigned to the nature of the Lake water (high carbonate ion concentration, due to karstic environment and bedrock) and dominance of carbonaceous particle within the lake sediment. Carbonate-rich water and sediment may affect (increase) pH, inhibiting thus phosphorus release into the Lake water (Gligora et al., 2007).

3.3.2. Excess fertilizers, herbicides and pesticides usage

Despite the fact that the Vrana polje is area of intensive agricultural land use, data related to herbicides and pesticides are still largely scarce. Herceg Romanić et al. (2018) reported on organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) in Vransko Lake fish (Cyprinidae species), however the results refer mostly to methodology of OCPs and PCBs measurements. Nutrient data was described in the previous section.

3.3.3. Grease, oil, chemicals and salt input (from energy production, mining activity, irrigation and urban runoff)

Data about grease and oil in the Vrana polje and Vransko Lake are not found in the published literature. Considering the intensive agricultural land use, accident including oil spills are not excluded in the future

Marković et al. (2006) investigated geochemical composition of soil and spring water in the Vrana polje in order to examine possible contamination due to the agricultural land use. They found that a total concentration of Al, As, Cd, Co, Cr, Cu, Fe,Hg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sr, U and Zn in soils of the Vransko polje are lower than the Croatian maximum threshold values given for arable lands (according to Official Gazette NN12/01). However, Mo, Cu, Cd, Pb, Ni, As, P showed its highest concentrations in the topsoil samples indicating their accumulation in the soil due to application of agrochemicals. Springwater contained low concentrations of metals, however, the main draining channel Kotarka showed increased concentration of almost all metals, indicating thus the impact of agricultural land use as well. However, the fact that increased concentration of some metals occurred only in the topmost soils and the high quality of spring water imply that groundwater in the Vrana polje is still protected by the surface impermeable deposits (soils).

Increased salt input is the most prominent characteristics of the Vransko Lake. This input is recently studied by Rubinić (2014) and Rubinić and Katalinić (2014). They showed together with Gajić-Čapka et al. (2011) that ongoing climate changes already affect the Lake. Two models - REGCM3 (Pal et al., 2007) and Aladin (Bubnova et al., 1995)- were used for climate change projections for period 2010-2100, while data sets were based on the precipitation and temperature data. Reference period was 1961-1990. Obtained results showed that the average annual temperatures in period 2021-2050 might increase 8%. Increase of

22% may occur during period 2071-2100 compared to the reference period. Average annual precipitation would increase 1-2% or decrease up to 2% (depending on model) for the period 2021-2050. Projections for the period 2071-2100 are 11% and 15% for REGCM3 and Aladin model, respectively.

Decreasing trend of water discharge within the Vransko Lake is shown in the Figure 3.3.10. Model projections are smoothly continuing the decreasing trend until 2100.

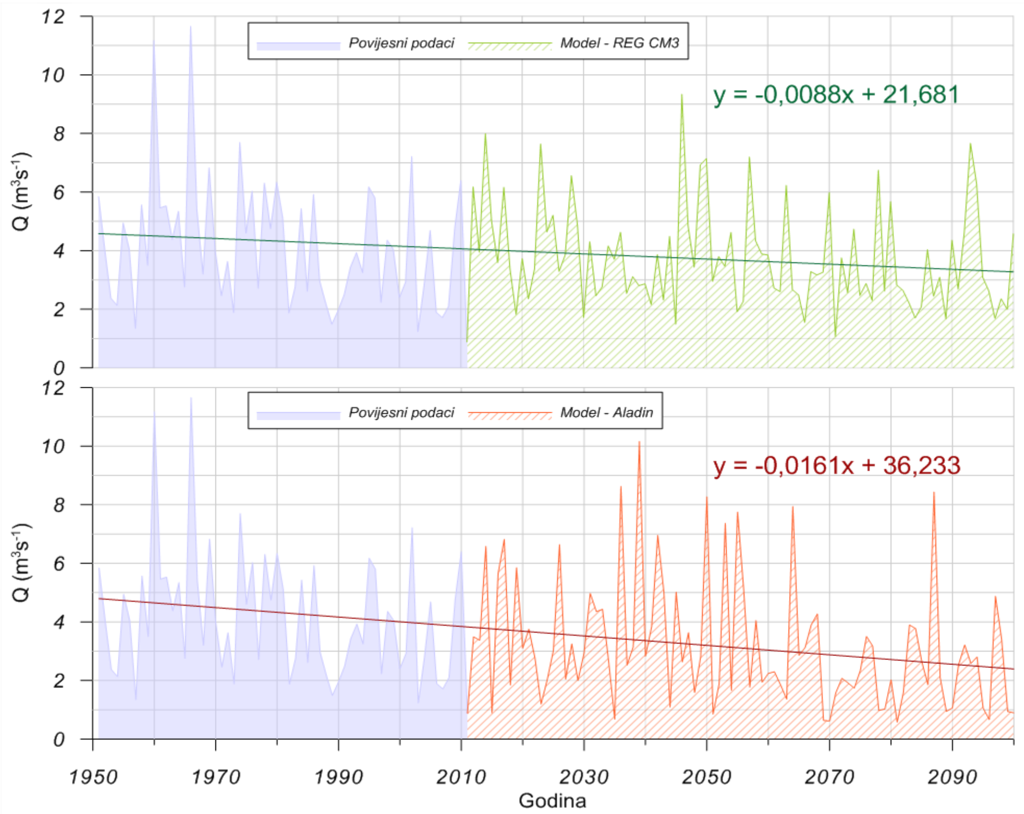

Figure 3.3.10. Vransko Lake water input: Historical data (purple; 1951-2011) and model projections for period 2012-2100 (green and red; depending on the model). Source: Rubinić, 2014.

3.3.4. Sediment as a pollutant

It was shown by Marković et al. (2006) that the surface soil cover may contain increased concentrations of some heavy metals and nutrients, as a result of intensive agriculture within the Vrana polje. Water and sediment flux toward the Lake in case of the surface runoff may eventually increase the concentration of contaminants in the Lake. However, nature of the lake water and lake sediment should be further investigated together in terms of contaminant behaviour and availability.

3.3.5. Acquisition of new in-situ data and analysis of recent trends of water and sediment fluxes

During the Change We Care Project activities (2018-2019), acquisition of new data continued in Vransko Lake Nature Park. Much of the data were merged with historical data and discussed in the previous sections. Results of meteorological and hydrological conditions during the last two year presented here were chosen to emphasize direct impact of precipitation on the hydrological regime of the Lake.

Precipitation data measured on the 3 stations in the wider Lake area showed that 2018 was extremely wet year with 130-303 mm/y compared to the historical average (1961-2019). In contrast, 2019 may be characterized as an average year. At the same time, data on the Biograd climate station showed that both years were 1.5 °C higher compared to the average (14.9 °C). Similar data were obtained for the Lake water level, directly pointing its dependency on the precipitation. Rainfall data were discussed in previous sections. Chlorides and conductivity values were consistently lower for the wet 2018 in case of the Kotarka discharge channel, which was expected.

3.3.6. Conclusion

As previously emphasized, Vransko Lake is one of the most sensitive environments of the surface water resources along the Croatian coast. Ongoing climate changes already recorded in presented data, together with historical trends and future projections clearly showed that salt water intrusion is the main problem in case of the Vransko Lake, mostly due to the temperature increase and precipitation decrease. Increased nutrient input due to the anthropogenic agricultural activities may further contribute to the environment deterioration.

3.4. Banco Mula di Muggia

3.4.1. General description of site catchment

The Banco Mula di Muggia is located in the Autonomous Region of Friuli Venezia Giulia (*Figure 3*). It is entirely included in the Municipality of Grado, on the northern coast of the Adriatic Sea, located between the Grado inlet and the mouth of the Isonzo River. The coordinates are between 13°24’36” and 13°28’15” East and between 45°21’17” and 45°39’30” North.

It is part of the system of low sandy beaches of the Friuli Venezia Giulia, limited to the west by the mouth of the Tagliamento and to the east by that of the Timavo, where the high rocky coast begins. The coastline has undergone significant changes in historical times due to natural processes but also to anthropic actions i.e. land reclamation and tourism development.

Grado is a touristic island at the eastern part of the Marano and Grado Lagoon (*Figure 3*). The town has about 8.000 inhabitants but during the summer season this number increases at least three times; statistic data say that 1.355.334 is the number of presences in the accommodation facilities for the whole 2017.

The Banco Mula di Muggia is a barrier-island system of relict sand banks, which extends up to 2 km seawards. A succession of sandy bars (between -2 m and -5 m), arranged in the form of an arc, represents the outer limit of a wide muddy intertidal zone partially covered by seagrass. In sedimentary and morphologic continuity is the bar complex of the Isonzo mouth, extending eastwards, beyond the Primero tidal inlet.

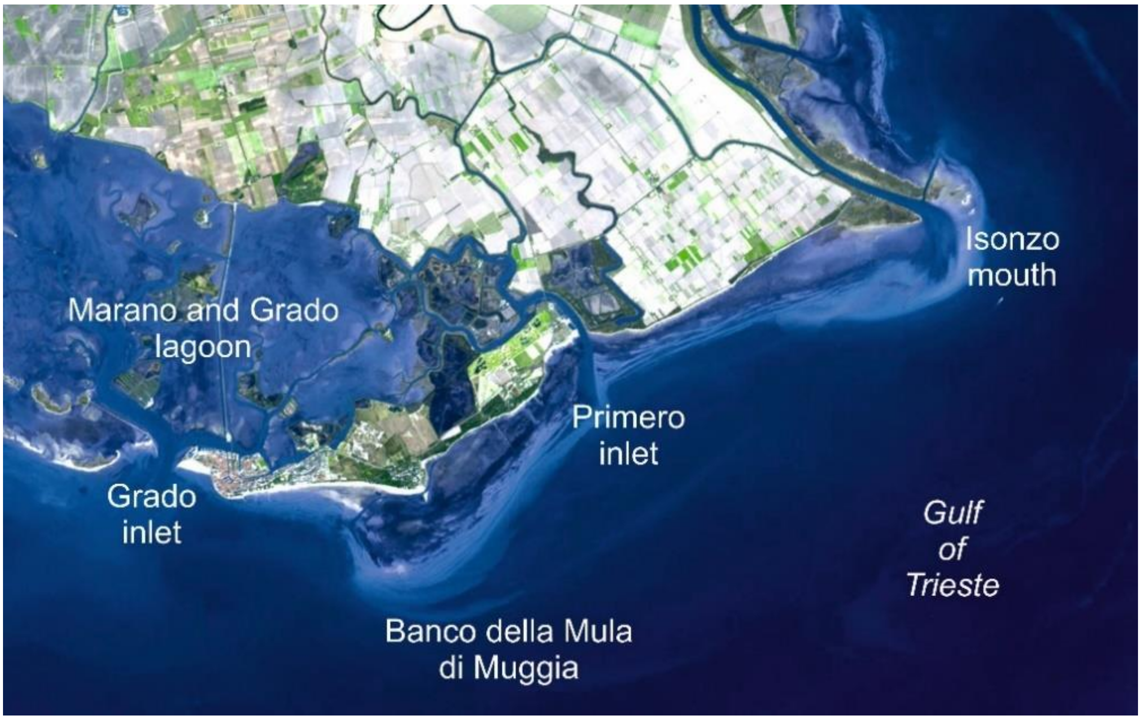

Figure 3.4.1. Overview of the study area.

Figure 3.4.2. Location of Grado (www.viamichelin.com).

3.4.1.1. Meteorological characteristics

The Friuli Venezia Giulia Region is characterized by a geographical position and by an orography that significantly affect its meteorology and therefore the climate. The Region is located in the middle latitudes, where the contrast between the polar and tropical air masses is marked: this contrast frequently generates disturbances of the normal state of the atmosphere.

Furthermore, Friuli Venezia Giulia is part of those regions, orographically complex, where the processes of formation of perturbations and their evolution are strongly influenced by the reliefs: specifically, it is the Alpine chain that modulates the atmospheric circulation with effects both on temperatures than on rains.

The Alps prevent the flow of particularly cold air masses from the North and in this sense operate a major mitigating action, especially on minimum winter temperatures. The Alps also constitute a barrier to the humid flows from the South West and South East, which are typical of regional meteorology, causing a significant increase in rainfall, both in terms of quantity and frequency, compared to other areas in northern Italy.

The Adriatic Sea tends to mitigate temperatures: the coastal areas compared to those of the internal plain have higher average temperatures in winter and lower in summer. However, it should be noted that the Upper Adriatic is a relatively shallow basin and this element causes the mass of water to cool down considerably in winter and to heat up considerably in summer. Consequently, the mitigation effects of the winter and summer thermal extremes are contained. On the other hand, the contribution to the increase in rainfall (both summer storms and autumn and spring storms) caused by the transfer of humidity from the sea to the air masses passing through the Adriatic before investing Friuli Venezia Giulia is very important.

The average annual temperature for the coastal area of Friuli Venezia Giulia is 14.5° C – 15.5°C (Figure 3.4.3).

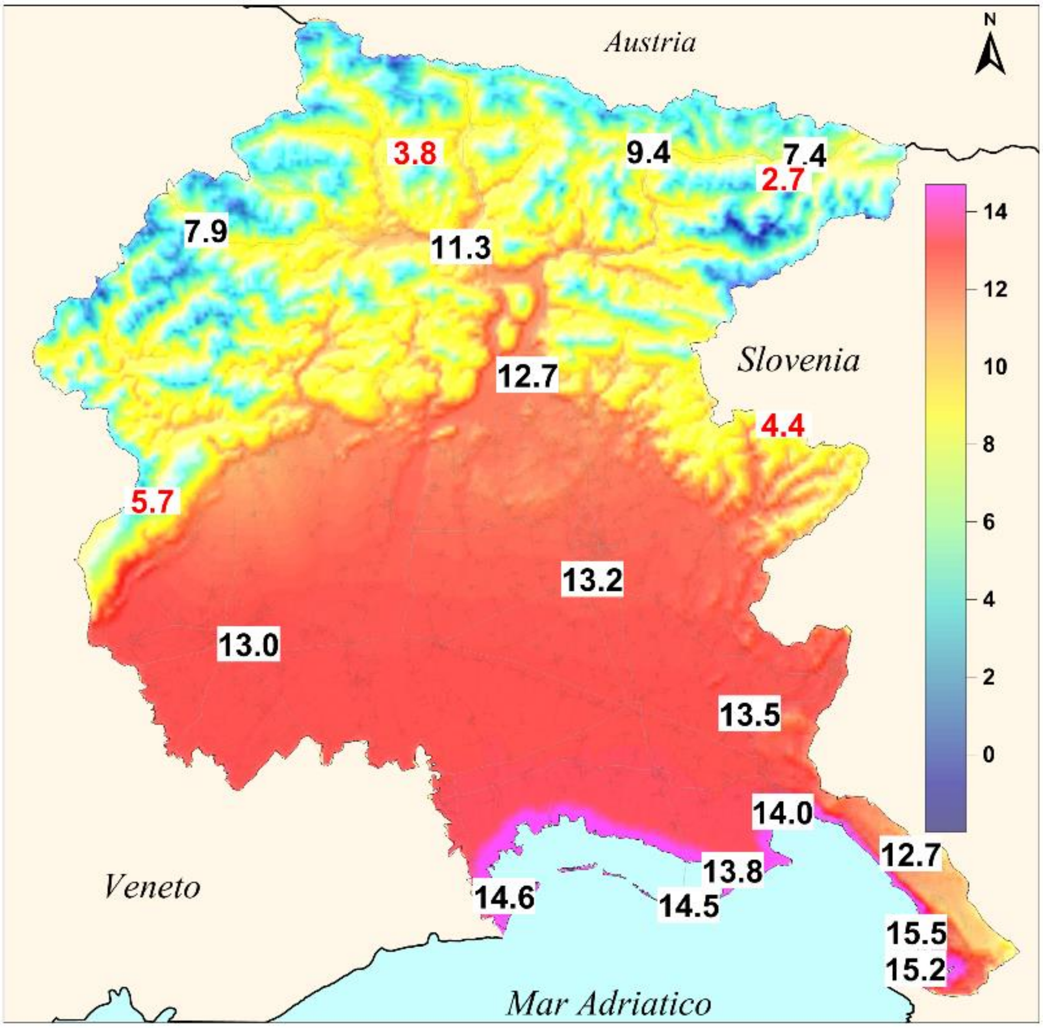

Figure 3.4.3. The Average annual temperature for Friuli Venezia Giulia (1993-2013). ARPA FVG - OSMER.

Considering the trend of the average monthly temperatures, it is noted how the maximum values are recorded in the months of July and August and the minimum values in February (Figure 3.4.4, Figure 3.4.5, Figure 3.4.6).

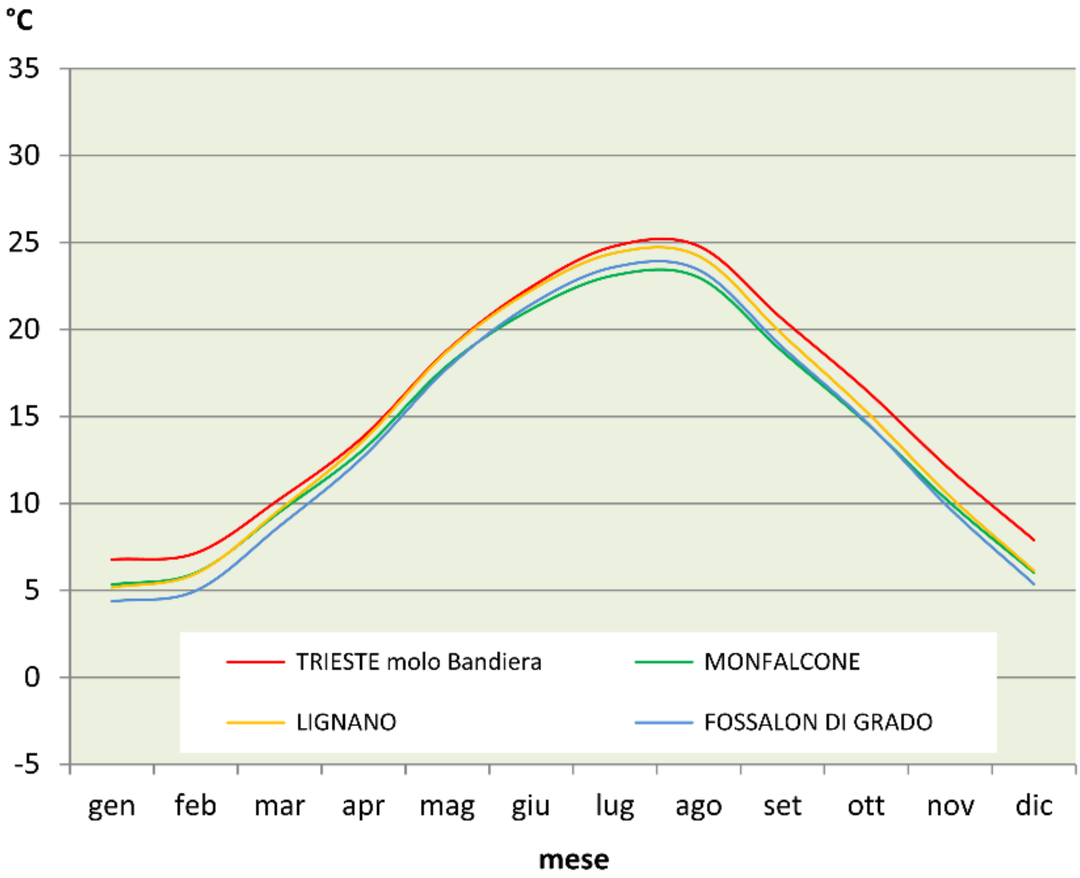

Figure 3.4.4. Coastal locations: average monthly temperatures (regional meteorological network data 1991-2010). ARPA FVG - OSMER.

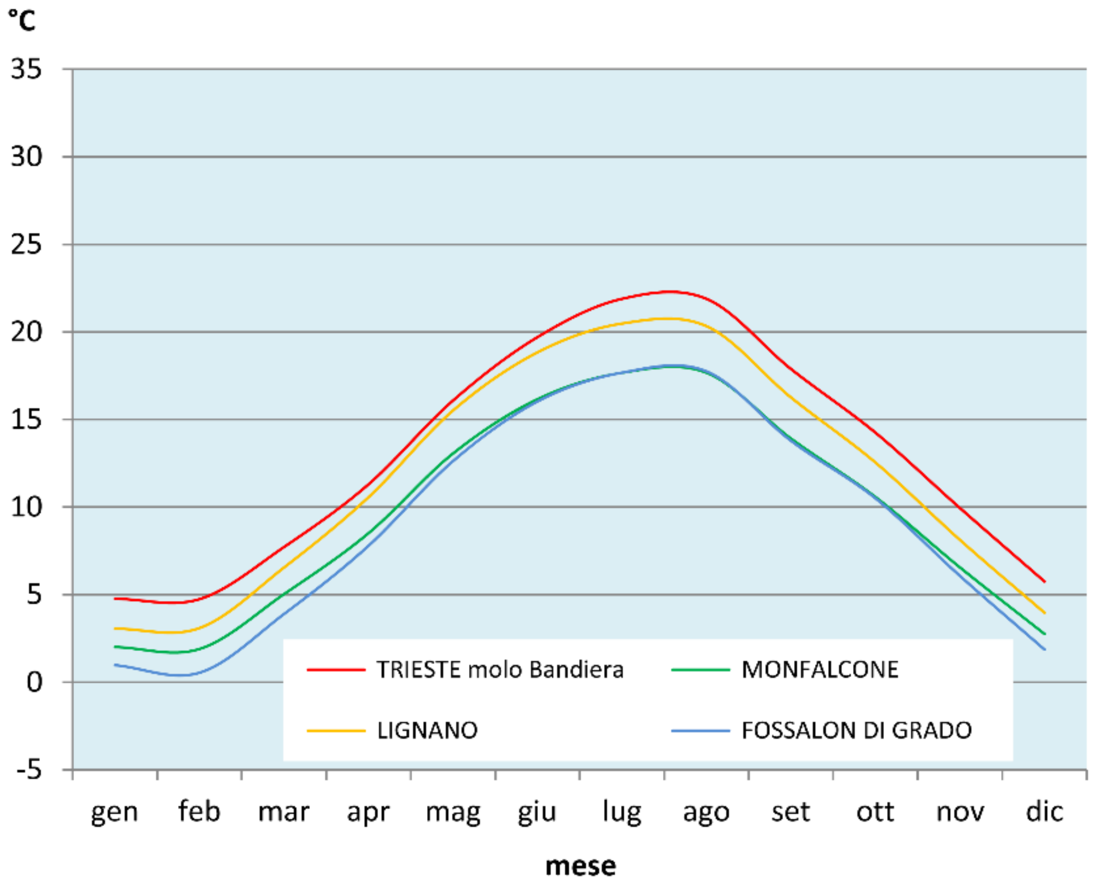

Figure 3.4.1. Coastal locations: average monthly minimum temperatures (regional meteorological network data 1991-2010. ARPA FVG - OSMER.

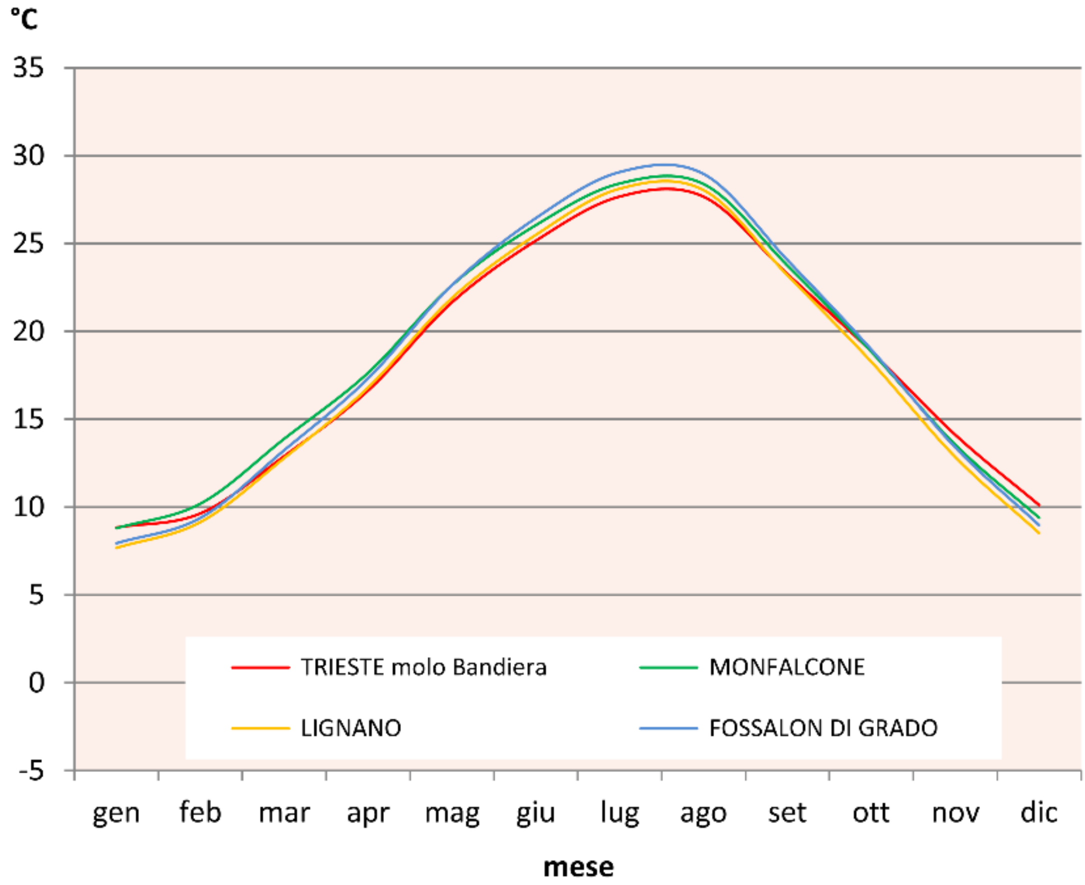

Figure 3.4.2. Coastal locations: average maximum monthly temperatures (regional meteorological network data 1991-2010). ARPA FVG - OSMER.

Also, in Friuli Venezia Giulia the sea conditions the thermal trend on the coast. However, it is important to know the values that reflect this conditioning: the average annual sea temperature measured in Trieste in twenty years (1995-2014) is around 16 °C, the annual average of the absolute minimum is 7 °C and the annual average of the absolute maximums is 27.5 °C. By contrast, in the plains the annual average of the air temperature is 13 / 13.5 °C, the average of the annual minimums is around -9 °C, while the absolute maximums reach an average of 35/36 °C each year.

It can be noted how the sea mitigates the average daily temperature range: in Trieste the difference between minimum and maximum temperatures in winter is on average 4 °C and in summer 6 °C; in Fossalon these values become 7 and 11 °C, in Palazzolo dello Stella 9 and 13 °C.

The analysis of climatic data collected by the regional network and processed by ARPA FVG - OSMER shows, as a more evident trend, the increase in the average temperature in FVG

At the annual level, this trend is well represented *Figure 3.4.3*. In the entire period 1961-2016 the average increase in average temperature was 0.3 ° C every 10 years, with a clear acceleration trend in more recent decades (dotted line *Figure 3.4.3*).

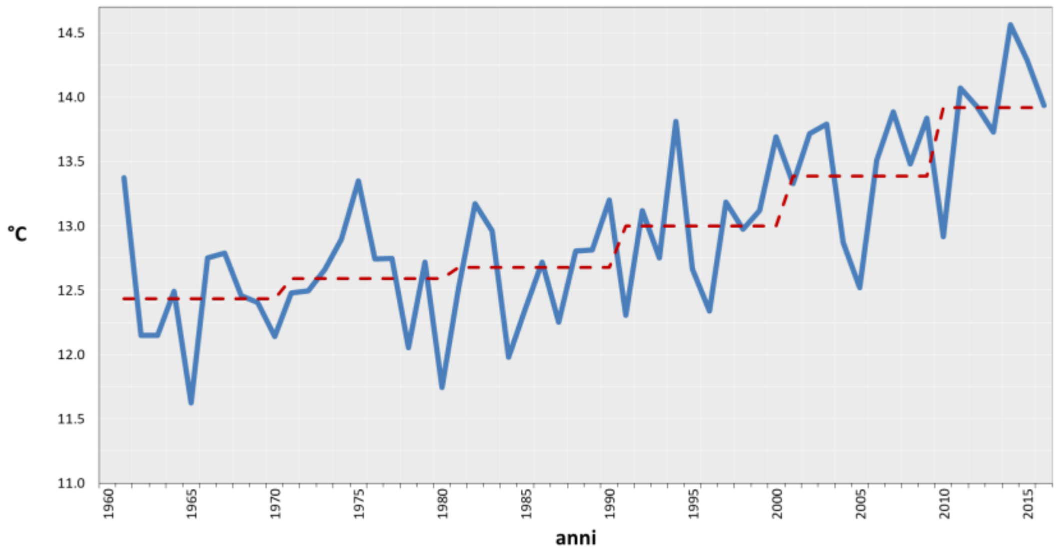

Figure 3.4.3. Trend of average annual temperatures in the period 1961-2016 for the Friuli Venezia Giulia plain (continuous blue line). The dotted line represents the trend of average temperatures in the various decades. Processing by ARPA FVG – OSMER.

The nature and origin of the rains, of course, vary during the year: during the late autumn, winter and spring months, the rains are generally linked to the synoptic circulation (large-scale atmospheric circulation - even a few thousand km) and the southern humid flows; during the summer and early autumn months, the contribution to total rainfall of rains of convective origin (showers and thunderstorms) or in any case linked to dynamics at the mesoscale (a geographical extension from tens of km to a few hundred km) becomes significant or even prevalent.

On the Friuli Venezia Giulia coast, annual rainfall is around 1000 mm. On average, in a decade, in the least rainy year, rainfall accumulations vary from 800 mm in the least rainy areas, to 1000 mm in the karst ones; in the wettest year of the decade, the territorial distribution varies in the same way from 1300 mm to 1500 mm (*Figure 3.4.4*).

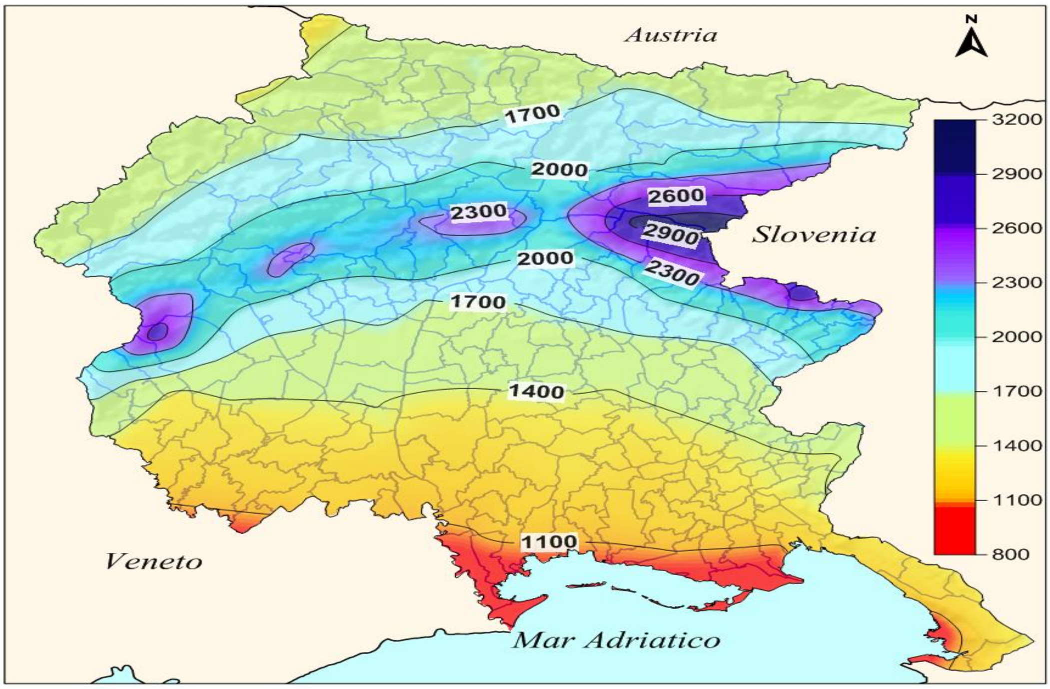

Figure 3.4.4. Friuli Venezia Giulia: the average annual rainfall (regional meteorological network data 1961-2010). ARPA FVG - OSMER.

The *Figure 3.4.5* shows the trend of multi-year average monthly rainfall in 4 stations in the coastal area. In the whole area the least rainy month is February with average rainfall around 55-60 mm; the months where rainfall is most abundant are September, October and November with values around 110-120 mm.

The autumn season is definitely the wettest and the average monthly precipitation data in November vary from 100 mm of the coast to 400 mm of Uccea, place included in the supply basin of the Isonzo River.

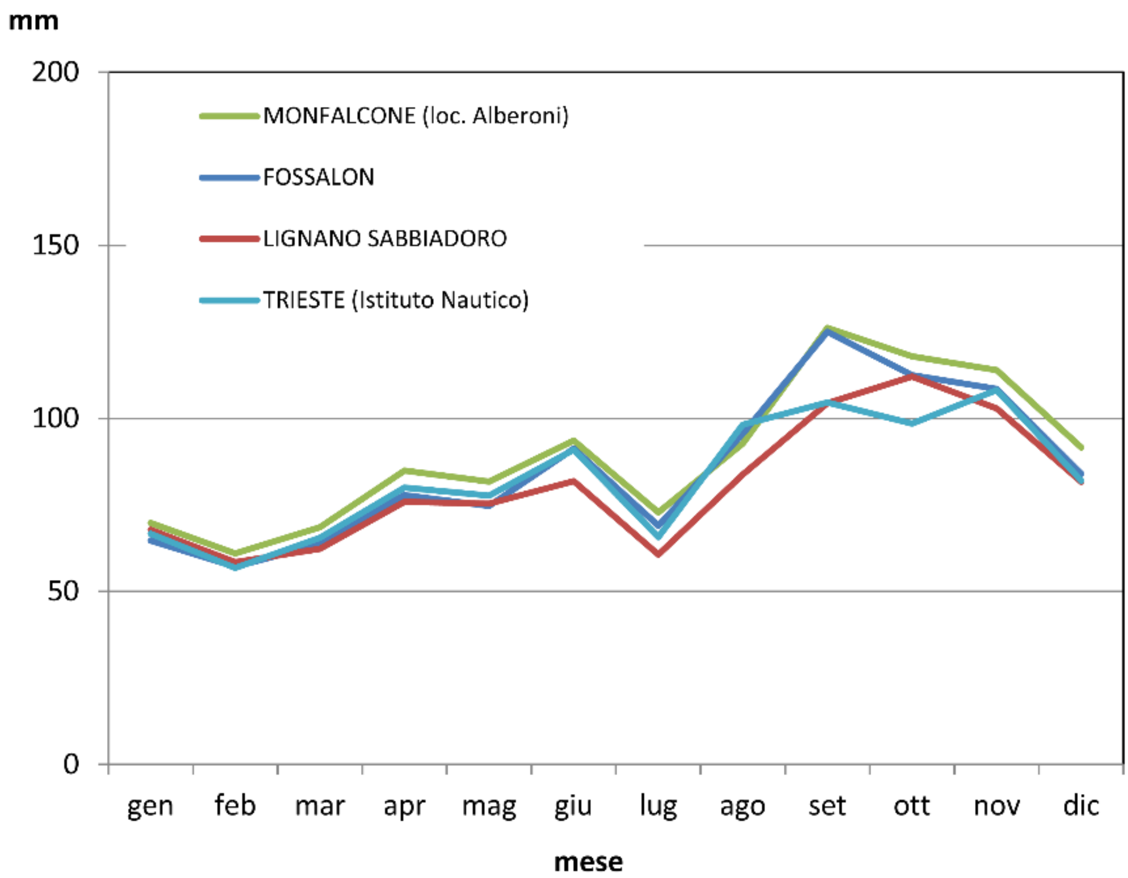

Figure 3.4.5. Coastal locations: average monthly rainfall (regional meteorological network data 1961-2010). ARPA FVG - OSMER.

The number of rainy days, i.e. the days when it rains at least 1 mm, in the average annual values varies, from south-west to north-east, going from 85-90 in Lignano to 95-100 in Monfalcone and the karst area of Trieste (*Figure 3.4.6*).

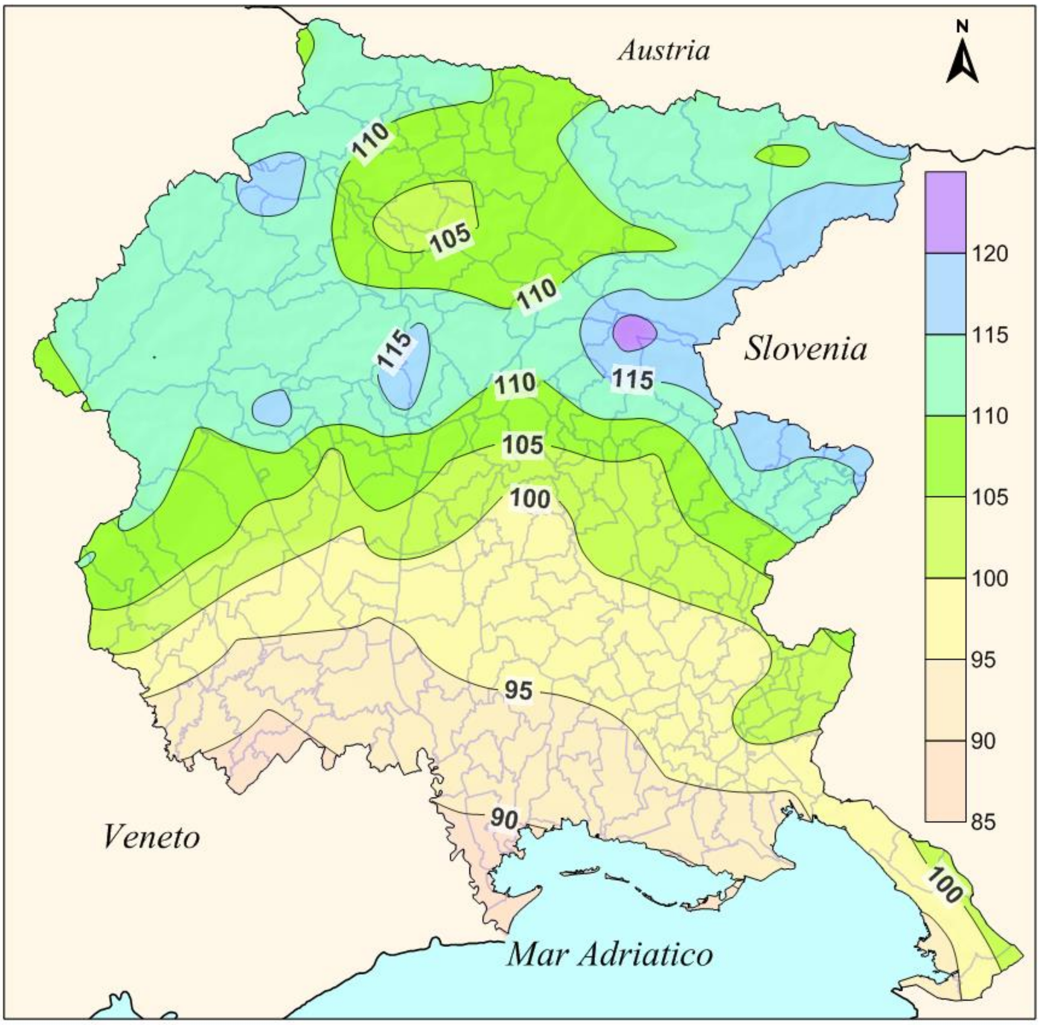

Figure 3.4.6. Friuli Venezia Giulia: average annual number of rainy days (regional weather network data 1961-2010). ARPA FVG - OSMER.

The signal of climate change on the rainfall of our region is less clear, also due to the strong interannual variability of this meteorological quantity. If you analyze daily rainfall data for the period 1961-2015, it is noted that over a large part of the region there is a general reduction of rainfall during the spring and summer season which varies from -2 to -4 mm per season. During the autumn and winter seasons there is an increase in rainfall even if the trends are not statistically significant.

The reconstruction of the local anemological regime was conducted on the basis of the wind data recorded by the ISPRA station in Grado (http://www.ispravenezia.it). ISPRA data were measured on the ground (inside the Marano-Grado lagoon).

The weather station is located at the jetty of the dock on the main channel of the Grado inlet. The registrations from 2000 to 2009 were analysed (excluding 2002, because not available). The data, scanned every 15 minutes, were transformed into a three-hour series and merged into both direction and intensity classes. The results obtained are summarized in *Table 3.4.1* and

Table 3.4.2.

The most frequent winds have speeds between 2 and 4 m/s (breeze regime), while the winds with velocity greater than 8 m / s, correspond to about 4.5% of the total (*Table 3.4.1*).

The direction analysis (

Table 3.4.2) shows that the most frequent winds are those coming from the 1st quadrant (Bora). Winds from the eastern sector (Levante), southern (Scirocco) and south-western (Libeccio) are less frequent, while winds from the western sector (Ponente and Mistral) are much rarer.

Table 3.4.1. Wind speed statistics for Grado station for the period 2000-2009.

TABELLA 1		
v(m/s)	*n°valori*	*Frequenza%*
0-1	3632	13.81
1-2	5738	21.81
2-4	9251	35.17
4-6	3362	12.78
6-8	1441	5.48
8-10	778	2.96
>10	386	1.47
N/D	1716	6.52

Table 3.4.2. Wind direction statistics for Grado station for the period 2000-2009.

TABELLA 2		
Direzione	*n°valori*	*Frequenza%*
N	141	0.54
NNE	1925	7.32
NE	3954	15.03
ENE	3752	14.26
E	1834	6.97
ESE	1579	6.00
SE	1395	5.30
SSE	1828	6.95
S	1840	7.00
SSO	1881	7.15
SO	1550	5.89
OSO	1173	4.46
O	628	2.39
ONO	553	2.10
NO	373	1.42
NNO	182	0.69

The wind roses in Figures 3.4.11 and 3.4.12 indicate that the winds from the first quadrant are generally also the most intense. In fact, the Bora wind can blow at speeds even higher than 100 km/h. However, intense winds are also coming from the eastern sector (Levante) and from the south-eastern sector (Scirocco).

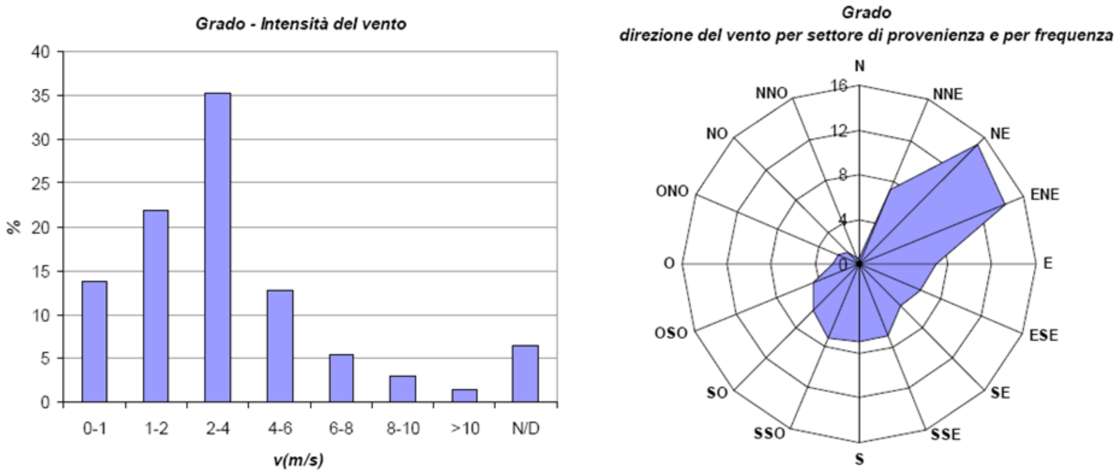

Figure 3.4.7. Grado station: occurrence percentages of wind speed and direction. Tri-hourly data 2000-2009;

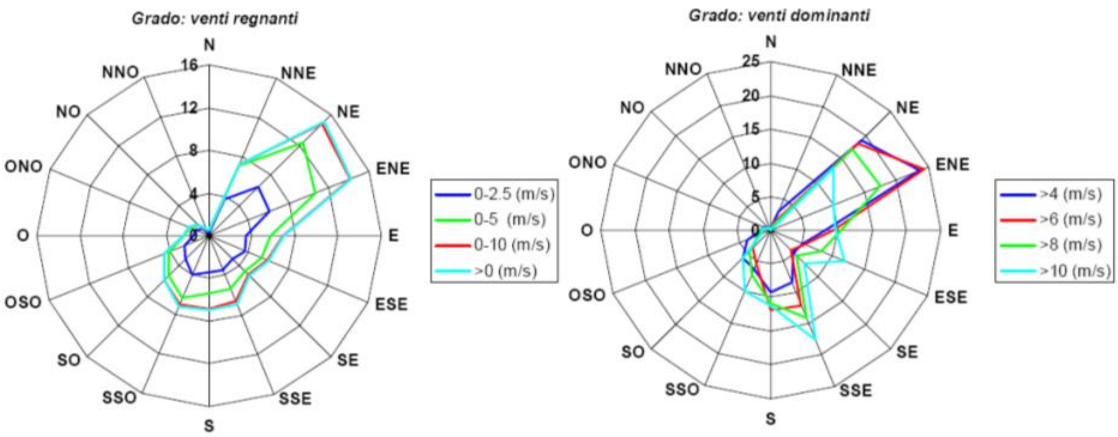

Figure 3.4.8. Grado station: most frequent wind rose (links) and dominant wind roses. Tri-hourly data 2000-2009.

3.4.1.2. Hydrological characteristics

The marine areas of interest for Friuli Venezia Giulia include the Marano-Grado Lagoon and the open sea overlooking the coast from the border with Veneto to Slovenia. It is the northernmost part of the Adriatic, and therefore of the entire Mediterranean.

The area of Mula di Muggia is part of the water body CE 13 (**Errore. L'origine riferimento non è stata trovata.**), as classified by Regional Agency for Environment Protection (ARPA-FVG).

Figure 3.4.9 The water body CE 13. ARPA-FVG

The water body has a low water flow, with a maximum depth of 10-11 meters. It is affected by the contributions of the lagoon transition waters from the mouth of Primero and the Isonzato Canal, as well as the Isonzo River ones. The reduced water column involves the almost total absence of thermal stratification throughout the year, except in the late spring and early summer months. The contributions of lagoon waters mainly characterize the surface layer for an average thickness of 1 m and is rarely at 3-4 m. Dissolved oxygen can reach high values in over-saturation throughout the water column especially in the summer. It should be noted that the Northern Adriatic, in February 2012, was affected by an intense cold event accompanied by strong eastern winds. The entire water column of the water body had an average temperature and salinity of 4.01 °C and 38.00 psu respectively.

Average, minimum and maximum values of temperature, salinity, dissolved oxygen and pH in the surface layer in the period 2009-12 are presented in **Errore. L'origine riferimento non è stata trovata.**.

The semi-continental position makes the area subject to the high variability of the atmospheric forcing, which characterizes the region, and to the contribution of the continental waters. This, associated with low depth (maximum 25 m in the Gulf of Trieste) causes significant variations in the thermal and hydrological balance, and therefore in the characteristics of the water mass.

sett_09 - ago_10	T (°C)	S (psu)	O.D. (%)	pH
media	16.61	28.97	98.9	8.18
min	5.59	22.21	86.0	8.03
max	25.23	34.63	112.9	8.30

sett_10 - ago_11	T (°C)	S (psu)	O.D. (%)	pH
media	14.78	26.18	97.9	8.18
min	6.09	6.91	85.2	7.98
max	24.52	33.40	109.4	8.27

sett_11 - ago_12	T (°C)	S (psu)	O.D. (%)	pH
media	15.75	34.41	102.1	8.20
min	3.35	29.00	87.0	8.09
max	25.95	36.27	126.6	8.31

sett_09 - ago_12	T (°C)	S (psu)	O.D. (%)	pH
media	15.69	29.88	99.6	8.19
min	3.35	6.91	85.2	7.98
max	25.95	36.27	126.6	8.31

Figure 3.4.13. *Physical and chemical elements for the surface layer of the water body CE 1. Period 2009-2012. ARPA – FVG.*

From the point of view of the freshwater input from mainland, **Errore. L'origine riferimento non è stata t rovata.** illustrates the map of the artificial and natural streams of the RAFVG region. With an annual average flow rate of 204 m^3/s (Raicich, 1994) the Isonzo River represent the most important fresh water input of the Gulf of Trieste and the pilot site area is mainly influenced by them. The numerous artificial streams are mainly functional to the drainage of reclaimed areas and to irrigation.

The catchment basin of the Isonzo has a total extension of about 3,400 km^2, 2250 $km^2$of them are located in Slovenian territory (**Errore. L'origine riferimento non è stata trovata.**). It is a torrential river, that c ollects and discharges the waters of the southern slope of the Julian Alps. The flow rates of the river are controlled and regulated by a series of artificial dams built in the Slovenian territory. In Italy there are also some important intakes for irrigation channels (irrigation network of the Consorzio di Bonifica della Pianura Isontina).

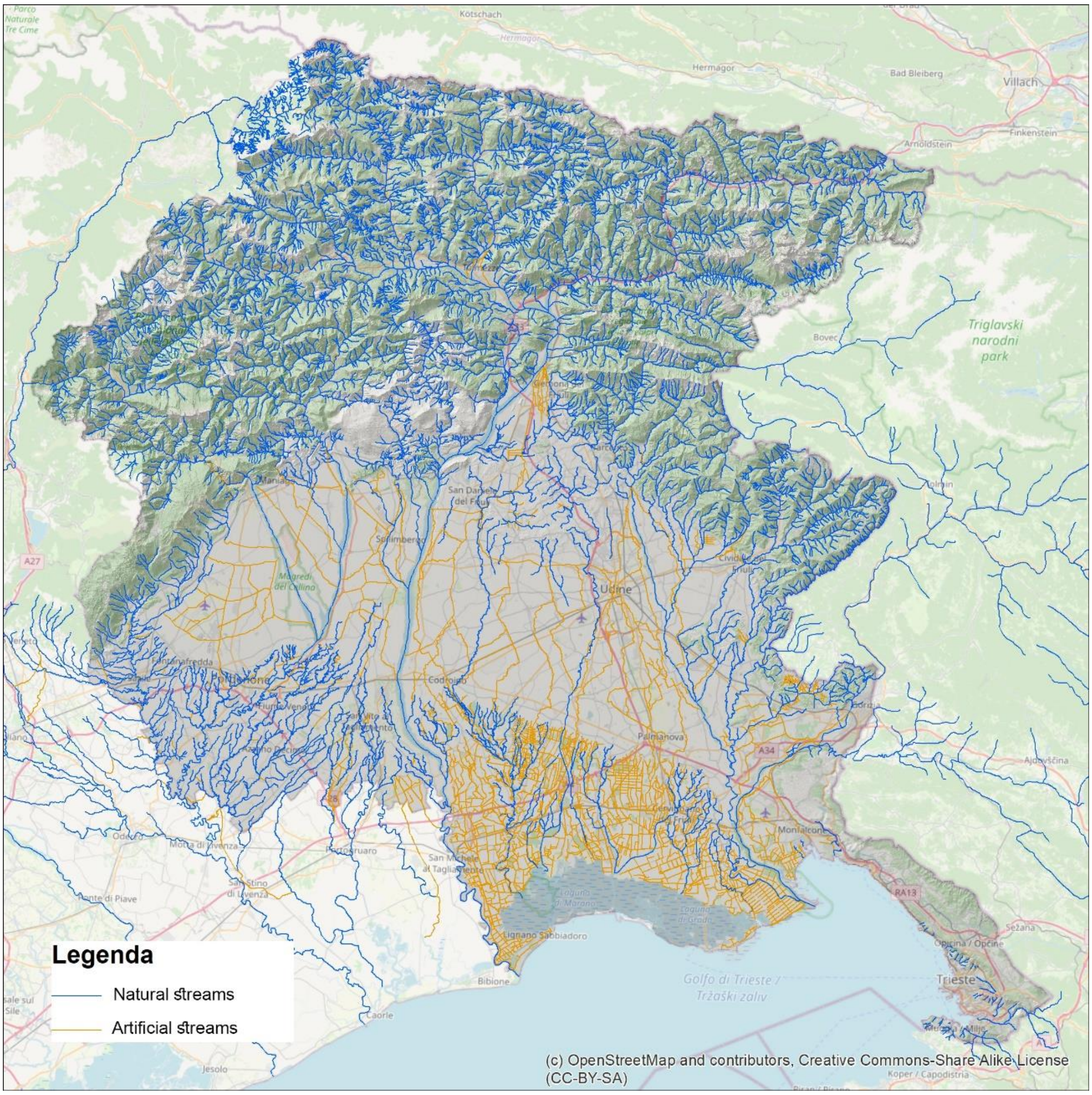

Figure 3.4.10. Natural and artificial streams in territory of the RAFVG region.

Water exchange with the Marano and Grado Lagoon occurs through the tidal inlet of Grado and Primero and are strongly controlled by semi-diurnal tidal fluxes, resulting from 65 cm and 105 cm mean and spring tidal range, respectively (Brambati et al., 1983). The hydrodynamics of the Lagoon have recently been modelled numerically (Ferrarin et al., 2010), showing a total average water exchange rate of 5000 m^3/sec through all the Lagoon's inlets as a result of the tidally-induced flow. The hydrodynamic model results reveal that the Grado and Primero inlets have a different role in terms of water fluxes, with approximately 22% and 3.5 % of the total water discharge between the Lagoon and the sea respectively. The proportion of the fluxes through the inlets remains unchanged during both ebb and flood phase, in case of considering only the tidal forcing. When a NE wind is blowing, the Primero inlet shows a strong asymmetry in the water discharges between flood and ebb phase (4.9 % and 1.7 % respectively).

Figure 3.4.11. Catchment basin and hydrographic network of the Isonzo River (Camis Project, 2014)

The coastal and marine water hydrology in the pilot site is also affected by the circulation of the entire Adriatic, which is dependent on that of the entire Mediterranean.

The circulation of the Adriatic is essentially cyclonic, with currents going up in the north-west direction along the Croatian coast and going in the south-east direction along the Italian coast (*Figure 3.4.9*).

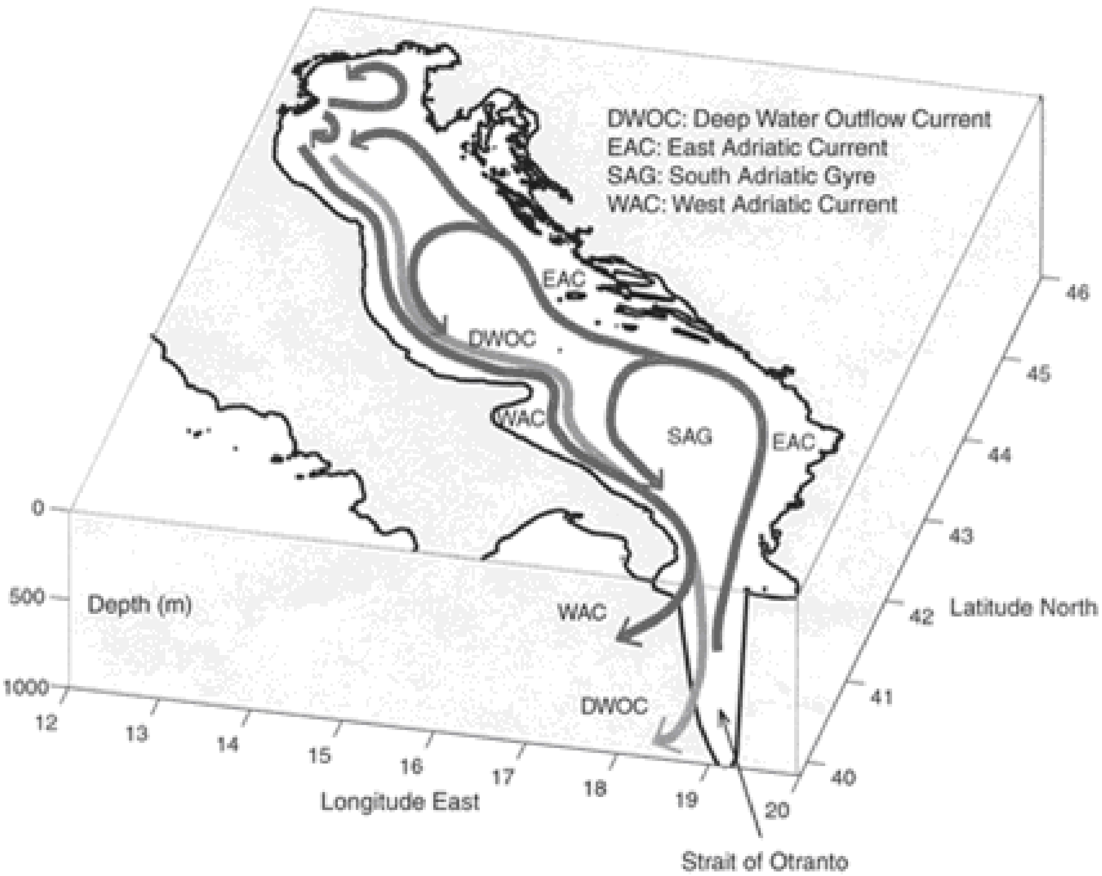

Figure 3.4.12. General circulation in the Adriatic Sea

Unlike other areas of the Adriatic Sea, the Gulf of Trieste does not seem to have a well-defined general circulation. The torrential nature of the Isonzo flows, the frequent and impulsive events of Bora, the effect of the southern winds (mainly the Scirocco) do not allow to determine a prevalent direction of circulation (cyclonic or anticyclonic) for the entire basin.

In addition, the decoupling that is often found between the surface and bottom layers indicates that in these conditions the axis of circulation is horizontal rather than vertical (*Figure 3.4.10* and *Figure 3.4.11*). In essence, a mechanism of water exchange, which does not provide for the circulation of homogeneous masses of water along the entire column but entering / leaving the surface and therefore leaving / entering the bottom, is often observed (Querin et al., 2006; Solidoro et al., 2010).

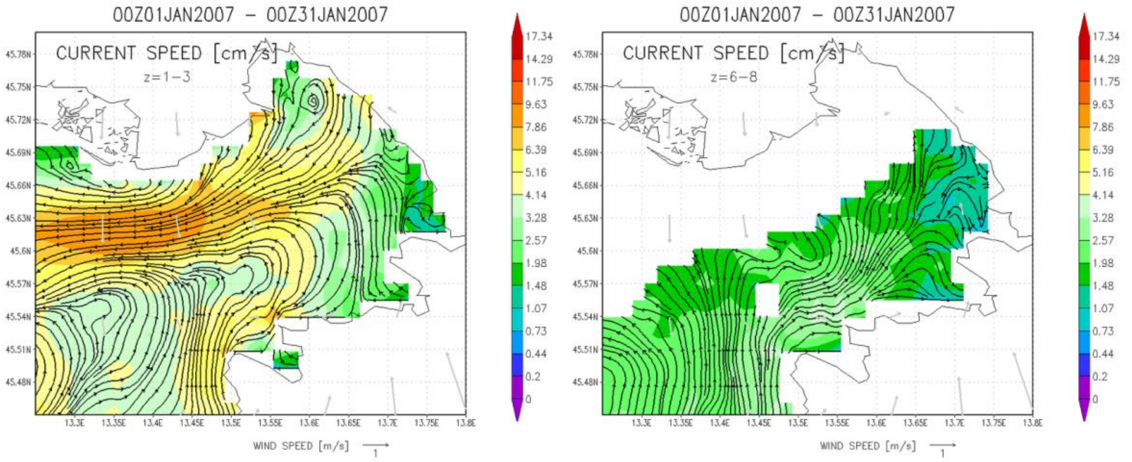

Figure 3.4.13. *Average circulation in January 2007. The surface circulation is cyclonic while the bottom currents generally enter the basin*

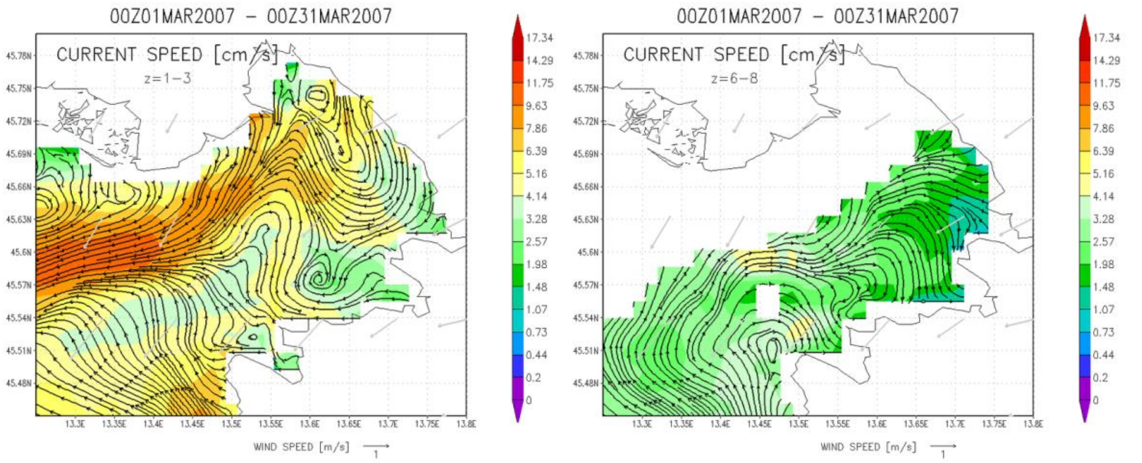

Figure 3.4.18. *Average circulation in March 2007. The fresh water supplies of the Isonzo River create an estuarine-type anticyclonic current affecting the north-eastern part of the basin. The incoming currents at the bottom balance the current leaving the surface.*

The Isonzo river, which provides the greatest contribution of fresh water to the basin, mainly influences the surface layer of the northernmost areas of the Gulf, but, in the event of significant floods and absence of wind, the river water plume can overcome Miramare and also reach Muggia (*Figure 3.4.11*). In other cases, and typically with winds from the south and especially from the east, the plume is quickly pushed towards the Grado coast. The high spatial variability due to the mesoscale structures (vortices and meanders) and their marked seasonality give an additional level of complexity to the circulation of the basin. These structures are particularly evident in the presence of weak winds.

Since the coastal area of the basin is shallow, it is strongly influenced by atmospheric variability and the contribution of continental waters, therefore seasonal and interannual variations in temperature and salinity are very marked. Marked spatial gradients can also be observed, due to the contribution of the continental waters, usually confined along the coastal strip and / or the more superficial layers of the water column.

The analysis of salinity data allows to highlight the areas of fluvial influence, but also allows to trace the entry of the southern saltiest waters that go up along the east coast. The analysis of the temperature data (Solidoro et al., 2009; Cossarini et al., 2012) shows that in the Northern Adriatic the seasonal variability prevails over the spatial one, with minimum values in January (coastal areas) or February (offshore areas) and maximum values in August (surface water) or September (bottom water). The analysis of the vertical profiles highlights the well-known phenomenon of winter mixing, with homogeneous values along the entire water column and the summer stratification.

Specifically, for the Gulf of Trieste and for the period 1991-2003, Malačič et al. (2006) found an increase in surface temperature of about 0.1 ° C/year in spring and summer and no significant variation in the other seasons; same trends at 10 m depth except in summer, the trend is 0.2 ° C/year. Surface salinity shows no significant trend in autumn and an increase to 0.2-0.3 per year in other seasons; at 10 m the trend is significant only in autumn and winter with 0.1 per year. All this is in line with atmospheric heating (*Figure 3.4.12*).

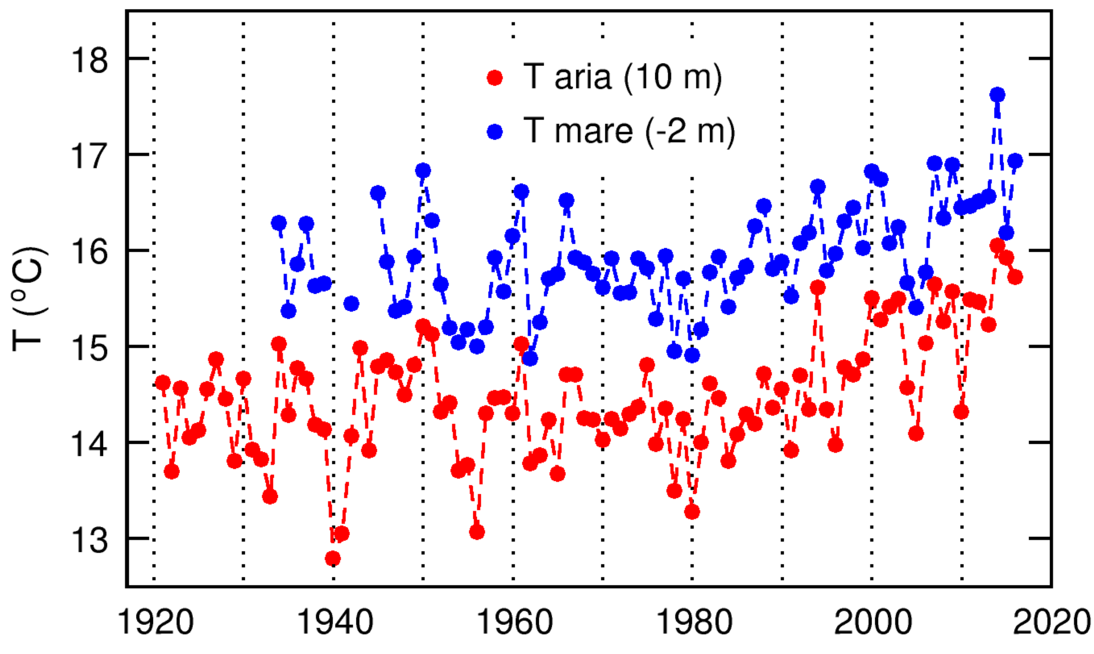

Figure 3.4.14. Average annual temperature of the air at 10 m and of the sea at a depth of 2 m in Trieste. CNR-ISMAR.

3.4.1.3. Sediment fluxes

The evaluation of the entity of the sedimentary input from the mainland to the coastal system is a focus problem for the pilot site area due to the chronical lack of data.

The river Isonzo is the most important sediment source in the area. Due to the lack of data about the solid discharge of the river, it is impossible to quantify the sedimentary supply.

Brambati (1985) estimated the potential solid discharge of the Isonzo river in an amount of 1 313 000 m^3 /year as potential discharge (by applying the Gravilovic indirect method, based on the assessment of the characteristics of the catchment area. After the applications of corrective factors and estimating in 22% of the total the amount of the sand supply to the coast, the Author indicates the final amount of 817 000 m^3 /year. Many uncertainties are related to the application of this type of methodology. Among them, the role of artificial basins that can significantly prevent sedimentary transport towards the valley. Over time, artificial basins can also change their role and once a certain filling threshold has been exceeded, they can in some cases become “permeable” to solid transport. This is the case, for example, of the Crosis dam on the Torre torrent (right tributary of the Isonzo) which has undergone a rapid filling process thanks to a solid annual supply of 40 000 – 50 000m^3 (Regione Autnoma Friuli Venezia Giulia, 2013).

Regarding the supply of fine sediments (silt and clay as *Suspended Particulate Matter*) to the coastal area, some experimental data can furnish data to describe the process. The most part of suspended load can be attributed to flood events, which generate evident turbidity plume as documented by satellite or aerial imagery (**Errore. L'origine riferimento non è stata trovata.**; **Errore. L'origine riferimento non è stata tr ovata.**). The suspended particulate in part tends to be removed from the Gulf due to the effect of sea currents and in part tends to settle along the water column.

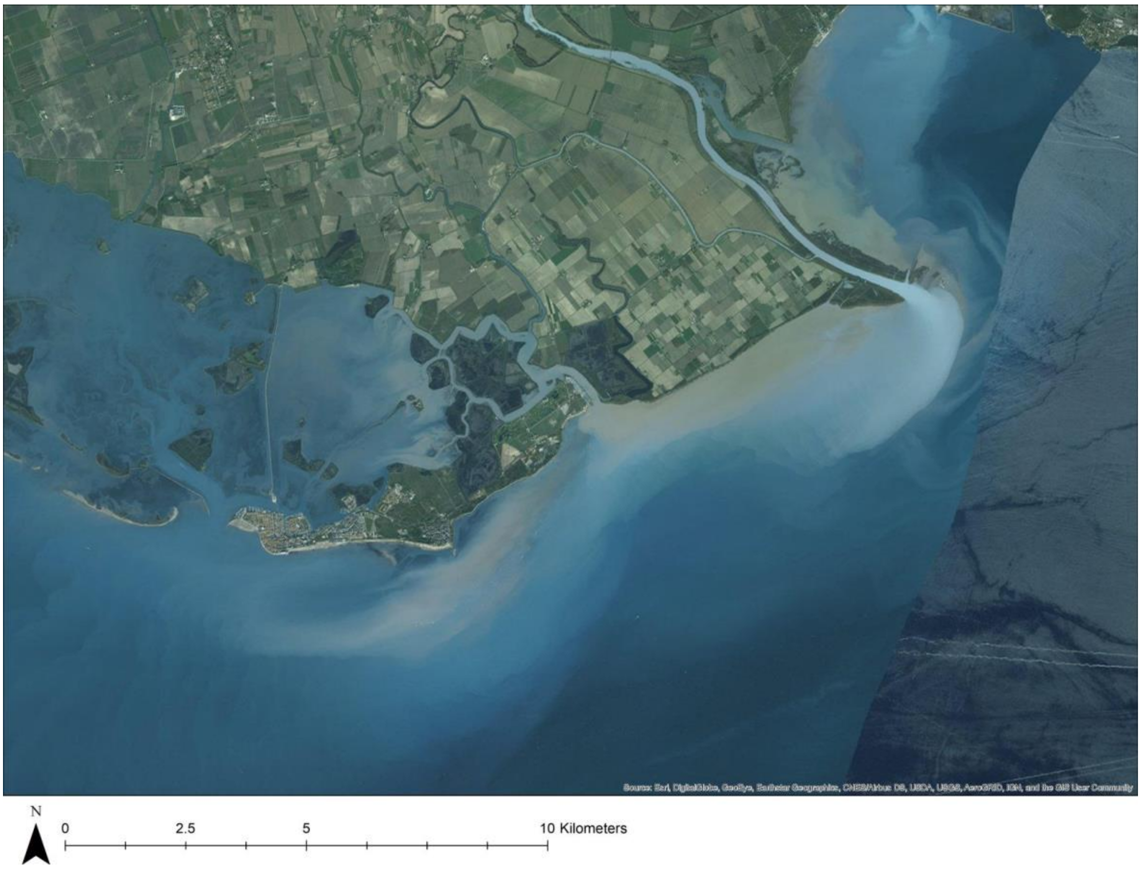

Figure 3.4.15. The Isonzo plume in the World Imagery (Clarity) - Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

During the plume diffusion, the turbidity is mainly associated with the circulation of fresh waters, because these processes are governed by the stratification between the fresh and less dense waters of fluvial origin, which flow on the surface, overlapping with the much more salty and dense waters of the sea, and mixing with them progressively.

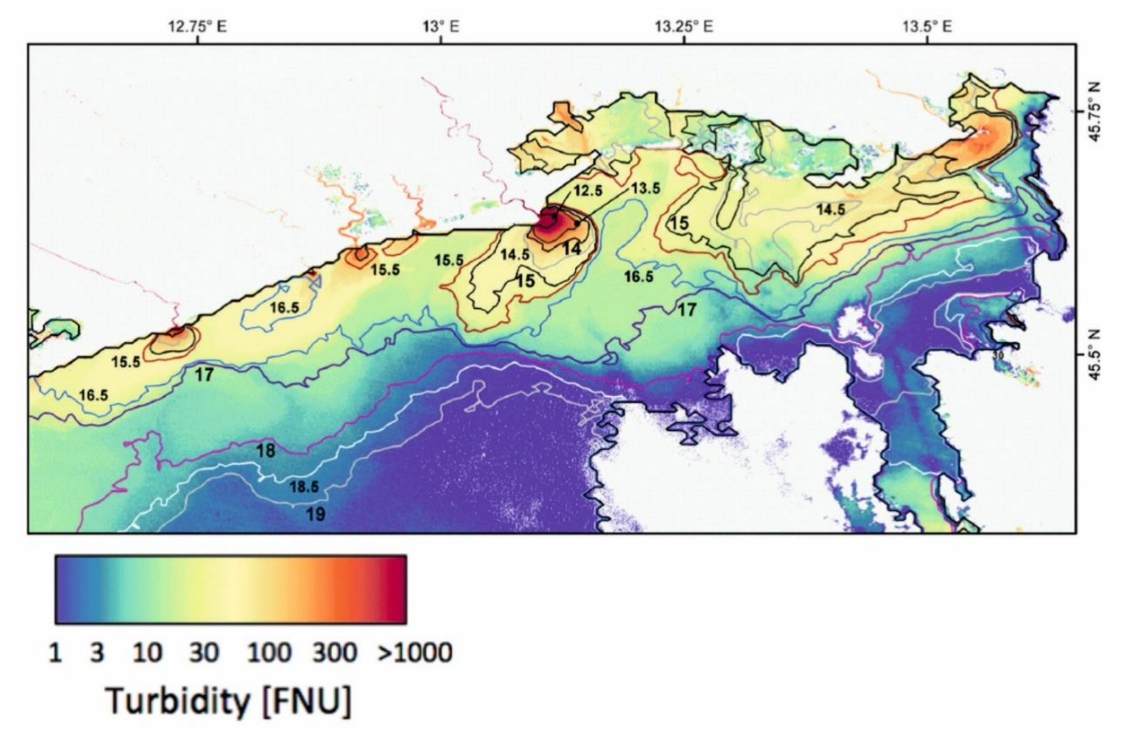

Figure 3.4.16. Turbidity map estimated from Landsat 8 OLI imagery acquired on 19 November 2014 for the river plumes in North Adriatic from the Isonzo to the Piave River, Isotherms from the Landsat 8 TIRS SST field are overlaid (from Brando et al. 2015 modified).

Based on the sampling carried out in the area of the Isonzo mouth, during a flood event with a maximum flow rate of 580 m^3/s, Covelli et al. (2007) found a strong correlation between the vertical distribution of salinity and turbidity. In all the water sampled profiles the turbidity was high only in the superficial layer, where the salinity was inferior for the presence of the freshwater, and the trend along the vertical of the two parameters was quite similar (Figure 3.4.17). The importance of the water stratification in the diffusion of river plume at sea and in the definition of the region of freshwater influence is even greater in the presence of wind, as the wind action is more pronounced on the surface layers of the water column.

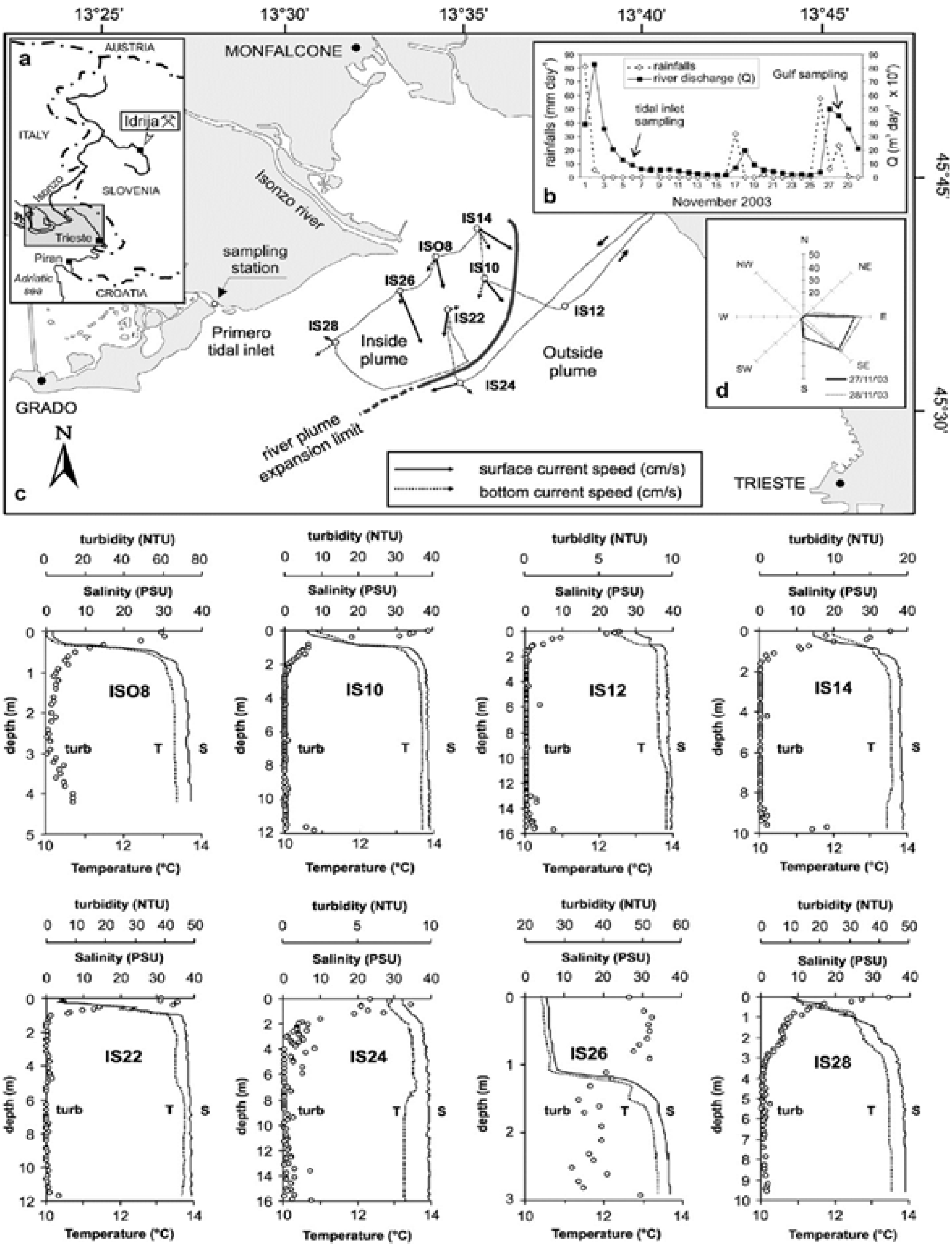

Figure 3.4.17. Vertical profiles of turbidity (turb, NTU, Nephelometric Turbidity Unit), Salinity (S, PSU, Practical Salinity Unit) and Temperature (T, °C) in the sampling stations in the Gulf of Trieste (28 November, 2003). Note change in scale for turbidity to emphasize vertical variability (from Covelli et al. 2007).

Based on this observations, Hydrosoil has applied the hydrodynamic modell 3DEF developed by Prof. A. Defina (University of Padova) in the Gulf of Trieste in order to study the fresh water diffusion during the Isonzo flood events. As example, the simulation of the salinity diffusion during a flood event with TR = 1 year (TR= Return Time) and Bora wind indicates an important westward diffusion of the plume in the coastal area until Grado Pineta. An estimated turbidity until 41 NTU occurs near the mouth and in the back-barrier area of the Banco della Mula di Muggia (Figure 3.4.).

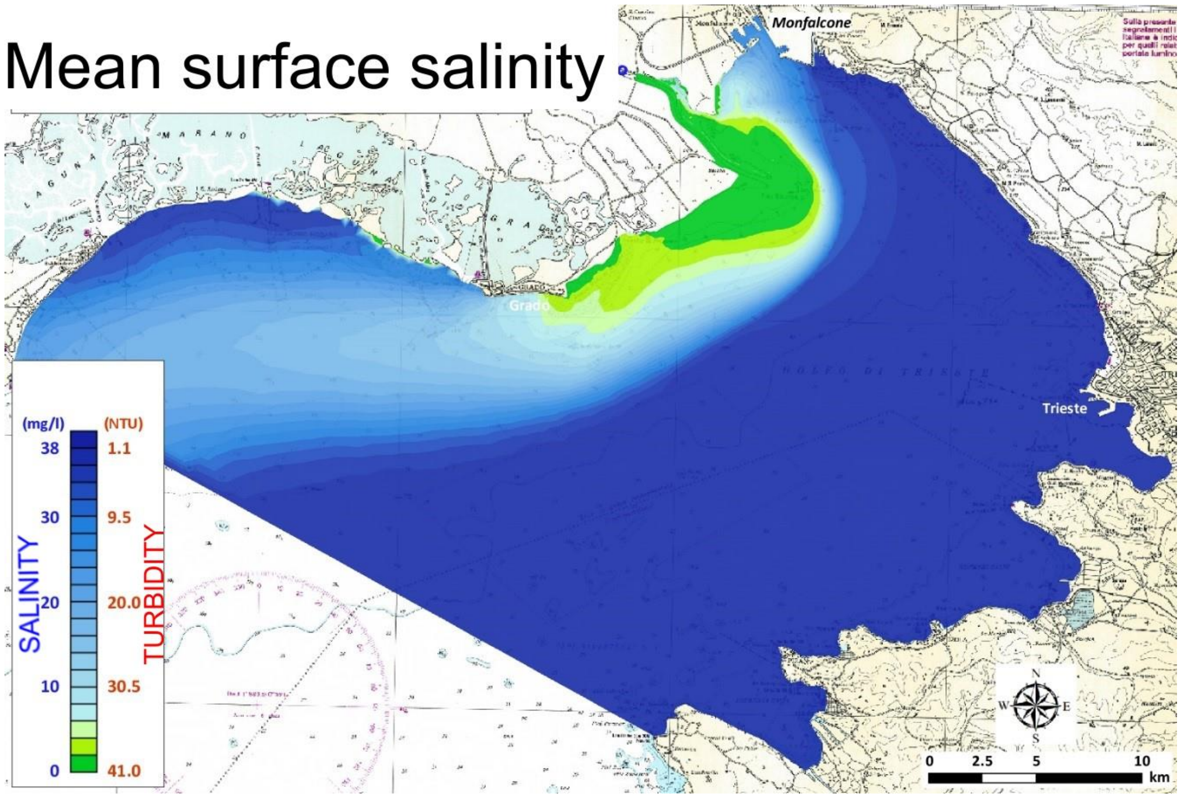

Figure 3.4.23. Simulation model of surficial salinity and turbidity during a flood event (4-10 novembre 2014, TR=1) and Bora wind (75° N v=11.64 m/s) computed by Hydrosoil.

Finally, the lagoon can represent a sediment source. Fine sediment could be transported outside of the lagoon, towards the coastal area in consequence of the erosion of lagoon morphologies (saltmarsh and tidal flats). Turritto et al. (2012) estimated a dominance of fine sediment output from the lagoon for the inlet of Grado, but its influence of the sedimentary budget of the Banco della Mula muggia is probably negligible due to the prevalence of the westward longshore drift. For the Primero inlet, a sediment budget estimation is not available, but the modelling of Ferrarin et al. 2012 and the turbidity measurements of Covelli et al. (2006) indicate a predominance of transport towards the lagoon.

3.4.1.4. <u>Nutrient fluxes</u>

In the Mula di Muggia, potential nutrients come from the mainland. A dedicated tool for evaluating the nutrient fluxes is the evaluation of the intrinsic vulnerability of aquifers by using the SINTACS code, it is a parametric system based on scores and weights that takes into consideration seven parameters to evaluate the intrinsic vulnerability of the aquifer such as:

- the subjacency of the aquifer,
- the characteristics of the infiltration according to the substrate and coverage,
- the characteristics of the self-purifying action of the Unsaturated,
- the type of coverage,
- the hydrogeological characteristics of the aquifer,
- the hydraulic conductivity of the aquifer and the unsaturated,
- the steepness and morphological characteristics of the topographic surface

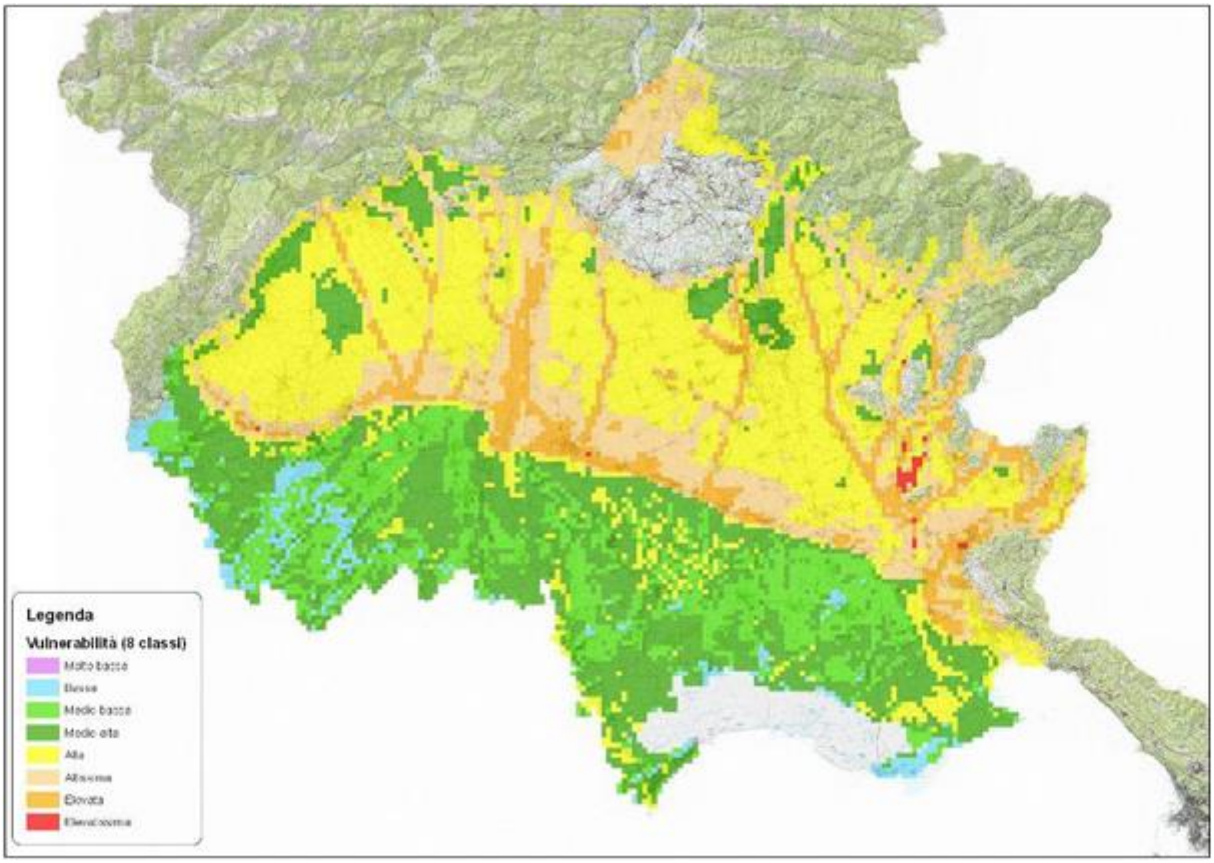

Figure 3.4.24. Map of the intrinsic vulnerability of aquifers using the SINTACS code, calculated for the RAFVG region.

Values from high-medium to low results for the mainland close the Mula di Muggia pilot site test, *Figure 3.4.24*. Several area code 211, non-irrigated arable land, characterize the mainland, *Figure 3.4.2*; they are agricultural areas potentially subject to the fertilizers, herbicides and pesticides usage.

Figure 3.4.25. Map of land use from CORINE Land Cover (CLC) inventory (land.copernicus.eu).

3.4.2. Excess fertilizers, herbicides and pesticides usage

The RAFVG region Council defined areas vulnerable from nitrates used in agriculture, in agreement with the Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. They are areas where the concentration of nitrates exceeds 50 mg / l in surface or underground fresh water or conditions of eutrophication of water occur (

Figure 3.4.2)

A dedicated dispatch is available on the website https://www.osmer.fvg.it/nitrati.php# for the areas vulnerable for nitrates. It indicates the agricultural activities permitted according to weather conditions.

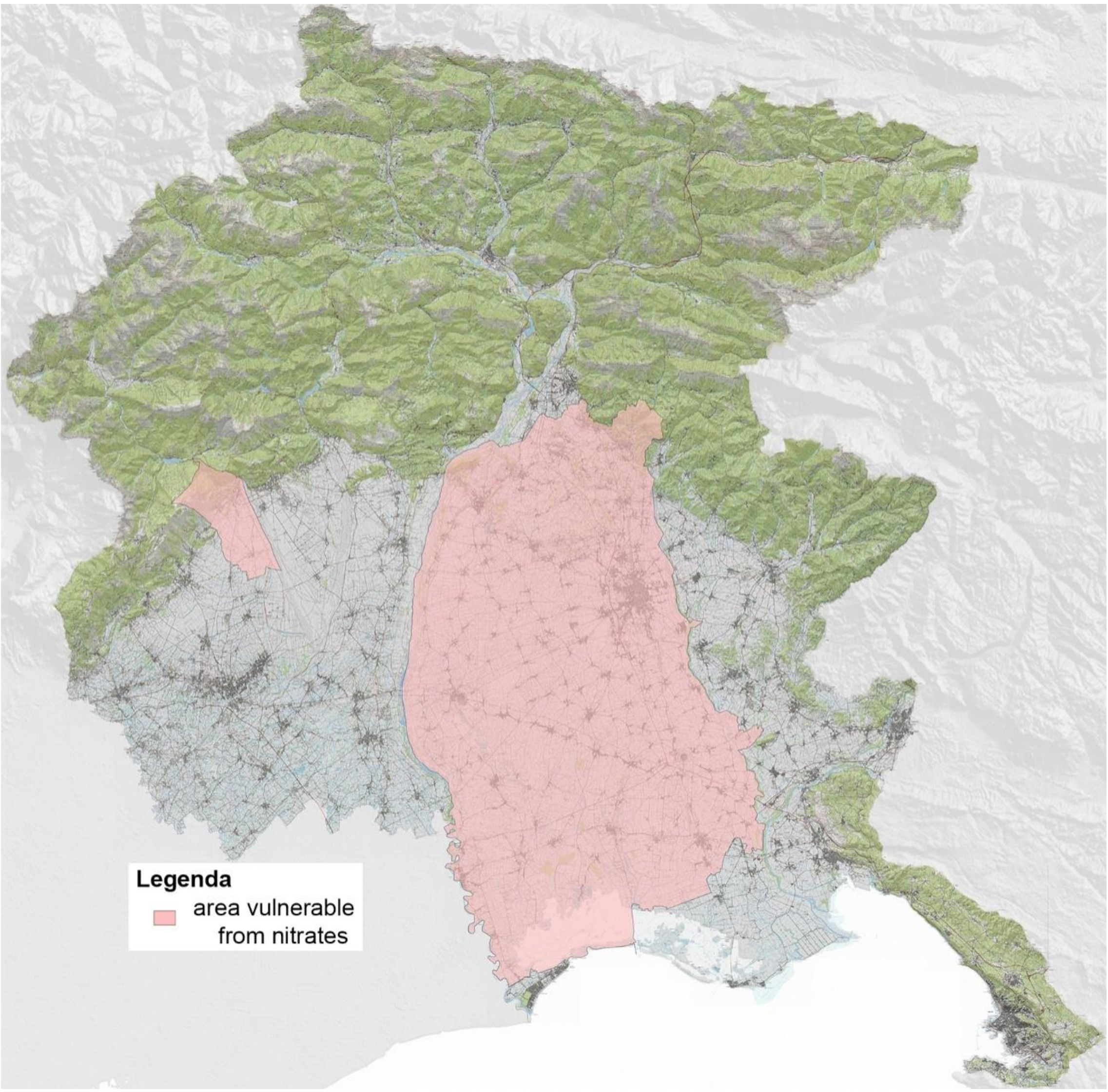

Figure 3.4.26. Areas vulnerable from nitrates used in agriculture.

The Banco Mula di Muggia and its mainland aren't area vulnerable for nitrates (

Figure 3.4.2). Just few areas close to Isonzo River are defined as dangerous. The map of *Figure 3.4.2* indicates that the nitrate concentration in the artesian aquifer in the pilot site test is close to zero.

The *Figure 3.4.* shows that the only monitoring point of the water quality of the Isonzo River, suitable for the pilot test, is about 20 km far. It has a "sufficient" ecological status.

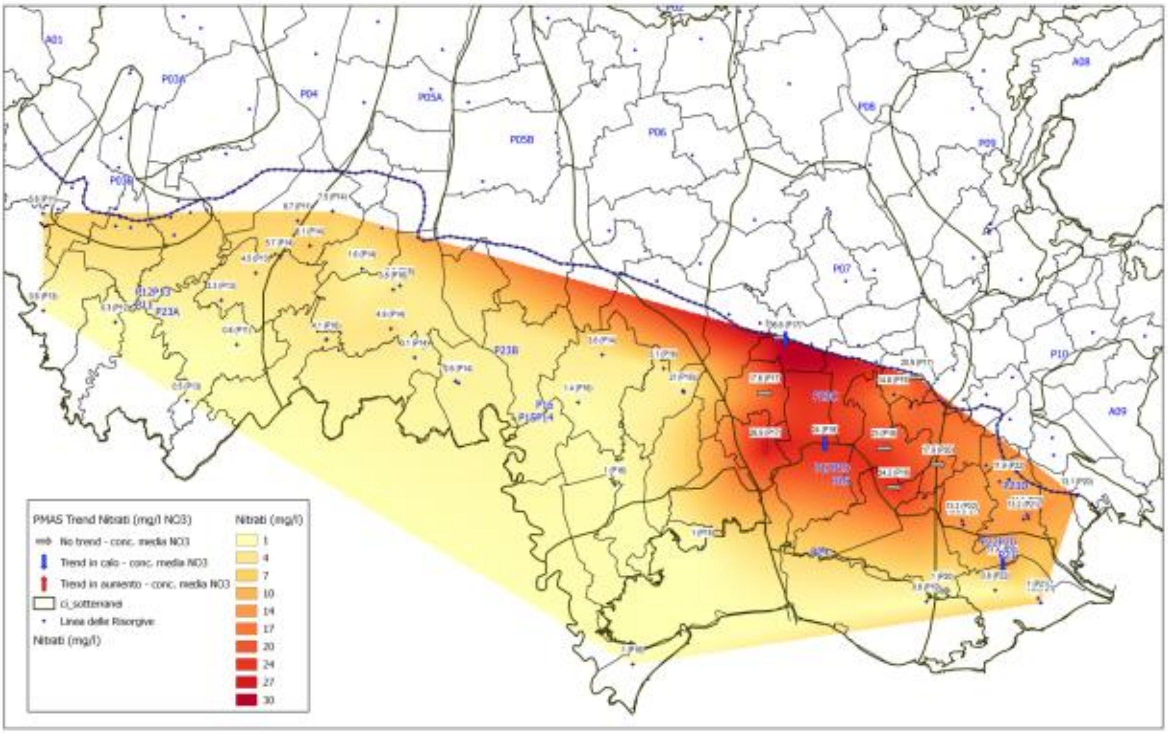

Figure 3.4.27. Average values of the nitrate concentration for the period 2006-2015 in the artesian aquifer (ARPA-FVG).

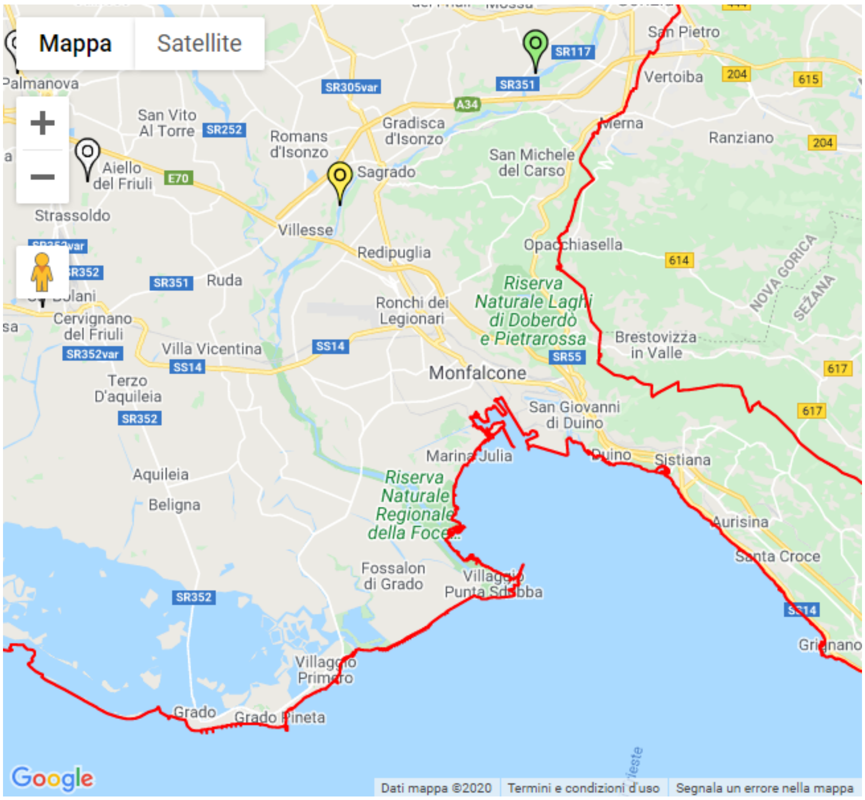

Figure 3.4.28. Monitoring points of the quality of the water of the rivers, managed by ARPA –FVG.

3.4.3. Grease, oil, chemicals and salt input (from energy production, mining activity, irrigation and urban runoff)

The data available for this topic refer mainly to the monitoring network of water quality for bathing. The Regional Agency for Environment Protection (ARPA – FVG) manages 55 sampling points on the seaside and 2 sampling points in the Grado Lagoon (*Figure 3.4.*). Data are available at the website http://www.arpa.fvg.it/cms/tema/acqua/balneazione/monitoraggio/mappa.html, and they are upgraded periodically.

The planned controls concern faecal microbiological parameters such as Escherichia coli and Intestinal Enterococci and, in case the bathing water profiles show a tendency to proliferation of cyanobacteria, macro-algae or marine phytoplankton, specific investigations are foreseen to determine their acceptability and health risks. Bathing water quality requirements should refer to the limit values set out in the Ministerial Decree of 30 March 2010.

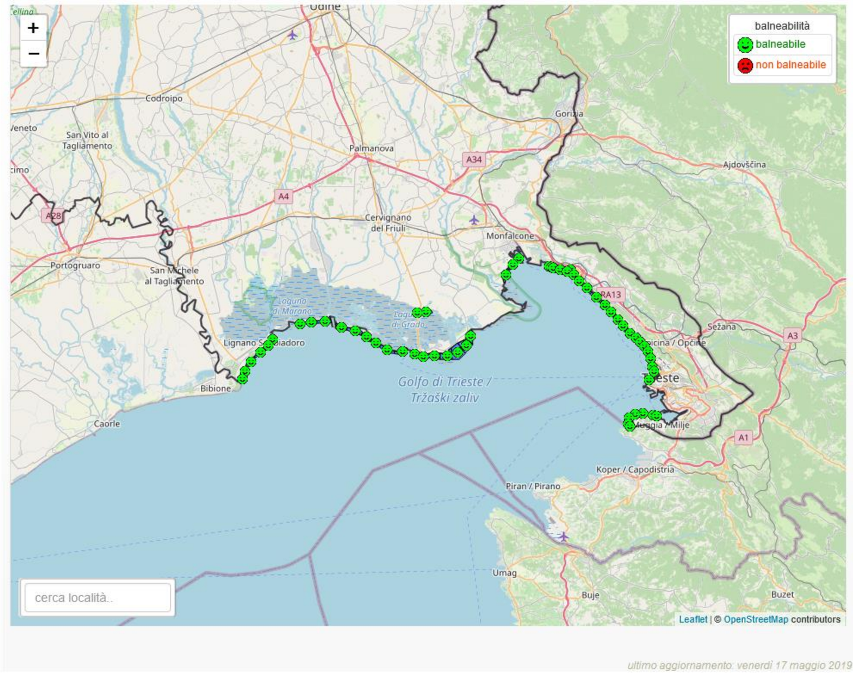

Figure 3.4.29. Sampling points for water quality assessment for bathing.

The results of PEPSEA project (https://www.italy-croatia.eu/web/pepsea) (Protecting the Enclosed Parts of the Sea in Adriatic from pollution), financed by the Interreg program Italy- Croatia, will get an innovative response system for most endangered parts of sea with strong and original planning and applicative solutions. Project will produce following outputs: adequate and timely approach for responding to sea pollution risk and incidents in EPSs based on detailed contingency plans; developed and tested technological solution and equipment for response in phases; training programmes for response teams and awareness campaigns for considerate use of sea.

3.4.4. Sediment as a pollutant

A widespread mercury contamination affects the Gulf of Trieste and the adjacent lagoon system of Marano and Grado. Values of 25-30 mg/kg (up to 200 times higher than the natural background value) have been highlighted since the seventies. Covelli, et al. (2001) estimate that mercury contamination in the sediment affects a thickness of about 90 cm, and from the analysis of accumulation rate show that the peak of the contribution probably dates back to the pre-war period (1913-1914).

The main source of Hg has been identified in contaminated sediment eroded from the riverbanks and the floodplain deposits (Gosar and Zibret, 2011; Kocman et al., 2011) of the Soča/Isonzo River drainage basin where the Idrija mining district is located (western Slovenia). Here, for almost 500 years, until 1996, 12 million t of Hg, mostly cinnabar, were excavated. More than 35 000 t of Hg have been lost into the environment during roasting processes (Dizdarevič, 2001). A further, more recent, contribution of Hg has been added by the operation of a chlor-alkali plant located in the drainage basin flowing into the Marano and Grado Lagoon, but it regards mainly the central and western part of the lagoon (Covelli et al., 2009)

Žagar et al. (2006) estimated that a total amount of 10 000 t of Hg is still stored in riverbed, riverbanks and flood plains between the Idrija mining site and the Isonzo River mouth. Surveys has demonstrated that dissolved and particulate Hg concentrations are still very high during low and normal river discharge (Faganeli et al., 2003; Covelli et al., 2006a). Flood events account for most of the particulate Hg influx into the Gulf of Trieste (Rajar et al., 2000; Covelli et al., 2007), despite the fact that they are not common during the year.

According to the measurements performed by Covelli et al. (2007), considerable amounts of Hg enter the Lagoon following the Isonzo plume as described in the 3.4.1.3 Section. The Primero inlet seems to represent the preferential pathway for Hg associated to fine suspended sediments to enter the eastern sector of the Grado lagoon. At the same time, the mercury present in the lagoon is exported toward the sea through the Grado inlet (Turritto et al. 2017).

In the marine ecosystem, the greatest load of contaminants is found at the sediment level, which are the final acceptors and accumulators of the particulate material that passes through the overlying water column. Contaminants adsorbed or incorporated into the particulate are transferred by sedimentation to the bottom, which, in turn, can represent a potential source of pollution of the aqueous matrix above.

The predominant and long-term impact of the cinnabar-rich Isonzo River sediment is evident not only in the bottom sediments of the Gulf of Trieste (Horvat et al., 1999; Covelli et al., 2001, 2006b), but also of the Marano and Grado Lagoon. Here, a decreasing concentration gradient in surface sediments from east (>11 µg/g) to west (0.7 µg/g) occurs (Acquavita et al., 2012).

The limit value of mercury Environmental Quality Standard in the sediment is 0.3 mg / kg (as reported in the Water Framework Directive) and in the regional coastal waters almost all the sediment samples exceeded them, with a mean regional value of 4,4 ± 3,9 mg/kg (Figure 3.4.).

However, there is no direct correlation between the total mercury content, its mobility and the potential transformation into MeHg, the most toxic species of mercury. The MeHg determinations carried out by ARPA report an average concentration of 2.0 ± 0.9 ng / g, comparable to what has already been reported in the literature (Covelli, et al., 2008). MeHg represents on average the 0.08% of total mercury and there is no direct correlation between the two species.

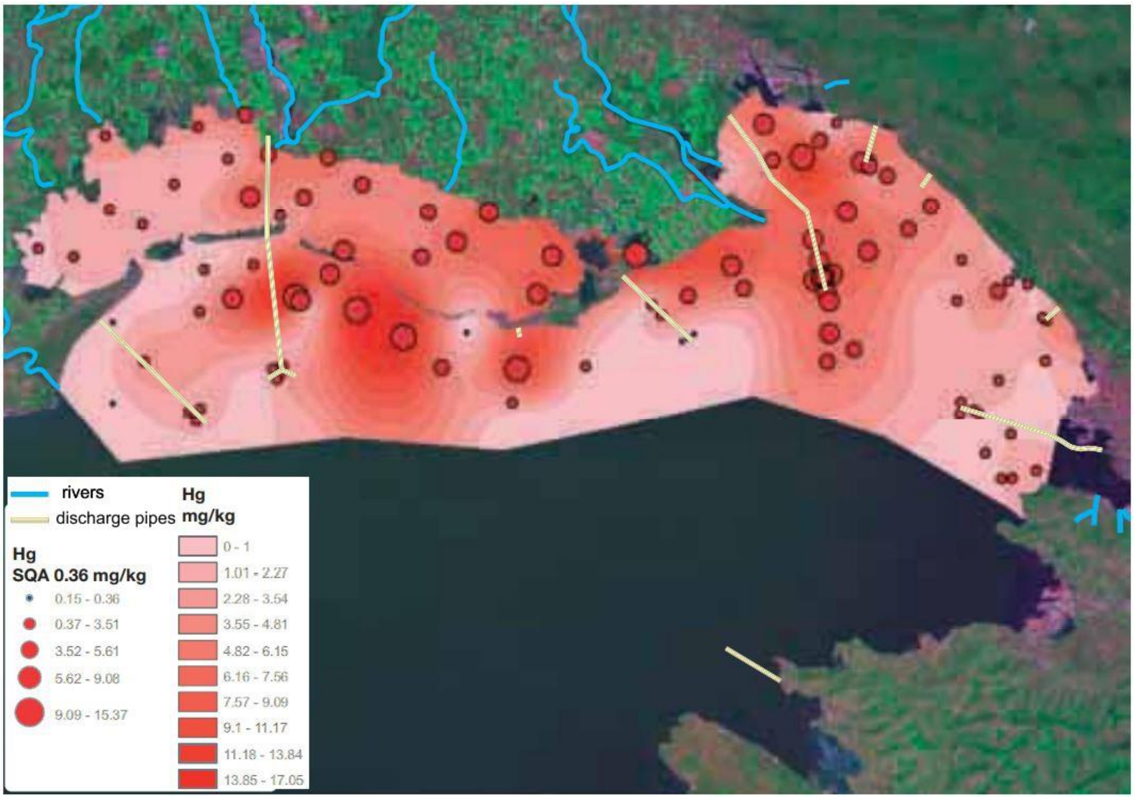

Figure 3.4.30. Spatial distribution of Hg total content obtained from the PRTA analysis (Piano Regionale Tutela Acque - Regione Autonoma Friuli Venezia Giulia), from Acquavita et al. 2012 modified.

The high amount of Hg in the coastal sediments represent today legislative and environmental constrains for the sediment management and the possibility to plan coastal defense interventions involving sediment handling (dredging or nourishment).

3.4.5. Acquisition of new in-situ data and analysis of recent trends of water and sediment fluxes

The acquisition of an acoustic Doppler current profiler (ADCP) and it set up in the Isonzo mouth is planned in this WP (*Figure 3.4.31*). Actually, the purchase process is ongoing, but the Covid-19 lockdown slowed down the work.

Figure 3.4.31. Example of acoustic Doppler current profiler (ADCP) configuration.

Figure 3.4.32. Expected position for the ADCP at the mouth of the Isonzo River.

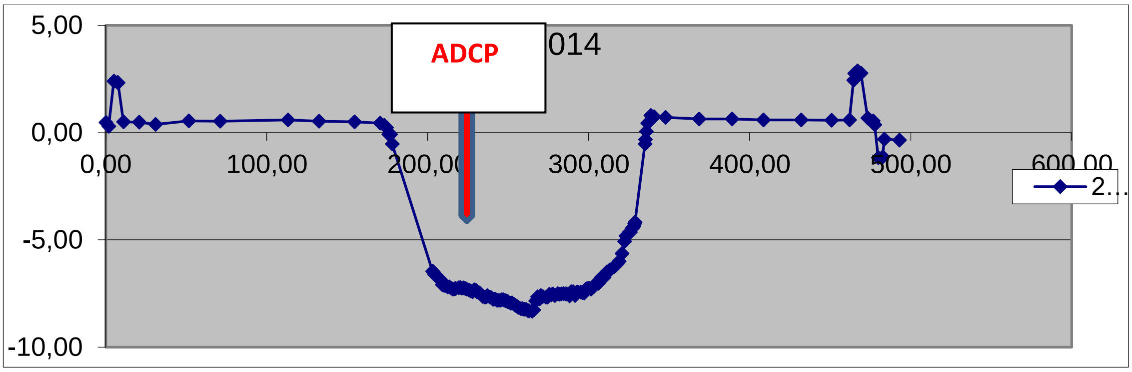

Figure 3.4.33. River section diagram near the installation site, the section is represented with a view from upstream to the valley, so the site is located on the right bank. The red arrow gives an indication of the position.

The unit is typically bottom frame-mounted and hard-wired to shore to provide real-time monitoring of river currents, data can be stored internally for short or long-term deployments. The installation point has been located in *Figure 3.4.32*, in an easy-to reach place where some infrastructures are present and the river section is suitable for a good data quality (*Figure 3.4.33*).

The results of the measures will be important in estimating the sedimentary contribution of the Isonzo River, currently unknown, and its influence in the evolution of the morphology of the Banco Mula di Muggia.

3.4.6. Conclusion

3.4.6.1. Results of the activities and discussion

The analysis of the available data allows us to describe the pilot study area as a coastal environment strongly influenced by some geographical and morphological factors: the location in the northernmost part of a restricted and shallow sea basin (the Adriatic Sea), the orography (Alps), the supply of fresh waters and sediments from the mainland (in prevalence from the Isonzo river) and the connection with the large Marano and Grado Lagoon.

Due to the shallows of the basin, seasonal and interannual variations in temperature and salinity are very marked. The average annual sea temperature (measured in Trieste 1995-2014) is around 16 °C, the annual average of the absolute minimum is 7 °C and the annual average of the absolute maximums is 27.5 °C.

The most important freshwater input from mainland comes from the Isonzo River (with an annual average flow rate of 204 m3/s), which hydrology and sediment supply to the sea is strongly influenced by a series of artificial dams and intakes for irrigation channels. The annual rainfall on the coast is around 1000 mm, but it reaches the 2600- 2900mm in some part of the Isonzo catchment basin. Flood events generate unquantified supplies of sand to the mouth of the river and evident turbidity plumes associated with freshwater diffusion. The plume diffusion interest different parts of the coastal area in dependence of the meteorological conditions and, settling along the water column, contribute to the sediment supply to the coastal environment.

The coastal and marine water hydrology is essentially cyclonic, with currents going in the south-east direction along the coast. Nevertheless, it is frequently modified due to the torrential nature of the Isonzo flows, the impulsive events of Bora wind and the effect of the southern winds.

Water exchange with the Marano and Grado Lagoon occurs through the tidal inlet of Grado and Primero and are strongly controlled by semi-diurnal tidal fluxes, resulting from 65 cm and 105 cm mean and spring tidal range, respectively.

The presence of agricultural areas in the mainland potentially affect the supply of fertilizers, herbicides and pesticides. A widespread mercury contamination of historical origin affects the area and the adjacent lagoon system. Almost all the sediment samples exceeded the limit of Hg Environmental Quality Standard of 0.3 mg / kg with a mean regional value of 4,4 ± 3,9 mg/kg.

3.4.6.2. Problems and solutions

The strong influence of artificial dams and intakes for irrigation channels on the hydrology of the Isonzo River represent an uncertain factor in the definition of the water and sediment flux from mainland. Rising temperature and the not clear climate change signal on the rainfall contribute to do difficult an assessment of the consequence of the climatic change on the freshwater input to the coast and on the related sediment supply.

The high amount of Hg in the coastal sediments represent today a legislative and environmental constrain for the sediment management and the possibility to plan coastal defense interventions involving sediment handling (dredging or nourishment). The involved area and the amount of Hg are such that it is not possible to follow a classic remediation strategy on a large scale. Rather, an orientation towards real targeted risk assessment and a consequent mitigation management should be considered.

3.4.6.3. Analysis of data quality

The meteo - climatic context and its influence on the coastal hydrologic system is well known in the pilot site area.

The water quality data refer to the monitoring network of water quality for bathing. The Regional Agency for Environment Protection (ARPA – FVG) manages 55 sampling points on the seaside and 2 sampling points in the Grado Lagoon. Data are available at the website http://www.arpa.fvg.it/cms/tema/acqua/balneazione/monitoraggio/mappa.html, and they are upgraded periodically.

The evaluation of the entity of the sedimentary input from the mainland to the coastal system is a focus problem for the pilot site area, due to the chronical lack of data and to the general difficulty to quantify this type of data. Nevertheless, it represent an important element in assessing the coastal sediment budget and the future resilience of the coastal system to the rising sea level. For this reason, the acquisition of an acoustic Doppler current profiler (ADCP) and its set up in the Isonzo mouth was planned in this WP, but actually, the purchase process is still ongoing.

The Hg contamination is well documented and studied in the area. In recent years, the studies conducted in the Gulf of Trieste are aimed at understanding the biogeochemical cycles of the metal, its behavior in the suspended particle and in the water column, its speciation and re-mobilization at the water-sediment interface. This will allow improving knowledge about the real danger of this contamination and contributing to a new legislative approach about the Hg-rich sediment management.

3.5.Po River Delta and focus sites Sacca di Goro and Sacca del Canarin

3.5.1. General description of the catchment area

The Po river delta is fed by the waters and sediments of the Po river basin and it has grown in its eastern margin. The Po River basin is developed along the West– East direction of the river course, bounded by the Alps to the North and West and by the Apennines to the South, while to the east it borders the Adriatic Sea. The total area of the Po basin's watershed is 74,500 km^2, of which 30,790 km^2 are above 200 m a.s.l. in elevation and the remaining part is flat territory of alluvial plain that is below 50 meters of elevation for about a half.
The Po River is 691 km[1] long and has a relatively steep gradient upstream of Pontelagoscuro (located 100 km landward of the present delta mouth of Po di Pila), where the river enters the coastal region and flattens considerably.

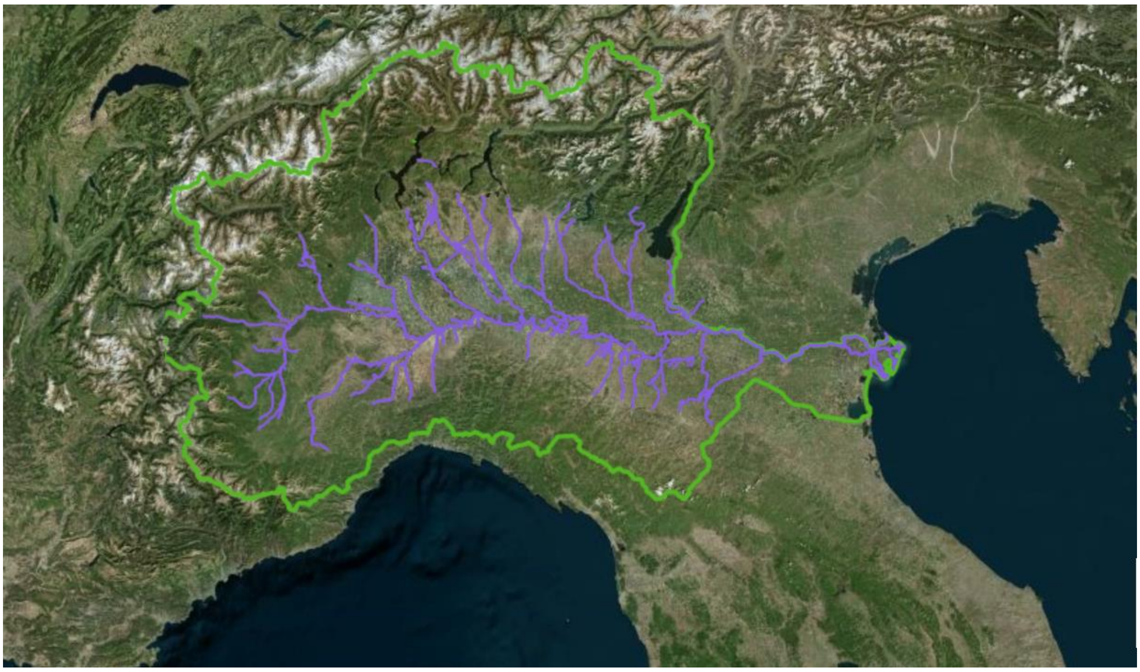

Figure 3.5.18. Catchment basin of Po River and main tributaries

The Po River
The Po River is the longest Italian river, crossing all the north Italy from East to West with several administrative regions.

[1]The length is computed considering the watercourse starting from the Maurin spring. Thus, it comprises the entire extension of the Po River, along the Maurin/Maira/Adriatic Sea course

Figure 3.5.19. Drainage basin of Po River (from Wikipedia, Elevation Data by USGS)

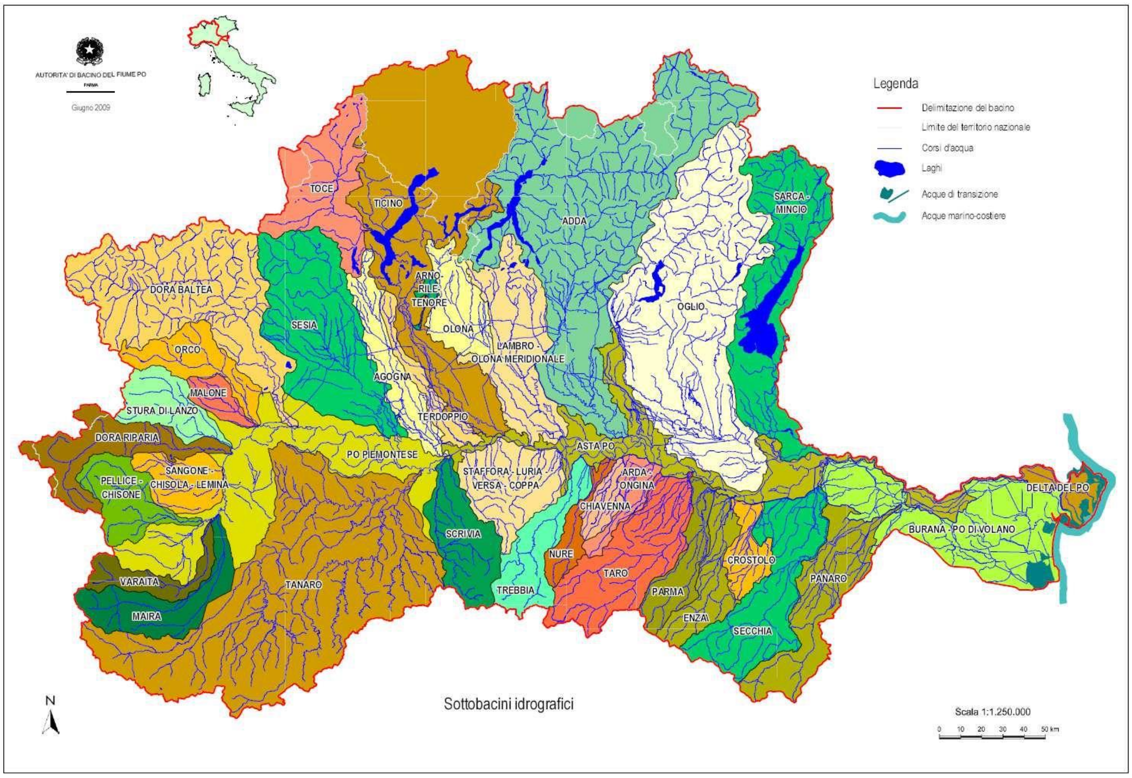

Figure 3.5.20. sub-basin of the Po River catchment; (Piano di gestione del distretto idrografico del Fiume Po, Stato delle risorse idriche, 2016)

The artificial and natural hydrographic network of its catchment is extremely developed and articulated in 35 main sub-basins (Figure 3.5.20), with distinct geological and morphological features. The overall extension of this network spreads for almost 55,700 km.

The Po river originates from Monviso at an altitude of 2,100 m a.s.l. The river course first goes north, up to Chivasso, then folds south towards Valenza and finally turns east again; between Moncalieri and Valenza, the river flows at the foot of the Turin hills and Monferrato and at the confluence with Tanaro River, it is about 270 km long, closing a partial catchment basin of 25,320 km^2.

From the confluence of the Tanaro to the Po di Goro, for about 375 km, the river has a predominantly artificial connotation, with a flow regime influenced by the hydrological conditions and hydraulic arrangement of the tributaries, as well as by the defense works. In the first section, between the Tanaro and Ticino, it still shows substantially torrential characteristics, with a slope of the order of 0.35 ‰.

The confluence of Ticino involves a transformation of the river regime, due to the regulated water supply, with a significant glacial contribution and the absence of solid transport; the average slope reaches 0.18 ‰, then decreases regularly and gradually downstream to about 0.14 ‰ next to Revere-Ostiglia. The difference of level between ordinary and flood conditions exceed 10 m in this section.

The main embankments, continuous on both sides, have very irregular development, affected by their fragmentary origin, and are located at distances ranging from less than 1 to over 4 km. The high distance of the embankments delimits a large area along the riverbed that performs essential lamination functions. From the valley of Revere-Ostiglia to the Delta, the riverbed becomes canalized between the embankments, in some sections at distances of less than 500 m, and no longer receives contributions, with the exception of the Panaro. Until the end of the last century the embankment system starting from Becca was not completely closed and the Po, as most of its tributaries, constantly flooded the surrounding plain; the terminal part of the Po River essentially functioned more as a lake basin than as a natural stream.

Table 3.5.3: Most relevant features regarding the Po River catchment, data from Interregional Agency for Po River AIPO web site https://www.agenziapo.it/content/mission

Length of the Po River	691 km
Spring	Monviso Mount (Piemonte)
Outlet (Delta)	Adriatic Sea (Veneto-Emilia-Romagna)
Basin extension	ca. 74000 km^2
Ordinary discharge at the closure section of Pontelagoscuro	ca. 1500 m^3/s
Maximum water discharge at Pontelagoscuro	More than 10000 m^3/s
Number of tributaries	141
Largest lakes in the basin	Garda Lake (370 km^2), Maggiore Lake (210 km^2), Como Lake (145 km^2), Iseo Lake (65 km^2)
Length of the embankments along the main course	More than 1000 km
Length of the embankments in the whole catchment	ca. 3600 km
Extension of the protected areas	517000 ha (26% of the protected areas in Italy)
Number of the crossed regions	7 in Italy (Piemonte, Lombardia, Emilia-Romagna and Veneto), with one in Switzerland (Canton Ticino)
Number of the Municipalities in the catchment	3210
Residential population	ca.16 million

The secondary hydrographic network, consisting of water courses shorter than 20 km, extends approximately nine times more than the main one; the development of the artificial network (remediation and irrigation) is also consistent, closely integrated and interacting with the natural streams and river.

All over time, the watercourses in the basin have undergone significant transformations and hydraulic arrangements that have led to a rather intense level of artificialization.

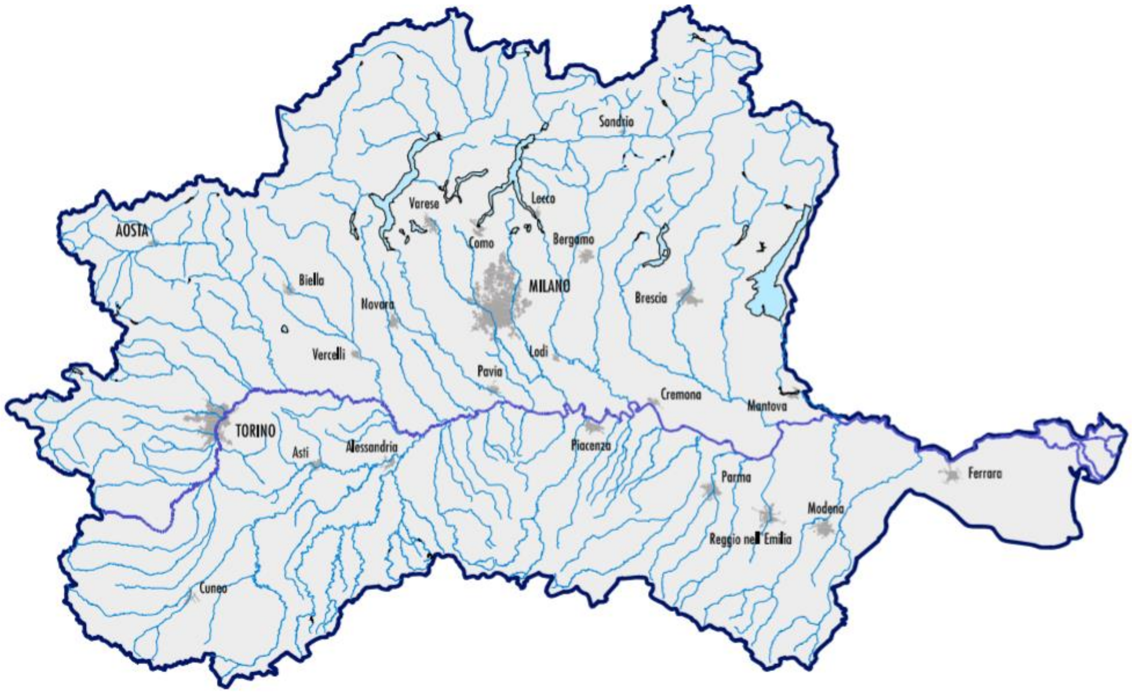

Figure 3.5.21: Hydrographic network of Po basin

The Po Delta

The Po Delta represents the final sub-basin subtending the entire Po catchment, and it develops as a flat region with a surface of 472.55 km^2 (1.6 % of the total Po catchment), which is almost completely below the sea level (Piano di gestione del distretto idrografico del Fiume Po, Stato delle risorse idriche, 2016).

It is divided into seven active branches: Po di Levante, Po di Maistra, Po di Pila (with the mouths of Scirocco and Tramontana), Po di Tolle, Po di Gnocca, Po di Goro.

The branches that make up the Delta begin at Papozze (Rovigo), at km 625 of the progressive along the Po axis, where the main course deviates northward then to the west – east direction.

From the main branch, the Po di Goro branches off to the right toward the south-east and the Po della Gnocca separates at km 656 with a direction parallel to the Po di Goro; in the left, the Po di Maistra branches off at km 659.

The Po di Venezia is divided into two branches at 668 km, the Po della Pila towards the east, the most important, and the Po delle Tolle that flows southward.

The branches of the Po della Gnocca, the Po di Venezia and the Po di Tolle delimit the Donzella Island respectively to the west, north and east. The further branches of the Po della Pila are called “buse” (the “Busa dritta” is considered the main mouth of the river).

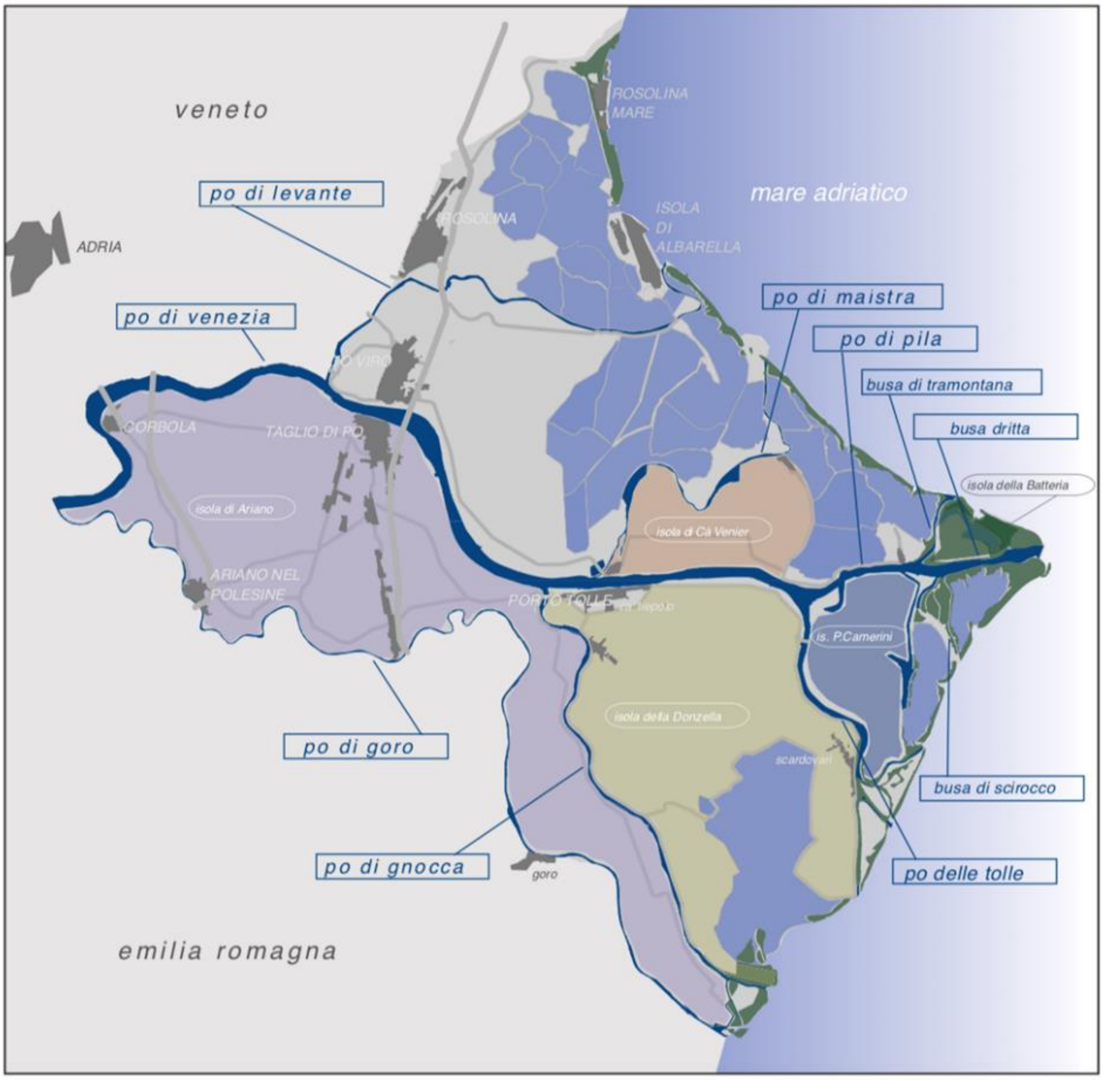

Figure 3.5.22. Scheme of the Delta Po region and the main fluvial branches. The different colors distinguish the portions of land bounded by the river and sea waters (Atlante del territorio costiero, lagunare e vallivo del Delta del Po).

From an environmental point of view, the Po Delta, with its interconnection of aquatic and land habitats, of fresh and salt water, represents a very important environmental ecological complex.

This is an area of recent formation, created by a slow sedimentation of the soil and extraordinary interventions of human reclamation; it is still in continuous evolution and in continuous expansion (60 ha/year) due to the great contribution of sediments.

The Po Delta represents a heritage of inestimable naturalistic, cultural and social value, so much so that a good part is counted among the wetlands of international importance under the Ramsar Convention (1971).

Due to its great environmental value, it is a UNESCO World Heritage Site. It is an "ecosystem" to protect and preserve, also in accordance with the "Habitat" Directive (92/43/EC) and the "Birds" Directive (79/409/EC). In this area, in fact, there are Sites of Community Importance (SCI) and Special Protection Areas (SPAs) which are part of the Natura 2000 Network.

3.5.1.1. Meteorological characteristics

The Po basin is located in correspondence with a natural limit between the Mediterranean climate and the Central European continental climate, constituting a transition region between very different rainfall and thermometric regimes.

The Po valley is protected from the cold northern winds by the Alpine system but also from the mitigating influence of the Tyrrhenian Sea by the Ligurian Apennines. An important phenomenon in the coastal area is the presence of particular sea current from north to south that determined, at the same latitude, a colder climate than the Tyrrhenian one.

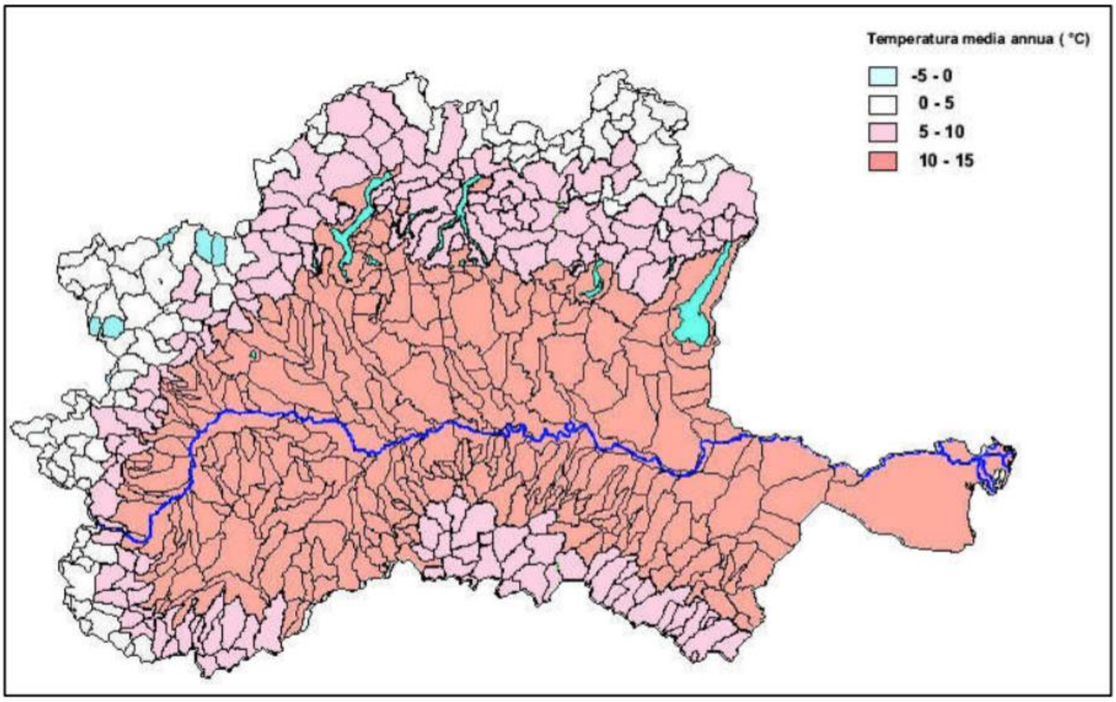

Figure 3.5.23. Annual average temperatures in the Po basin; areas with lowest temperatures are light blue colored, with highest temperatures are orange (from general report of Water Balance Plan for Po river district, Po River Basin Authority AdBPO, 2016).

The time series on the maximum and minimum annual average temperatures show values, reported at sea level, corresponding respectively to about 18 -19 °C and 9 -10 °C. The gradient with respect to altitude is similar for both maximum and minimum temperatures; it corresponds approximately to the decrease of one degree every 180-200 m of altitude.

The thermal regime throughout the year is substantially homogeneous over the entire basin, but with significant differences concerning the extreme values from one area to another, which show a regular dependence on the altimetry. The average minimum temperatures occur in January, rise gradually until July, when the maximum is recorded, remain high in August and moderate in September, and then drop down to reach, in December, values not much greater than in January.

The number of frost days and ice days (i.e. days when the maximum temperature was below 0 °C) also depends strictly on the altitude, even if sometimes local factors can influence it. The highest values were recorded at Monte Rosa (Goillet Station, 2500 m a.s., annual average of 227 days of frost and 94 days of ice) while the lower values refer to stations located on the Lombard-Piedmont lakes (average annual 24-day frost for Desenzano on Lake Garda and less than 1 day of ice for the stations of Bellano on Lake Como and Pallanza on Lake Maggiore).

As for snowfall, the maximum values were measured at the Plateau Rosà station with an average of 1051 cm/year.

The extent of the precipitation depends on the altitude, although also the exposure can affect, similarly to what happens for the rainfall. The annual average on all stations, that are mainly mountain stations (average altitude 1,189 m a.s.l.), is 296 cm/year.

The areas with the most intense rains are those exposed to the meteoric disturbances that come from the Mediterranean and the Gulf of Genoa on the Apennine watershed, with peaks on the most elevate portion of the Bormida, Scrivia, Trebbia and Taro basins and on the pre-Alpine area between the Stura di Lanzo and lake Maggiore. High values are also found in the area of the large Lombard lakes and in the upper Tanaro basin. Significantly lower rainfall intensities characterize the plains and theupperpart of valleys, especially in the western Alpine arc, such as the Aosta valley, the upper Susa valley, the upper Ossola valley, the Sarca and the Bormio area.

The average annual rainfall in the basin area, derived from 600 rainfall stations spread over the territory, is about 1080 mm (period 1923-2008). The largest area with precipitation greater than 1000 mm/year belongs to Lombardy, with the exclusion of areas pertinent to Valtellina, the upper Val Camonica and the upper Sarca valley. In Piedmont, the average annual precipitation exceeds 1000 mm only in some areas, located in the Sesia, Orco and Stura di Lanzo basins. The Tuscan-Emilian Apennine area shows this intensity only at the ridge, otherwise it is much drier. Low precipitation values are found in the valleys E-W oriented as Susa Valley, Aosta Valley and Valtellina.

In the Alps, the relationship between the rainfall and the altitude appears complex due to local factors while in the Apennine system the dependencies quite regular. The most notable precipitations tend to concentrate in the area of the great alpine lakes. In spring (March-May), maximum rainfall between 500–700 mm occurs in the pre-Alpine hills and along the Apennine ridge. In summer (June – August) rainfalls up to 400–500 mm are spread in the Lombard Prealps and in the upper plain. In the same period, in the plains rainfalls reach 150-200 mm, whereas In the Apennines the maximums are between 200–300 mm.

In the autumn, the peaks of 600–700 mm are concentrated in the area of the Prealps, from the Dora Baltea to the Oglio area, and also they affect the Apennine ridge; in the plains the values are between 200 and 250 mm.

During the winter season there are reduced values in the Western Alps (100–150 mm) and slightly higher in the central Alps (150–200 mm), instead, greater precipitations (up to 500 mm) are recorded at the Apennine ridge. In the plain, rainfall of less than 150 mm dominates vast areas (Canavese, Monferrato, Langhe and the area along the Po river), whereas higheraverages, between 200 and 350 mm, are recorded in the upper plains of Lombardy and Emilia.

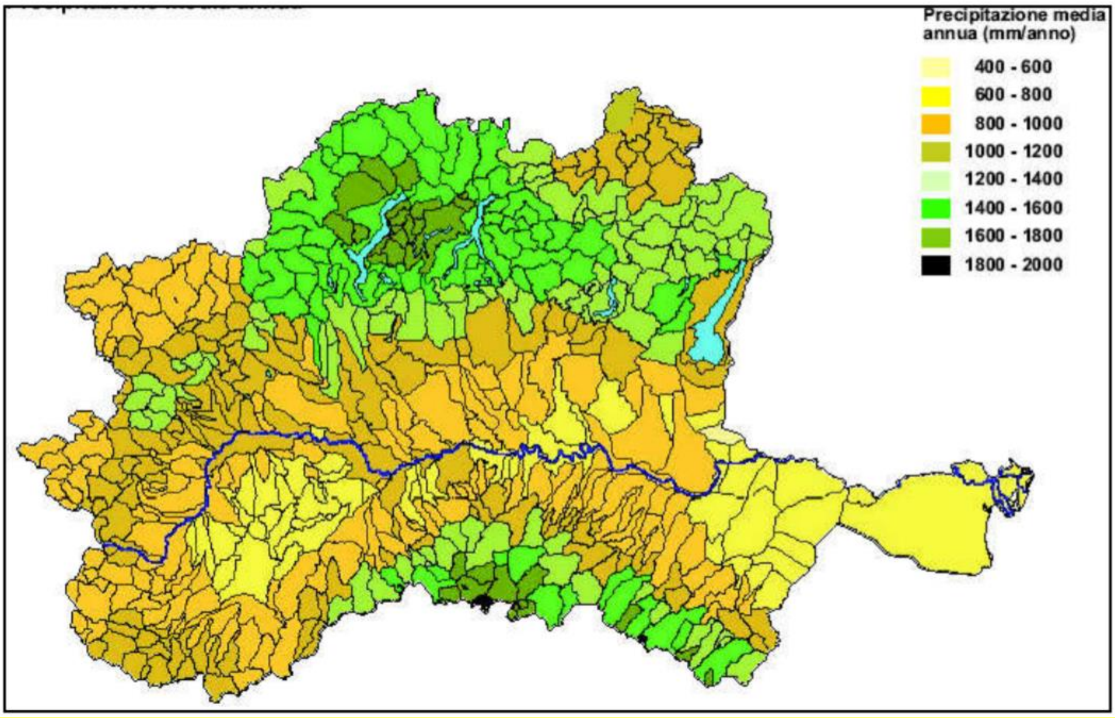

Figure 3.5.7. Annual average precipitations in Po basin; the unit of values in legend is mm/year (from General report of Water Balance Plan for Po river district, Po River Basin Authority AdBPO, 2016).

The rainfall data on the Po basin come from the Hydrological Annals (former Hydrographic Office) until 1996 and from the regional agencies on behalf of the Po River Basin Authority, for the purpose of preparing the Water Balance Plan, from 1997 onwards.

As regards the monthly average precipitation, the basin shows a rainfall regime characterized by two equivalent maximums, in spring and autumn, and by two minimums, winter and summer, in which the clear prevalence of the winter minimum is noted.

The average least rainy decades are 1941-1950 and 1989-1998, with an average minimum value of 1000 mm/year. It is noted that the four major flood events for the Po (1951, 1994, 2000 and 2004) occurred in these periods characterized by below-average rainfall.

Focus on the Delta Po

The Regional Agency for Environmental Protection and Prevention of the Veneto Region (ARPAV) is in charge for the climatic measurements regarding the Delta Po Region and it publishes the data on its website (https://www.arpa.veneto.it/bollettini/storico/Mappa_2020_PREC.htm?t=RO, for the Rovigo province). The data on the temperature, precipitation, humidity, solar radiation, hydrometric level, wind velocity and direction, as well as data on wind gusts and pressure are available starting from 2010 until today. Moreover, the Agency provides the average and aggregate values of the measured variables from the 1994 to 2019, distinguished according to the measuring station (available as .csv from https://www.arpa.veneto.it/dati-ambientali/open-data/clima/principali-variabili-meteorologiche):

- Annual rainfall sum (mm)
- Number of the rainy days
- Global solar radiation (MJ/m^2)
- Air temperature at 2 m (°C), mean, of the mean, minimum and maximum values
- Relative humidity at 2 m (%), minimum of the minimum and max of the maximum values
- Mean wind velocity (m/s)
- Wind prevailing direction (sector)

Regarding the monitoring stations, 175 were active in 2019 in the Veneto Region, with two located in the Po Delta:

1. Measuring station at Porto Tolle (RO) – Pradon (see Figure 3)
2. Measuring station of Rosolina – Po di Tramontana

Some elaborations of the Regional Agency for Environmental Protection and Prevention of the Emilia Romagna Region (ARPAE, 2008) show an increase of the temperature in the Po Basin between the 1961 and 2006 and a decrease of the precipitation registered at the Pontelagoscuro station between 1975 and 2006. This latter trend is not visible during the temporal range covered by the graph that is reported below and that refers to the Porto Tolle station.

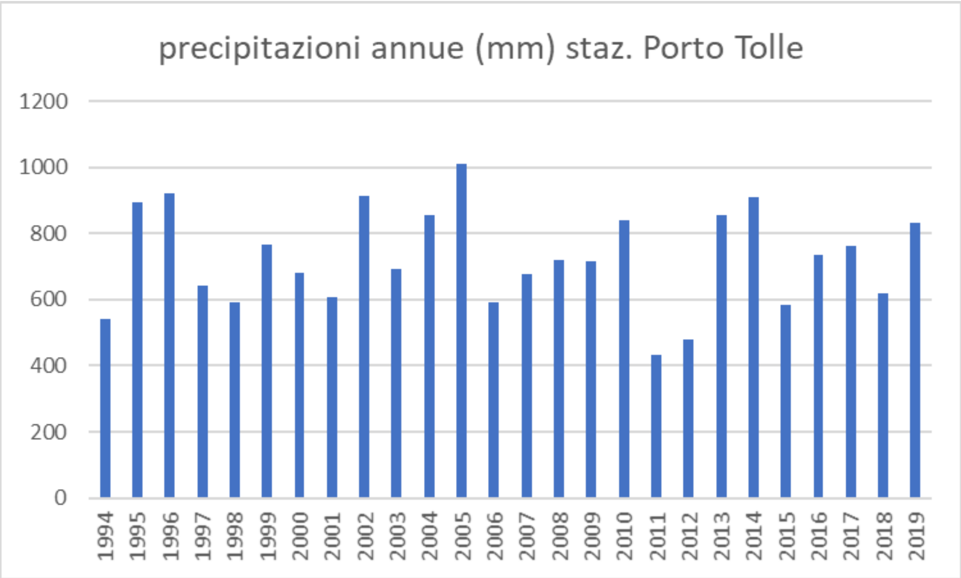

Figure 3.5.8.Annual rainfall for the temporal interval 1994-2019. Measuring station of Porto Tolle.

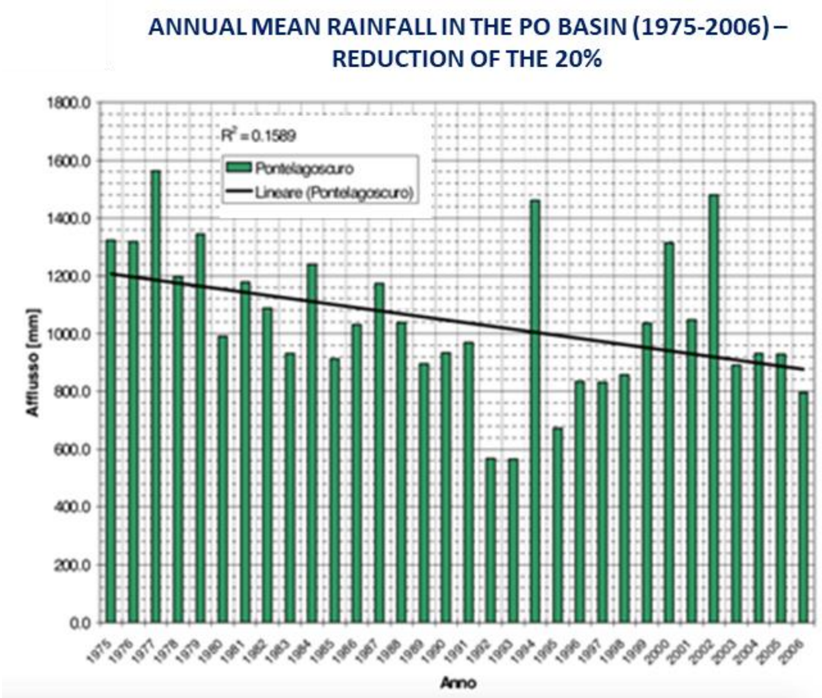

Figure 3.5.9. Annual mean rainfall height measured in the Po Basin with a linear trend highlighting a reduction of the 20%.

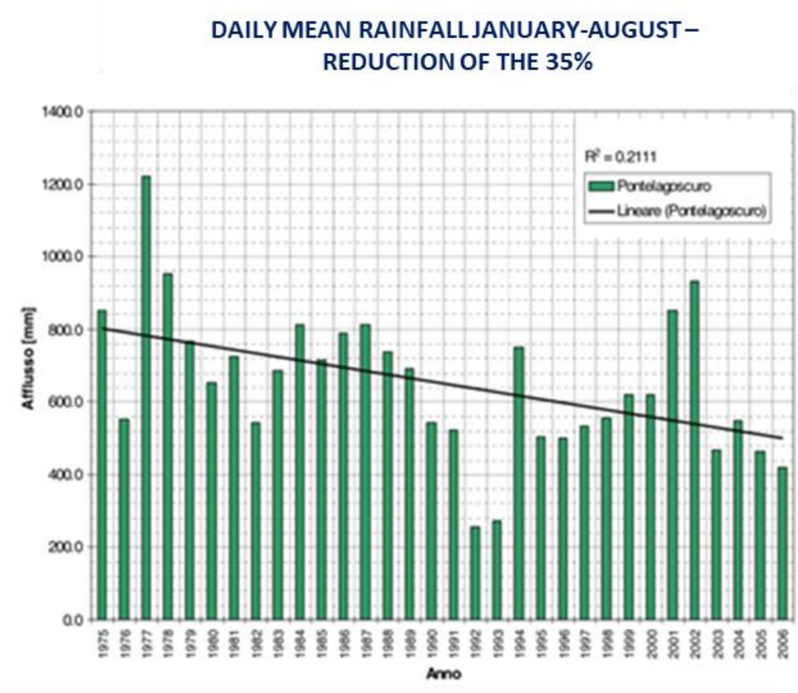

Figure 3.5.10. Daily mean rainfall measured in the Po Basin with a linear trend highlighting a reduction of the 35%.

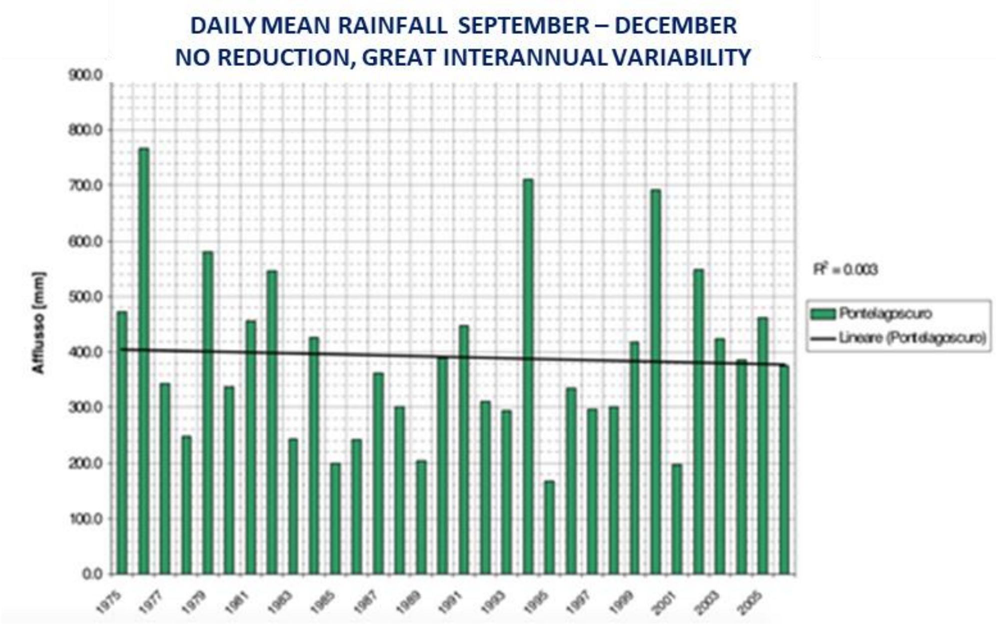

Figure 3.5.24. Daily mean rainfall during the period September-December: highly variability without a clear trend.

3.5.1.2. Hydrological characteristics

In the European context, the most representative characteristic of the Po valley hydrology is variability both in time (seasonal, annual and interannual) and in space (Alpine area, Apennine area, lowland regions).

As mentioned before, the average least rainy decades are 1941-1950 and 1989-1998, with an average minimum value of 1000 mm/year. It is noted that the four major flood events for the Po (1951, 1994, 2000 and 2004) occurred in these periods characterized by below-average rainfall.

The flows of the Po River are measured at hydrometric stations, for which there are continuous historical series since the 1920s. These data, measuring the actual flow in the riverbed, are subject to the influence of all withdrawal, inputs and modifications of the natural hydrological regime. For this reason, both trends and runoff must be interpreted as inclusive of such anthropogenic effects, with the consequence that a possible tendency cannot be attributed to anthropogenic exploitation or climate change without further investigation.

Given these premises, it is reported that in Pontelagoscuro, the easternmost of the stations and close to the delta, the average flow based on the data measured there from 1923 to 2011, is 1506 m^3/s.

During the historical events of 1951, 1968, 1994 and 2000 high water flows recorded in this station were between 97500 and 10300 m^3/s. In the 1923-2011 period, there were also several drought events.

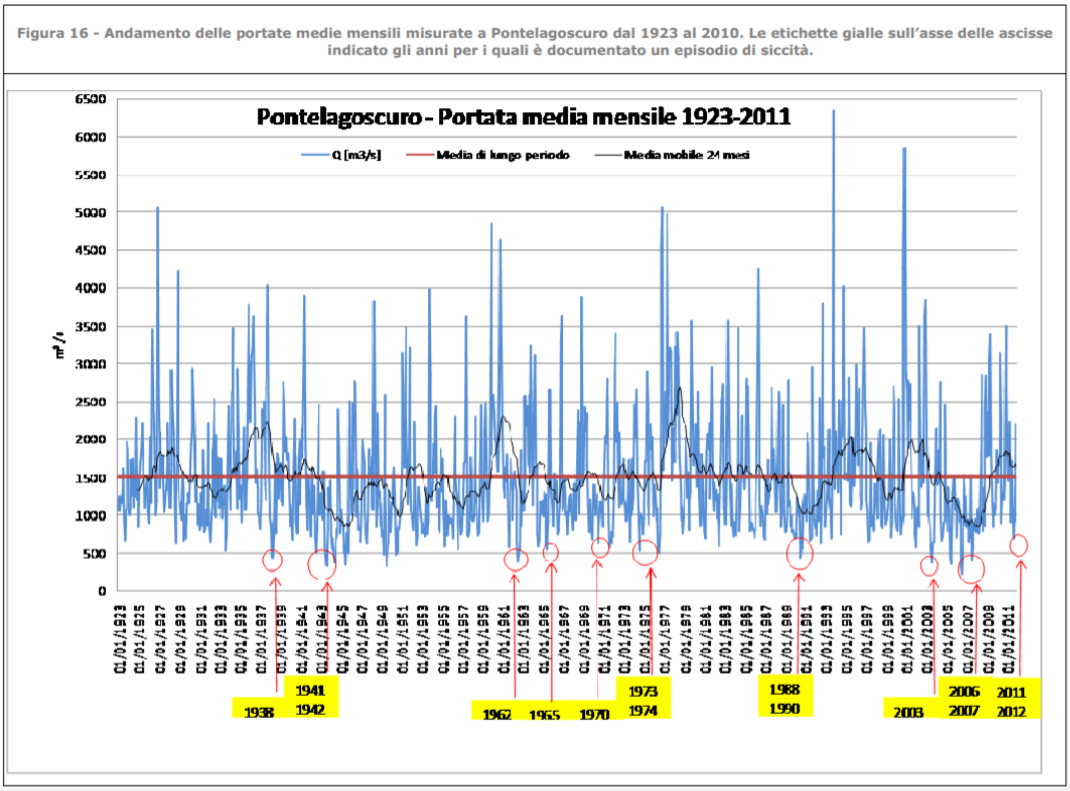

Figure 3 .5.12. Monthly average flow rate measured in Pontelagoscuro from 1923 to 2010. Yellow labels on the X axis indicated the years for which a drought episode is documented. The upward peaks indicate main flood events (from General report of Water Balance Plan for Po river district, Po River Basin Authority AdBPO, 2016).

The monthly average and annual average flows show that the values tend to decrease with differences, although modest in absolute terms, significant for the low water periods (durations exceeding 274 days/year).

All the reference values in the decade 2001-2010 were lower than the historical average and the last major water crises in the Po basin were observed precisely in this period (2003, 2006, 2007, 2011, 2012). In 2003 and 2006 the two lows have exceeded the historical minimum of 1944 twice in intensity. The highlighted trends cannot be definitively interpreted in the light of the ongoing climate changes until it can also be correctly analyzed the withdrawals from the rivers of the Po basin for irrigation purposes in the same period.

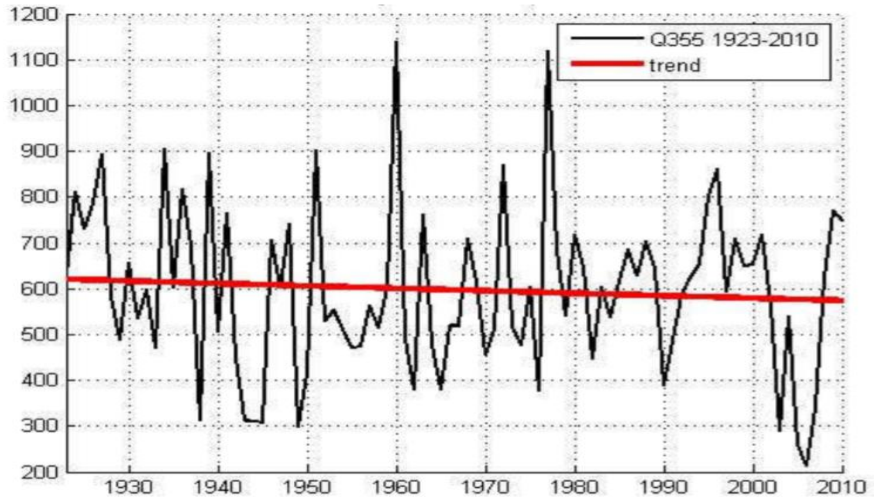

Figure 3.5.13. Flow rate with duration 355 days/year with its trend at Pontelagoscuro (from General report of Water Balance Plan for Po river district, Po River Basin Authority AdBPO, 2016).

In particular, in the period 2001-2010, the reduction of the average flow affecting especially July then October and November,is observed.

Previous study (Cati, 1981) estimated between 180 and 280 m^3/s the total annual average flow subtracted at Pontelagoscuro by all irrigation withdrawals, which is equivalent to about 6-9 billion m^3/y; in 1990, the overall average withdrawal for irrigation was estimatedover 13 billion m^3 between April and September, while in 2009 the estimate of the volume withdrawn for irrigation was over 18 billion m^3/y.

It appears that the withdrawal for irrigation purposes has increased significantly over the time considered. It has been estimated that in the months of May and June about half of the available water volume is withdrawn for irrigation purposes, with an average of more than 900 m^3/s.The decade 2001-2010 is also characterized by low water flow far below the average calculated for the complete period 1923-2010.

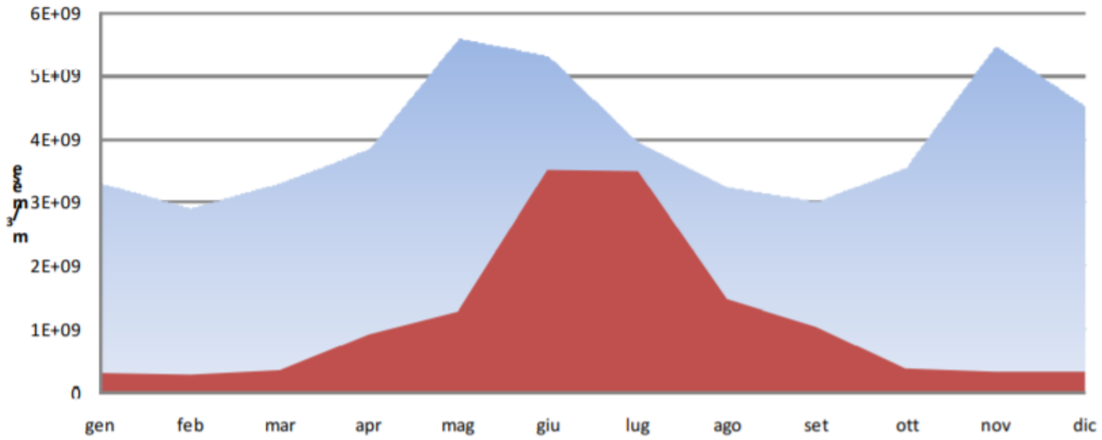

Figure 3.5.14. Monthly average trend of water availability relating to the Po river basin closed at Pontelagoscuro. Estimated monthly average of total water availability (light blue) and estimate of the monthly average withdrawals (red) (from General report of Water Balance Plan for Po river district, Po River Basin Authority AdBPO, 2016).

Seaward of the Pontelagoscuro section, the five branches of the Po river show different hydraulic capacity as estimated through periodic measuring campaigns carried out during the last decades. The most recent study dates back to 2012 (Arpa Regione Veneto, 2012), and it was conducted by ARPA Veneto, in collaboration with ARPA Emilia Romagna and Consortium for the remediation of Po Delta. It investigated the water discharge (through Acoustic Doppler concentration profiler ADCP) and turbidity (by sampling with DH 59 bottles, throughout different verticals in the measuring cross-sections) in the five branches of the Po River, by means of synchronous measurements and following the historical campaigns of Visentini (UIPO, 1940). The results were compared to theprevious studies to understand the historical evolution of the final part of the Po River (Canali, 1959; UIPO, 1962, 1971, 1981; Grego, 1990; Enel, 1992).

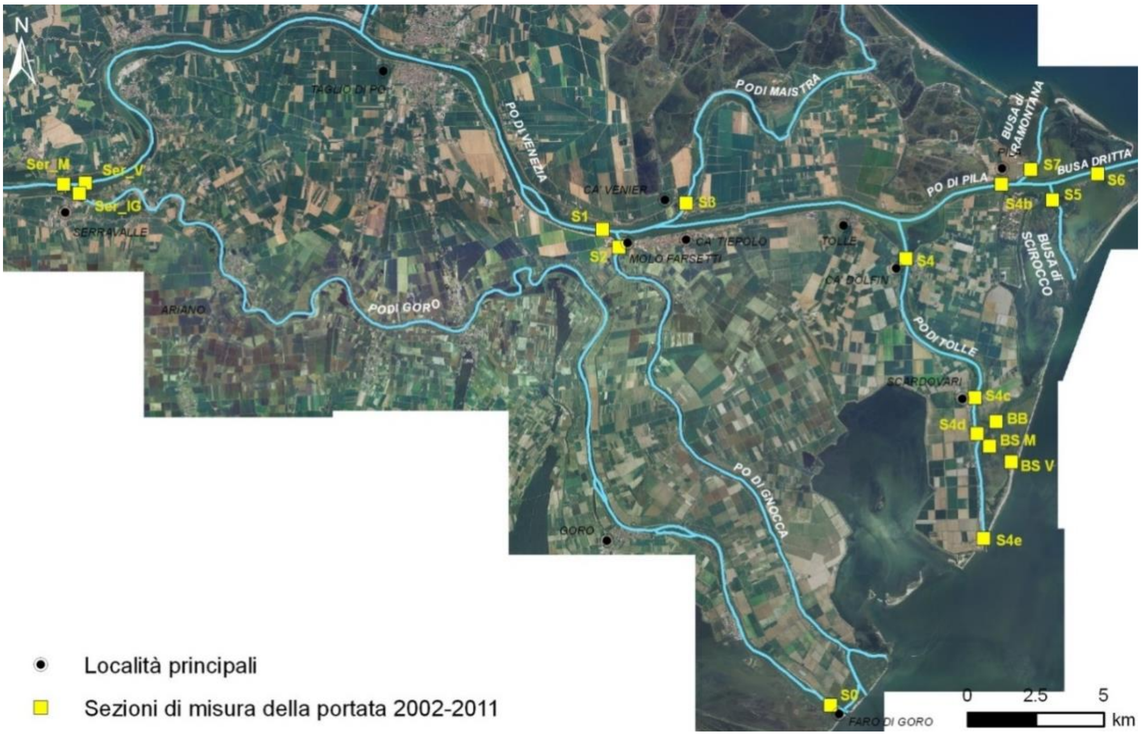

Figure 3.5.15. Locations of the measuring stations for the water discharge in the 2002-2011 campaign.

This measuring campaign comprised several years, from 2002 to 2011, involving different flow regimes (low and high-water periods, respectively in September 2002 and November 2007, dry periods in May 2007, and two phases corresponding to the lowering part of the hydrograph after floods, in June and November 2010), and considering not only the five branches but also the mouths at the sea. A flood episode in 2011 was also monitored simultaneously at Pontelagoscuro and Po di Goro.

The data are summarized in

Table 3.5.4 and Table 3.5.5, which report the water discharge partitioning among the different branches and mouths for different water fluxes measured at Pontelagoscuro.

Table 3.5.4. Measuring campaign to assess the water discharge partitioning among the five branches of the Po River.

Date dd/mm/yy	Po di Goro (S0)		Po di Venezia (S1)		Po di Gnocca (S2)		Po di Maistra (S3)		Po di Tolle (S4)		Po di Pila (S4b)		Po Pontelagoscuro
	m³/s	%	m³/s	%	m³/s	%	m³/s	%	m³/s	%	m³/s	%	m³/s (day av.)
14/09/2002	542	**23.5**	1782	**76.5**	338	**14.7**	77	**3.3**	390	**16.9**	954	**40.5**	***2300***
30/05/2007	34	**5.2**	623	**94.8**	74	**11.2**	9	**1.4**	103	**15.7**	437	**66.6**	***657***
27/11/2007	282	**11.64**	2140	**88.36**	387	**15.9**	102	**4.2**	492	**20.3.**	1158	**47.8**	***2422***
22/06/2010	668	**13.8**	4093	**84.4**	743	**15.3**	208	**4.3**	1037	**21.4**	2193	**45.2**	***4936***
6/11/2010	655	**13.6**	4139	**86.3**	789	**16.45**	215	**4.5**	993	**20.7**	2141	**44.7**	***5102***
11/11/2011	748	**13.5**	4785	**86.5**	-	-	-	-		-	-	-	***5803***

Table 3.5.5. Values of the water discharges measured at the sea mouths of the different branches.

Datedd/mm/yy	Busa di Tramontana		Busa di Levante		Busa di Scirocco		Busa del Bastimento		Busa Storiona		Bocca Po di Tolle	
	m³/s	%	m³/s	%	m³/s	%	m³/s	%	m³/s	%	m³/s	%
14/09/2002	247	25.9	623	65.3	84	8.8	-	-	-	-	-	-
27/11/2007	263	22.7	809	69.9	86	7.4	27	6.7	322	76.2	73	17.2
22/06/2010	671	31.1	1215	56.2	275	12.7	-	-	-	-	-	-
6/11/2010	661	28.9	1337	58.5	286	12.5	48	4.4	845	77.7	194	17.8

The comparison with the historical data reported in the study highlighted the evolving trends of the Po branches and consequently of their transport capacity, which in turn affects the development of the single lobes of the Delta. The main findings can be summarized as follows:

- The hydraulic capacity of Po di Goro has increased during the years, while Po di Venezia has presented a specular and opposite trend. Same considerations can be drawn for the two branches of Po di Tolle, with increasing hydraulic capacity, and Po di Pila, with a reduction in its water discharge. However, Po di Tolle has generally shown a higher variability in comparison to the other branches.
- Po di Gnocca maintained a stationary behavior, except for the first years of the '900, when it delivered more water.
- Regarding the mouths at the sea, Busa di Levante has not shown relevant changes during time, delivering in percentage more water than Busa di Tramontana. The hydraulic capacity of this latter mouth increases with higher discharges coming from Po di Pila, while during low water conditions it delivers less water with respect to Busa di Scirocco, which is the smallest mouth of Po di Pila.

3.5.1.3. Sediment fluxes

The Po river runoff accounts between 1/4 and 1/3 of the total Adriatc river runoff (Raicich, 1994). Previous study (Nelson, 1970) evaluates mean sediment discharge equal to 15x106 t/y with a sediment yield of 201 t/km^2/y and highlights the extreme variability of the sediment load. The same study reports the values of water discharge and sediment load partitioning, in percentage terms, among the five main outlets of the Po delta.

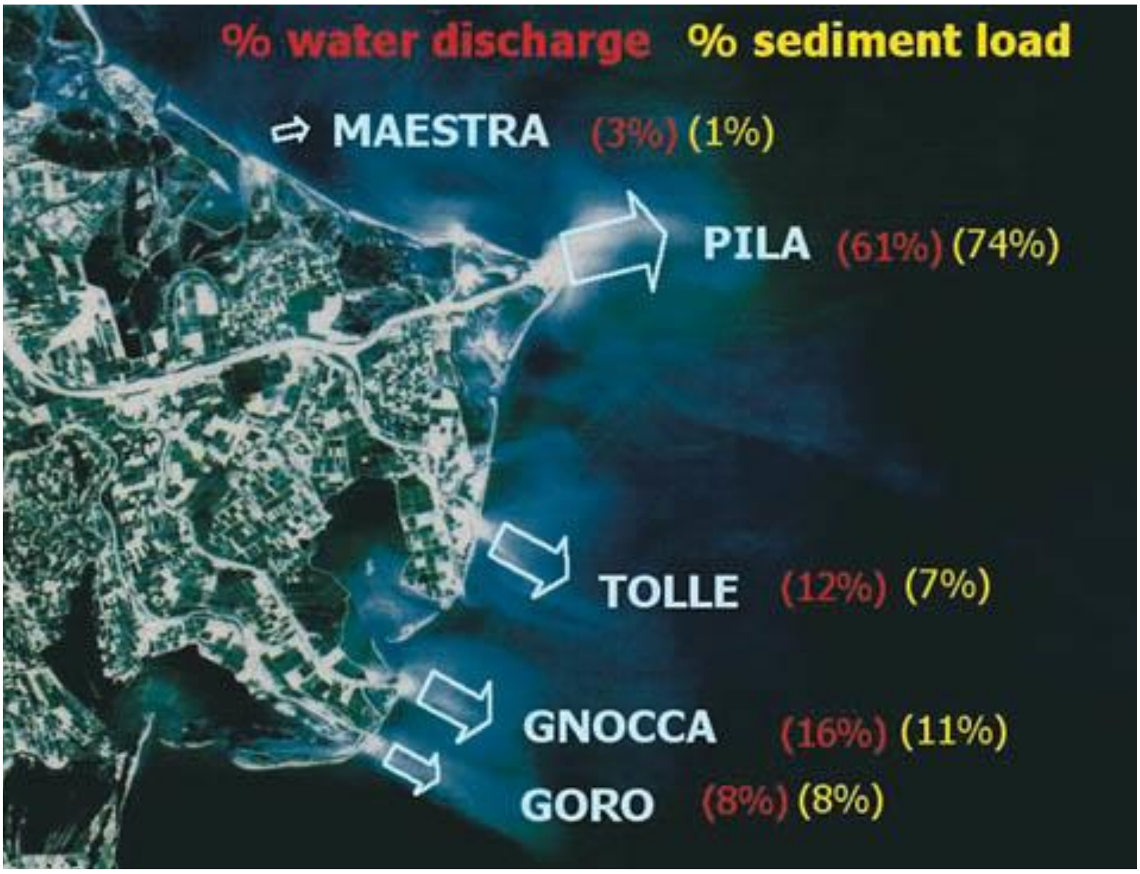

Figure 3.5.256. Water discharge and sediment load partitioning among the five main outlets of the Po delta (Nelson, 1970).

The sediment load partitioning has been reviewed during the years by different authors on the basis of local measurements and specific campaigns (see Table 3.5.6). Recently, Ruol et al. (2016) provided a new estimate of the sediment fluxes in the five branches of the Po river, by adopting the water discharge partitioning updated by ARPA Veneto in 2012 together with a one-dimensional movable bed model. The authors estimated the formative discharge for Po di Goro (where bathymetric surveys were available at different sections) and for the main branch of the Po river, reproducing the observed topography and the corresponding sediment transport capacity. Then they extended the results to the other branches, assuming the same ratio of the sediment loads between Po di Goro and the main branch of the Po river.

Table 3.5.6. Estimates of the water discharge and sediment load partitioning, in percentage terms [%], among the five main outlets of the Po delta; Ruol et al. (2016) and reference therein.

Branch	***Syvitski***	***Albani***	***Caiti***	***Canali***	***Ruol (Meddelt)***	***Ruol***
	1932-37	***1934-44***	***1960-70***	***1960-61***	***1971-85***	***2016***
Pila	63.00	63.00	71.42	72.42	54.5	62.07 (→ 3.465 Mm^3/y)
Tolle	13.20	12.00	6.28	6.28	16.5	15.48 (→ 0.864 Mm^3/y)
Maistra	2.00	2.00	2.46	2.46	1.7	3.10 (→ 0.173 Mm^3/y)
Gnocca	13.70	17.00	11.26	11.26	17	11.61(→ 0.648 Mm^3/y)
Goro	8.10	6.00	7.24	7.58	10.3	7.74 (→ 0.177 Mm^3/y)

As pointed out also by the review of Syvitzky et al. (2007), the pattern in the flux of sediment through the distributary channels seaward of Pontelagoscuro generally follows the water discharge. Although the historical trends seem be confirmed by the recent estimates, a generally variability is observable, especially concerning the Tolle branch, whose transport capacity has alternatively increased and decreased during the years.

In the last decades, river sediment transport has also been a topic dealt with by regional and interregional territorial administrations such as the Po river basin Authority.

In the first Coast Plan of the Emilia-Romagna Region (Idroser, 1981) it was highlighted that the increase of coastal erosion is correlated with the reduction of solid transport. According to estimates, solid transport has dropped 3-4 times since the late 1970s. A main reason was attributed to the massive artificialization of the river and streams with the construction of hydraulic works which trapped the sediments inland, preventing the feeding of the beaches.Another cause mentioned was the change of land use towards practices that reduced the erodibility of the hillsides. The materials accumulated in the riverbed were subject to strong exploitation and sand excavation within the river was estimated to be 690 x 106 $m^3$from 1958 to 1981 (Dal Cin, 1983).

Following these evaluations, the Emilia-Romagna Region blocked the extraction of aggregates from the riverbeds in 1982 and in 1990 the Magistrate of the Po adopted the same provision for excavations in the river Po riverbed and its tributaries.

In the 1981 Coast Plan and in the subsequent 1996 Plan, as well as in the ARPA studies (2000 and 2007), the estimates regarding the solid transport of the river Po were based on indirect assessments relating above all the changes of the Delta, in particular in the area closerto the coast, to the volumetric variation of the sandy deposits and subsidence. The changes were related to the subtraction of sediments from the Po riverbed and to the lowering of the depositional profile due to subsidence, in order to evaluate the contribution to the sea. The available measured data were in a reduced quantity compared to the past and related only to the suspended solid fraction.

Direct measurements of sediment transport in the Po River were obtained at the cross-section of Pontelagoscuro, which can be considered the closure section of the river as it is located downstream of all the Po tributaries. Therefore, all the sediments flowing through this measuring station are expected to arrive to the sea (Vicentini, 1940; Nelson, 1970).

Ruol et al. (2016) grouped the measurements involving the volumes (m^3) of suspended sediments into three different periods, highlighting the reduction of the sediments transported by the Po river during the time as reported also by Dal Cin (1983):

- 1932-1937: 10 Mm^3/year of suspended sediments according to the measurements of Visentini (1940) interpreted by Syvitski et al. (2005);
- 1961: 10 Mm^3/year, according to Canali (1961);

- 1960-1970: 8 Mm^3/year, from the measurements carried out by Caiti (1981).

A cumulative annual sediment load computed by Syvitsky et al. (2007) based on the collected data at Pontelagoscuro highlighted that the 1930s was the period with the highest sediment yield, with decreasing loads in the 1970s and again in 1980s.

The bedload has been generally assumed as a percentage of the measured suspended sediments with different values according to different authors (Ruol et al. 2016 and references therein):

- Visentini (1940) gives a value of 15% of the suspended sediments
- Giandotti (1959) considered it equal to 20%
- Canali and Allodi (1963) 22%
- Nelson (1970) 12%
- Idroser (1994) 15%

The most recent measurements refer to the flood event occurred in November 2019, where ARPA Veneto carried out a series of measurements of water discharges and sediment loads together with Genio Civile di Rovigo of Veneto Region (ARPAV, 2019). They measured the hydrograph and water discharge at Pontelagoscuro (8100 m^3/s), and the water and sediment fluxes at Po di Pila. The investigation reported a sediment flux of almost 917 kg/s for a flood peak of 2380 m^3/s at Po di Pila.

From a quantitative point of view, the second "Coast Plan" of the Emilia-Romagna Region (1996) evaluated an average bedload contribution to the sea, useful for beach nourishment, close to 3 Mm^3/year around 1950, of 1.5 Mm^3/year to 1990 and estimated a possible increase to 1.8 Mm^3/year to 2010, also considering the finest sandy fraction.

From this analysis, the quantity of sand transported by the Po river in several years was also elaborated (Idroser 1996):

- 4.5 million t/y in 1940
- 1.3 million t/y in 1980
- 1.5 million t/y in 1990
- 1.8 million t/y in 2010

In the study of the state of regional littoral by ARPAEmilia Romagna (2000), a sharp reduction in sediment transport in the 1990s, compared to previous years, was confirmed as no evidence of an increase in sand at sea. Causes of this trend were attributed to the decrease of rainfall and the impact of the hydraulic works which caused an upstream deposition and a downstream sedimentary deficit.

Parallel to these studies, the Po River Basin Authority (AdBPo) undertook analysis at the scale of the entire river basin. In particular, a study was carried out in 2007 to evaluate the balance of the solid transport of the Po river from the confluence of the Stura di Lanzo river to the Delta. The main objective of the study was to determine the bedloadmoved along the Po in the period 1982 – 2005, through an experimental modeling approach, based on the application of the balance equation.

In the same year, the general program for the management of alluvial sediments of the riverbed between the confluence with the Arda river and the Po di Goro was produced by AdBPo; this study was based on a morphological approach with quantitative volumetric analysis of the sediments through topographic and bathymetric monitoring .It considered the material deposited and eroded by the banks and bars (comparison between successive plano-altimetric surveys) and the submerged riverbed (comparison between successive measures in monitored cross-section); the contribution from the reliefs and from the tributaries and the extraction of aggregates were also considered. For the period 1982-2005, estimates ranging from 0.2 Mm^3 / year downstream from Isola Serafini, to values of around 1 Mm^3/ year at confluence of Mincio-Secchia rivers, up to 1.4 Mm^3/year at confluence of Panaro River were reached, with increasing discharge in the last years of the period. Bed load monitoring through direct measurements with sedimentary traps was not used due to the excessive uncertainty on the measurement of considered instruments and the poor representativeness of the sample scale to that of the entire riverbed.

In the Delta Hydrogeological Asset Plan (PAI delta) approved in 2009, these quantitative analyses were used considering the morphological changes over time for the central riverbed that precedes the branching of the delta. Among the results of the study it is interesting to mention:

- a strong accumulation of sand in the riverbed with the flood of 1951;
- sharp modifications of the riverbed:a marked erosion with loweringof 2.3 m of the average depths and widening by 70% due to the reduction of upstream solid contributions in the period 1954-1991.
- a countertendency and recovery of the levels of 1954 with a strong control of the exceptional floods and their recurrence on the transport balance in the period 1991 - 1999.

Other works on the solid transport of the Po River came from research studies, often associated with European projects, such as Euorodelta (2001-2004) and Eurostrataform (2002-2006). In the studies of Correggiari et al. (2005a, 2005b) the annual average discharges from the various tributaries are reported and the volumes of the Po della Pila and Po di Gnocca / Goro lobes are defined. The thickness of the lobes would represent 93% of the river's sedimentary input and the accumulation rates over 114 years, between 1886 and 2000, was calculated respectively equal to 6.8 x 106 t/y for the Po di Pila lobe and 2.6 x 106 t/y for the Po di Goro lobe.

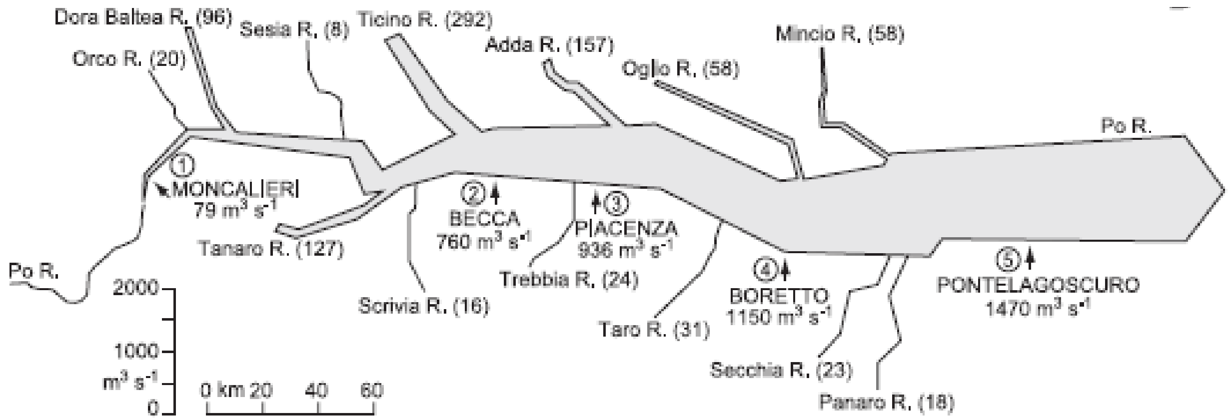

Figure 3.5.267. Annual average discharges of the Po River recorded at hydro-turbidimetric stations (from Tomadin and Varani,1998): (1) Moncalieri (79 m^3s^{-1}), (2) Becca (760 m^3s^{-1}), (3) Piacenza (936 m^3s^{-1}), (4) Boretto (1150 m^3s^{-1}), and (5) Pontelagoscuro (1470 m^3s^{-1}). Arrow width indicates discharge magnitude. Inbrackets, the average annual discharge of important tributaries in m^3s^{-1} (From Correggiari et al., 2005b).

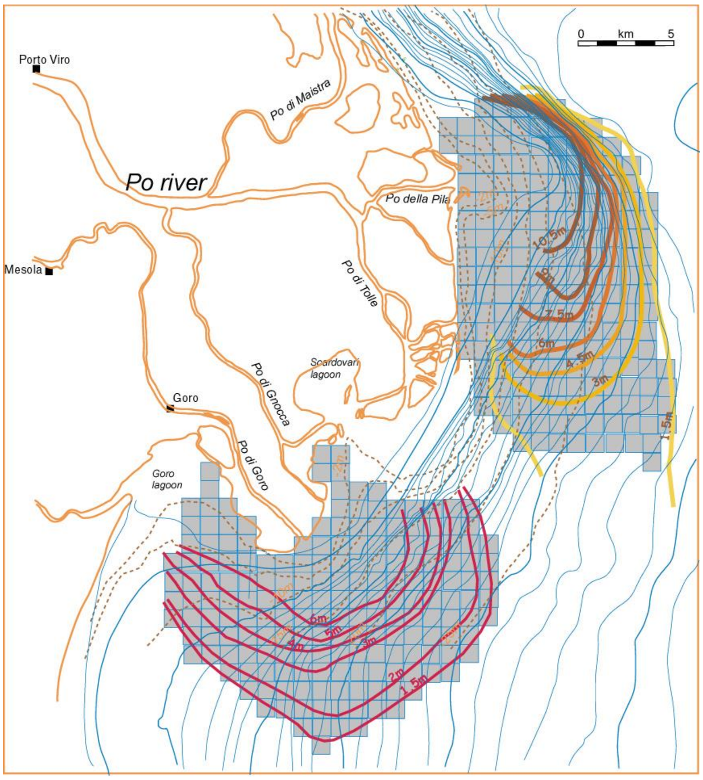

Figure 3.5.18. Geometry of Po Pila and Po di Goro/Gnocca lobes elaborated from 1886 and 2002 bathymetries and geophysical investigations (Correggiari et al., 2005a).

A further contribution to the topic comes from a study carried out in 2009 by the Distart of the University of Bologna, based on the application of the formula of Engelund and Hansenfor the calculation of the solid transport of the Po River. This formula was considered the most suitable for morphological characteristics and grain size of the Po river system and originated an average sediment load of about 1.1 Mm^3/year for the section of the river between Isola Serafini, downstream of Piacenza and the Mincio-Secchia confluence. Other estimates, generated by using other approaches, were between 1 and 2 Mm^3/year.

A recent study focused on a detailed sediment-transport model, based on 2002–2003 data, for the marine area near the Po River delta, is proposed by Baver et al. (2009). They have investigated the relationship between physical processes and the observed depositional products, e.g. the accumulation of sediment at the distributary mouths. Sediment transport near the Po River was evaluated using a three-dimensional ocean model coupled to sediment-transport calculations that included wave- and current-induced resuspension, suspended-sediment transport, multiple grain classes, and fluvial input from the Po River. High-resolution estimates from available meteorological and wave models were used to specify wind, wave, and meteorological forcing.

Model results indicated that more than half of the discharged sediment remained within 15 km of the Po River distributary mouths, even after two months of intensive reworking by winter storms. During floods of the Po River, transport in the middle to upper water column dominated sediment fluxes.
Otherwise, sediment fluxes from the subaqueous portion of the delta were confined to the bottom few meters of the water columnand correlated with increases in current speed and wave energy.

Spatial and temporal variation in wind velocities determined depositional patterns and the directions of sediment transport. Northeasterly Bora winds produced relatively more eastward transport, while southwesterly Sirocco winds generated fluxes towards both the north and the south. Eastward transport accounted for the majority of the sediment exported from the subaqueous delta, most likely due to the frequent occurrence of Bora conditions.

Progradation of the Po River delta into the Adriatic Sea may restrict the formation of the Western Adriatic Coastal Current, increasing sediment retention at the Po delta and reducing the supply of sediment to the Apennine margin. A positive morphodynamical feedback may therefore be present whereby the extension of the delta into the Adriatic increases sediment accumulation at the delta and facilitates further progradation.

More recently a new study has used remote sensing approach to evaluate the delta dynamics and has associated the apparent growth in the last decade to are covey of solid transport and deposition at the mouth (Ninfo et al. 2018). Through the interpretation of satellite images, coupled with the analysis of the flow discharge, and of the annual frequency of marine storms, the study shows that since 2010 the Po River has resumed delta progradation, especially in its northern portion, as a clear evidence of active constructive processes. The ongoing trend marks a countertendency compared to previous years, characterized by periods of erosion, followed by alternating regrowth and degradation phases, indicating conditions of substantial stability (1970–2000).

It must be stressed that for several decades, systematic measures of bedload transport of the Po river have not been carried out. Recent evaluations of the process derive from indirect methodologies based on mass balances or input estimates to the sea deriving from the evolution of the Delta mouths and beaches or the application of experimental correlations.

3.5.1.4. Nutrient fluxes

The nutrients (nitrogen and phosphorus), especially those of agricultural origin have been the subject of great attention for some years for the effect they have on the quality of the environment. Their presence is the main cause of the eutrophication of the surface bodies, river and lagoon waters, as well as marine areas close to estuaries of a certain importance: this is the typical situation in the Adriatic Sea surrounding the Po delta, which collects all the waters of the Po Valley.

Reference legislation

The Veneto Regional Council defined, among others, the entire province of Rovigo, thus including the Po delta, as area **vulnerable for nitrates used in agriculture**, in agreement with the Council Directive 91/676 / EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. It is an area where the concentration of nitrates could exceed 50 mg/l in surface or underground fresh water or conditions of eutrophication of water occur.

The designation of this area is motivated by the fact that in these regions, drainage is difficult and is done mechanically. Water pumps deliver into the water courses the flow drained from the drainage network and from the drainage channels in an artificial way, because the rivers are hanging and/or embanked; this leads to a consequent supply of nutrients to the sea through the mouths of the rivers.

In the areas vulnerable for nitrates, some agricultural activities are prohibited, or otherwise regulated, in order to reduce the quantity of nitrates released into the water bodies. For example, organic fertilizers (manure and slurry) have been limited on the basis of the laws in force on the matter, which defines a maximum value of organic nitrogen per hectare equal to 340 kg, while in vulnerable areas the limit is 170 kg/ha.

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The Veneto Regional Council also defined the water bodies falling within the Po delta as a **sensitive area**, and therefore subject to the limits for the discharge for nutrients provided for by Directive 91/271 / EEC relating to the treatment of urban wastewater.

Sensitive areas have been designated on the basis of article 91 of Legislative Decree 152/2006, which implements the European directive. The designation was taken up for Veneto by article 12 of the Technical Standards for Implementing the Water Protection Plan (PTA).

The Directive provides, specific emission limits for the Total Phosphorus and Total Nitrogen parameters regarding discharges in a sensitive area.

In particular, article 25 of the PTA Implementation Technical Standards establishes emission limits for the discharges from urban waste water treatment plants - serving agglomerations with more than 10,000 equivalent inhabitants (a terms that indicates the load of biodegradable organic substances, deriving from civil users or similar to this, conveyed to the sewer over a period of one day), regardless of the potential of the individual plant, which deliver both directly and through drainage basins, in the designated sensitive areas. The emission limits are set for the Total Phosphorus and Total Nitrogen parameters and they vary from 1 to 2 mg/l for phosphorus and from 10 to 15 mg / l for nitrogen, depending on the size of the served agglomeration.

These emission limits do not apply to waste water treatment plants delivering in the sensitive areas - directly or through the drainage basins - and regardless of the size of the served agglomeration, where can be demonstrated that the minimum percentage of reduction of the overall load at the entrance to all urban waste water treatment plants - is at least 75% for total phosphorus and at least 75% for total nitrogen.

A survey that covered 1,231 urban waste water treatment plants operating in 2014 in Veneto, for a total of over 8 million equivalent inhabitants certified that the Veneto Region has achieved and confirmed the 75% of total nitrogen and phosphorus abatement in urban waste water of the sensitive areas identified by the Regional Water Protection Plan, including water bodies in the Po delta.

Institutional monitoring and other regional studies – nutrient concentrations[2]

In Italy, the calculation of nutrient loads is not part of the Environmental Protection Agencies (ARPA) institutional activities, in the context of monitoring the quality of the water, according to the Directive 2000/60/EC and the Legislative Decree 152/2006. Therefore, a continuous series of nutrient loads of the Po, and consequently to the coastal lagoons and the coastal sea, is not available, at least with a monthly frequency.

In any case, many studies on **nutrient loads** have been carried out, both at regional level and by other institutions.

Monitoring and detection of **nutrient concentrations** is routinely performed in all water bodies.

With regard **to transition environments**, Legislative Decree 152/2006 "Environmental standards", which transposed the Water Framework Directive (Directive 2000/60/EC), introduced, for environmental

[2] The data come from: "MONITORING OF THE TRANSITION WATERS OF THE VENETO REGION" ANALYSIS OF THE DATA OBSERVED IN THE YEAR 2018 Technical report 2019– ARPA Veneto

monitoring, elements aimed at classifying the ecological and chemical status of transition waters, as well as defining the criteria for delimiting transition environments (lagoons and coastal ponds, river mouths).

All **lagoons** are monitored through a specific regional network of stations for checks, in accordance with Directive 2000/60 EC. In the areas of the Po delta there is also a network of fixed stations (buoys) for the continuous detection of the main chemical-physical parameters of the waters.

For **surface water bodies**, the environmental status must be defined on the basis of the degree of deviation from the conditions of a reference water body, having biological, hydro-morphological and physico-chemical characteristics, typical of a water body unaffected by anthropogenic impacts. Depending on the extent of the deviation from optimal conditions, a state of quality is attributed that can be high (high), good (good), sufficient (moderate), poo(poor), or bad (bad).

The Regional Transitional Water Monitoring Network is an integrated network for the classification of the quality status and for the evaluation of the conformity of the waters intended for the life of the clams. It is made up of 95 sampling points, including 35 in the lagoons of the Po delta.

In the lagoons, additional monitoring stations are also provided for the control of the chemical-physical parameters of the water (including 35 in the Po area) which consists of monthly investigations of the physical-chemical characteristics of the water by means of multi-parameter CTD probes, and of the parameters marine weather using portable instrumentation and/or field observations.

In addition, in recent years, some lagoons are also monitored continuously by 7 buoys, located in the lagoons of Marinetta (1), Vallona (1), Barbamarco (1), Canarin (1), Basson (1) and Scardovari (2), on the basis of a program agreement between ARPAV, the Province of Rovigo, the Delta Po Reclamation Consortium and the ULSS of Adria.

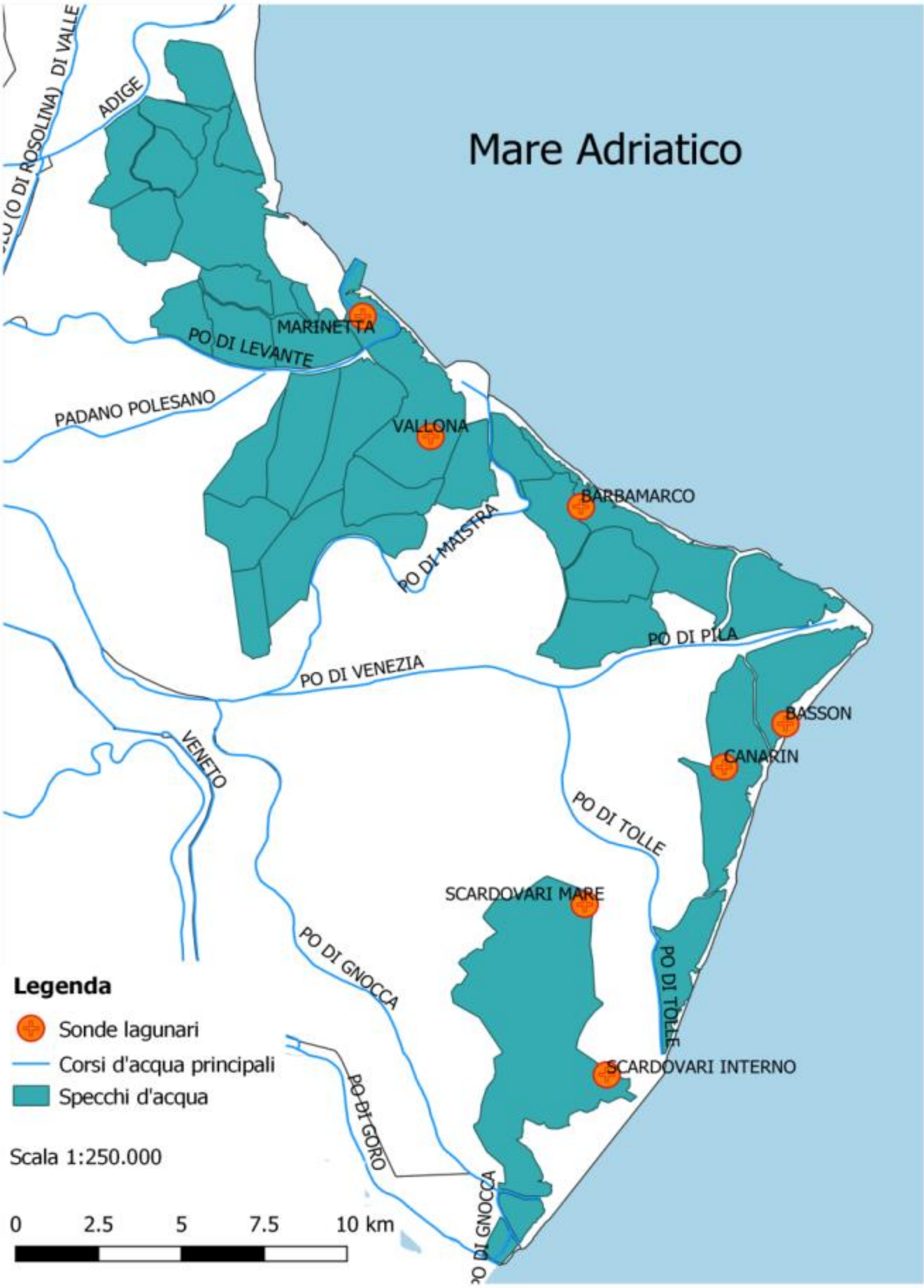


Figure 3.5.19. Location of the lagoon probes.

Figure 3.5.20. Monitored lagoons and monitoring stations.

The analysis of the data collected by ARPA Veneto, in relation to 2018, shows that the average concentrations of **ammonia nitrogen** reached 173.5 µg/l in Vallona. The minimum value (12.4 µg/l) was measured in the Sacca del Canarin in May, the maximum value (286 µg/l) in the Vallona lagoon in March.

Average **nitrous nitrogen** concentrations vary between 5.9 µg/l, detected in the Caleri lagoon, and 24.4 µg/l in the Vallona lagoon. The minimum value (1.8 µg/l) was recorded in August in Sacca di Scardovari, the maximum one (43.6 µg/l) in the Vallona lagoon in May.

Nitric nitrogen fluctuates in the average values between 106.3 µg/l, measured in Caleri, and 732.6 µg/l in Vallona. The minimum value (<LOQ) was always observed in August in Caleri, Barbamarco and Scardovari, the maximum (2312.2 µg/l) in Canarin in August.

The average concentrations of **phosphorus from orthophosphates** oscillate between 4 µg/l of Caleri and 15 µg/l of Vallona; the minimum value (0.5 µg/l) concerns the Baseleghe lagoon in February, the maximum value (36 µg / l) the Sacca of Scardovari in March.

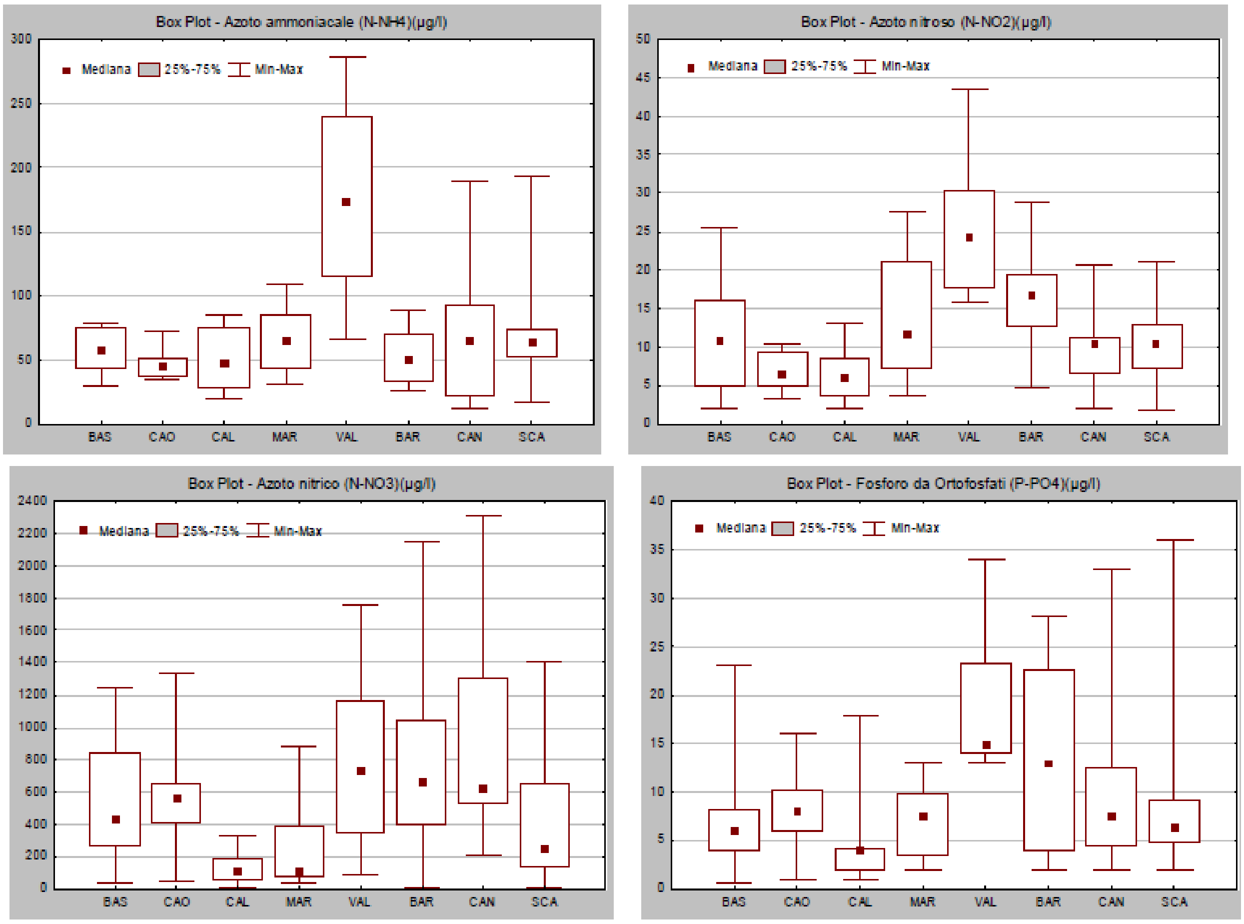


Figure 3.5.21. Box plot of nutrient concentrations detected in lagoon water bodies (CAL: Laguna di Caleri, MAR Marinetta, VAL Vallona, BAR Barbamarco, CAN Canarin, SCA Scarovari). DATA 2018.

Generally speaking, in 2018 the comparison between water bodies clearly differentiates Vallona from all other lagoons for all the nutrients analyzed, both in terms of average and maximum values. The concentrations of dissolved nutrients measured in each lagoon water body during 2018 are shown in the following figures. Out of a total of 416 data collected, only 7 (1.7%) were below the limit of quantification (LOQ) while 409 (98.3%) were detectable.

Compared to 2017, the most evident variations concern the lagoons of Vallona, Barbamarco and Canarin, whose nitrate concentrations increase slightly.

As for the concentrations of dissolved nutrients measured in the **delta (branches),** the concentrations of nutrients, as for the related physical-chemical parameters, are very homogeneous in the different water bodies, both in terms of medians and in terms of variability.

Average concentrations of **ammonia nitroge**n fluctuate between approximately 41 µg/l and 83 µg l, with peaks of approximately 250 µg/l in Maistra and Goro, while those of **nitrous nitrogen** settle on values close to 13 µg/l.

Nitric nitrogen also shows little variability between the different water bodies, oscillating on average values close to 1550 µg/l, and similarly also the **phosphorus** from orthophosphates which remainsat values just over 30 µg/l.

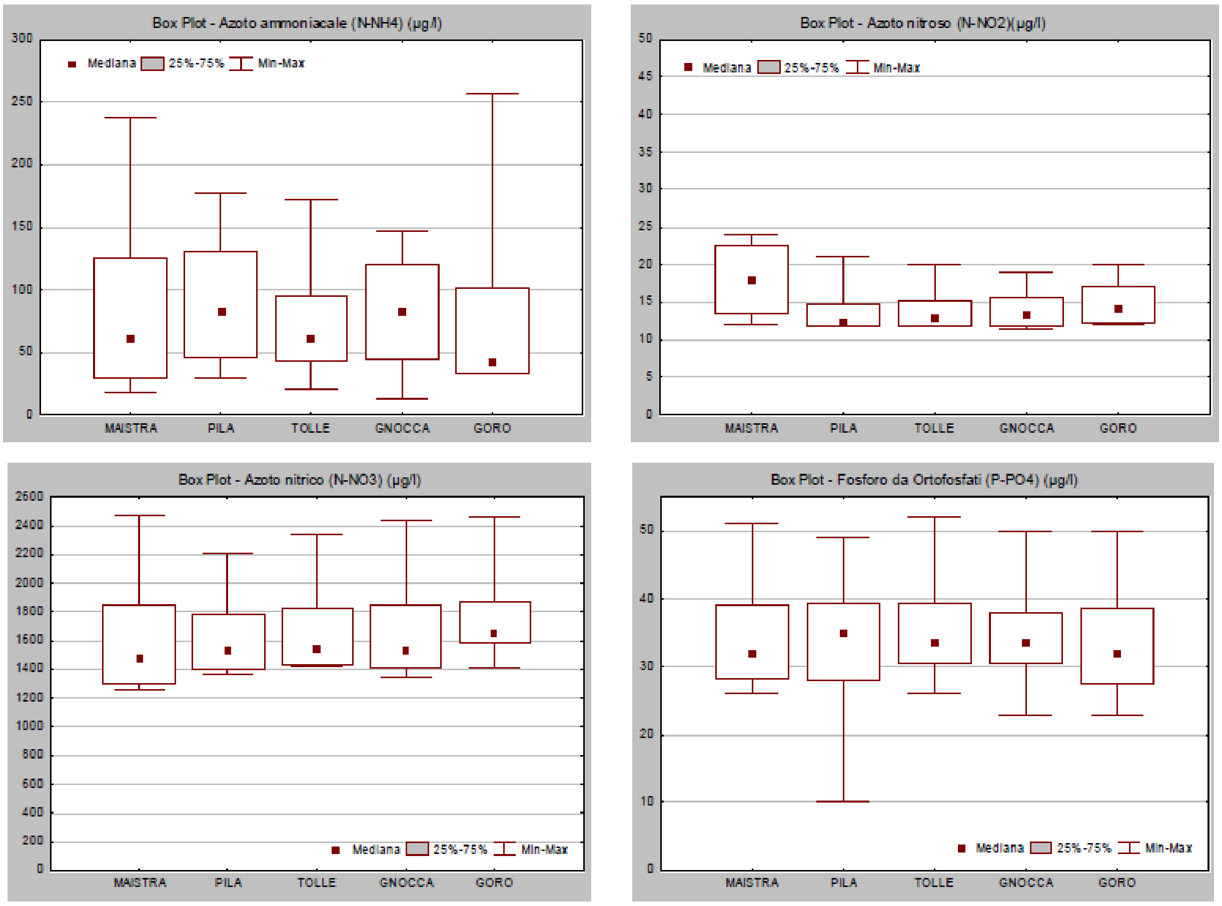


Figure 3.5.22. Box plot of nutrient concentrations detected in delta mouths (Po delta branches). DATA 2018.

Compared to what was observed in 2017, the average concentrations of nutrients remain comparable for ammonia and nitrous nitrogen, while those of nitrates and reactive phosphorus show a slight decrease.

In 2018 nutrient concentrations, with some exceptions, do not show a clear **seasonal trend**. Conversely, the data relating to the previous years showed presence of a maximum in the autumn-winter period and a minimum in the spring-summer period

On the other hand, as regards the seasonal trend of nutrients in the delta mouths, the most evident characteristics are the rather high values of ammonia nitrogen in the summer and, on the contrary, the marked increase in the concentrations of nitric nitrogen and phosphorus from orthophosphate in the winter months.

Based on the requirements of the Ministerial Decree 260/2010, in the classification of the ecological status of transition waters, the used physical-chemical elements are: Dissolved inorganic nitrogen (DIN); Reactive phosphorus (P-PO4); Dissolved oxygen. For each of these three elements, the Ministerial Decree 260/2010 defines a limit of class Good/Sufficient. For DIN, class limits are defined for two different salinity classes

(> 30 PSU and <30 PSU), while reactive phosphorus has, to date, a limit defined only for environments with salinity> 30 PSU.

The average concentrations of DIN and reactive phosphorus for each water body were calculated by averaging the relative seasonal concentration measured in all sampling stations within each water body.

For the purpose of processing the annual average of the physico-chemical quality elements, 50% of the value of the limit of quantification has been used, in cases where the analytical results have been lower than this limit. In the case of DIN, being the result of the summation of NH3, NO2 and NO3, the results below the limit of quantification of the individual substances were considered zero.

Regarding the DIN parameter, the Caleri lagoon falls in the good class, the others in the sufficient one.

Concerning the reactive phosphorus, it is only possible to classify the Marinetta lagoon that is the only euhaline lagoon body of water; it results in the good class based on its average concentration of reactive phosphorus (7 µg / l).

In the absence of specific metrics for delta foci and consequently applying those relating to other bodies in transition waters (salinity <30 psu), the branches of the Po delta would all be classified in a sufficient state.

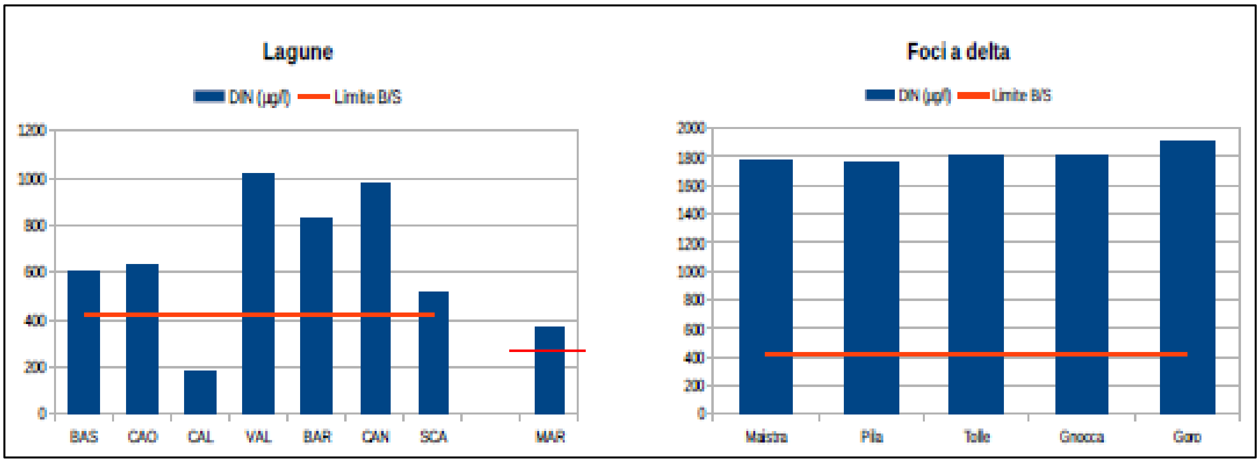


Figure 3.5.23. Status of nutrients in monitored water bodies DATA 2018- Limit B / S = Limit State Good / Sufficient.

Summary considerations on nutrients' concentrations

Transition environments are confirmed as environments with high spatio-temporal variability of all environmental parameters, since they are influenced by specific tide conditions, by the extreme variability of river supplies and exchanges with the sea, by meteorological conditions.

The monitored lagoons show, especially in spring and summer and in particular in the most confined areas, stratification situations of the water column, with hypoxia conditions near the bottom and hypersaturation of the dissolved oxygen on the surface. This situation particularly affected the northern area of the Sacca di Scardovari and some more localized points such as Barbamarco lagoon that is characterized by bathymetries greater than 1.5 m.

The branches of the Po delta, on the other hand, show a general homogeneity of the physico-chemical parameters between them, without showing any particular problem. Nutrients have relatively high concentrations, in particular nitric nitrogen and mainly in winter sampling.

The Vallona lagoon is the one with the highest concentrations of all nutrients. Compared to 2017, the concentrations of ammonia nitrogen and reactive phosphorus remain comparable, those of nitrous nitrogen decrease slightly, those of nitric nitrogen increase in the monitored lagoons. The delta mouths have concentrations comparable to those of the lagoons for ammonia and nitrous nitrogen, but higher in relation to both nitric nitrogen and reactive phosphorus.

The state of the nutrients, determined on the basis of the concentrations of dissolved inorganic nitrogen and reactive phosphorus, is good in the Caleri lagoon, sufficient in all the other water bodies.

Regional studies – nutrient loads

In the context of the development of the **Water Management Plan of the Po river Basin District** (revision of 2015-16) the Project "Monitoring of loads in the Po river" was started. The results reported here are shown in “Annex 2.5 - **Evaluation of nitrogen, phosphorus and silica loads in the Po river** and its main tributaries: contribution of floods and ecological stoichiometry problems” of the “elaborate 2” of the Plan "Summary of the pressures and significant impacts exerted by human activities on the state of surface and groundwater".

The Po river contributes to the load of freshwater and nutrients (nitrogen N and phosphorus P) which arrive to the Adriatic Sea from the Padano-Veneto basins for a share equal to 66%. The studies on the Po river basin conducted between 1970 and 1990 have shown a significant impact of the main anthropic activities with significant effects on the upper Adriatic, characterized by eutrophication of the waters and the growth of mucilage. Important legislative acts have been issued, aimed at reducing phosphates in detergents and improving depuration wastewater systems, have led to a good reduction of load of phosphorus. On the other hand, the contribution of the diffuse load of agro-zootechnical origin remains quite high.

The comparison of the loads relating to the period 1968-1993 with those detected between 1999 and 2007, showed a gradual decrease in the total phosphorus load, with minimum values of around 5000 t/yr in the drought years. Up to 40% of the total annual phosphorus load is released with short-duration flood events and in no more than 40 days in total. The analysis of phosphorus speciation also shows that over half of the load released by the floods is made up of insoluble and/or non-bioavailable particulate forms. The results of investigations relating to the period 2003-2007 had highlighted that no more 10% of the load of P was composed of low soluble and bioavailable fractions. The loads of nitric nitrogen, which is the prevailing nitrogen form, remain particularly high and are only partially associated with changes in the hydrological regime.

Dissolved reactive silica (DSi) has great relevance for the primary productivity of marine ecosystems as it is an essential nutrient for the diatoms growth. It can have significant effects on the development of algal communities and primary productivity in the coastal marine belt. The transport of silica is affected by the presence of dams and river basins, agriculture and the use of soils and the productivity transport capacity of the rivers.

The nutrient loads depend not only on the various factors that generate them, but also on the hydrological regime, in particular on the intensity and frequency of the flood events which are in turn related to the effects of wet deposition on runoff and surface transport of nutrients from the soils and sources that give them origin.

A study, funded by the Po River Basin Authority to investigate the variations in nitrogen and phosphorus loads transiting in the Pontelagoscuro station, had already highlighted the role of floods in the formation of P and N loads poured from the Po to the Adriatic Sea. The study concerned the analysis of a database of the Po River Basin Authority, and monitoring campaigns relating to the period 2003-2007, particularly dry years, in which the river had undergone prolonged and particularly low meager. The results of those investigations had highlighted the peculiar characteristics of the flood load of the P, showing that no more than 10% of its total fractions was not very soluble and bioavailable.

The temporal variations of the total phosphorus (TP) and soluble reactive (SRP) (orthophosphate), and of total nitrogen (TN) and nitric (N-NO3), relating to the River Po and 10 months of investigation (01.11.14 - 31.08.15), are described below.

The TP concentration varies in accordance with the total suspended solids and reaches maximum values of about 1 mg P/l when floods occur. Particulate phosphorus (TPP) represents the predominant form, higher than 70% of TP. The concentration decreases from upstream to downstream, passing from the more torrential conditions of Isola Sant'Antonio to the mainly fluvial ones of Pontelagoscuro. Instead, the concentrations of the SRP show limited variations and never exceed 150 µg P/l. In all stations the minimum SRP values were measured in the period July-August, when the development of river phytoplankton was maximum. About 90% of the total nitrogen is made up of dissolved forms, especially the nitrate ion which makes up on average about 70% of the total dissolved nitrogen.

The concentrations of the nitrate ion were between a maximum value of 4.738 mg N/m3 and a minimum value of 765 mg N/m3 both measured in the Pontelagoscuro station. The median concentrations increase from upstream to downstream, passing from 1.663 (Isola S. Antonio) to 2.066 (Pontelagoscuro) mg N/m3 In all stations the maximum values were measured in the period January-February, while a decrease is observed in the late spring and summer months.

The following figures show a first evaluation of nitrogen, and the phosphorus loads (in tons) referred to 10 months (November 2014-August 1015). The data must be considered indicative.

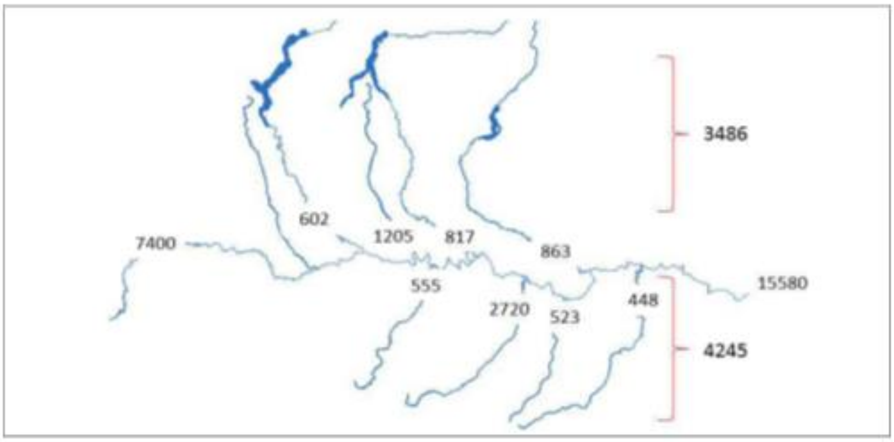


Figure 3.5.24. P loads (tons) transported by the Po River and its main tributaries from 1-November to the 31-August 2014.

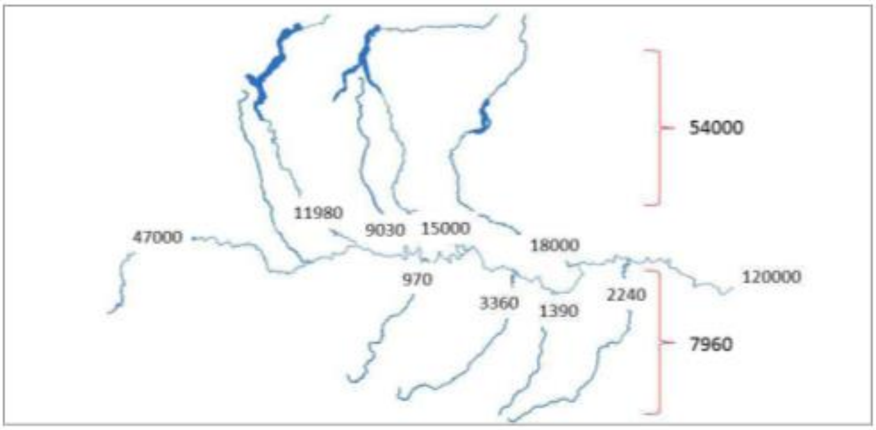


Figure 3.5.27. N loads (tons) transported by the Po River and its main tributaries from 1-November to the 31-August 2014.

Summary considerations:

1. The total load is not homogeneously distributed over the year but follows the frequency, duration and extent of the floods. In this way, the total quantity of N, P and Si arrives in an impulsive way in the Adriatic Sea, with peaks maxima which, for the period considered, are mainly included in the autumn and late winter period.
2. Floods are particularly affecting the loads of P and Si.
3. The TP load composition is essentially given by three fractions: SRP, labile PIP, refractory PIP. The effect of the load depends on the ratio of the three fractions. On the Alpine side, large lakes have a regulation and modulation effect and favor the release of dissolved loads compared to particulate ones. On the Apennine side and in the Piedmont basin, the particulate fractions of P tend to prevail. For the first time, dissolved reactive silica (DSi) and biogenic particulate (PSi) are monitored simultaneously. While DSi is readily available, PSi is present in solid form (diatom frustules, phytoliths in terrestrial plant debris) as hydrated silicon dioxide. The PSi is therefore not very soluble and, for this reason, any interruptions of the river continuity (e.g. dams, sleepers, etc.) could prevent its transport to the sea. With some delay,

however, the sedimented silica can return to the circulation, thanks to the bacterial mineralization processes. Hence, PSi may constitute an additional source of DSi, once mineralized.

Concerning phosphorus In general, there is a decrease in concentrations from upstream to downstream of the Po (there is probably a dilution effect due to the increase in the flow rates). The mean values are Isola S. Antonio = 1054 ± 301 µg/l, Pontelagoscuro= 232 ± 132 µg/l.

The tributaries of the Po on the left and on the right differ not only in the concentrations but also in the quality of the particulate material conveyed during the floods.

Research studies – nutrient loads

Still concerning the Po the nutrient loads, they have been studied for research purposes since the end of the sixties (Marchetti et al., 1989) and, more or less continuatively, in successive moments up to the present (Viaroli et al., 2013; Viaroli et al., 2018). All cited studies report annual loads but don't address monthly trends within single years.

Furthermore, detailed studies have been carried out for some sub-basins of the Po, aimed at identifying the relative weight of the various sources, livestock farming, synthetic fertilization, civil and industrial ones (Soana et al., 2011; Bartoli et al., 2012; Castaldelli et al., 2013; Pinardi et al., 2018).

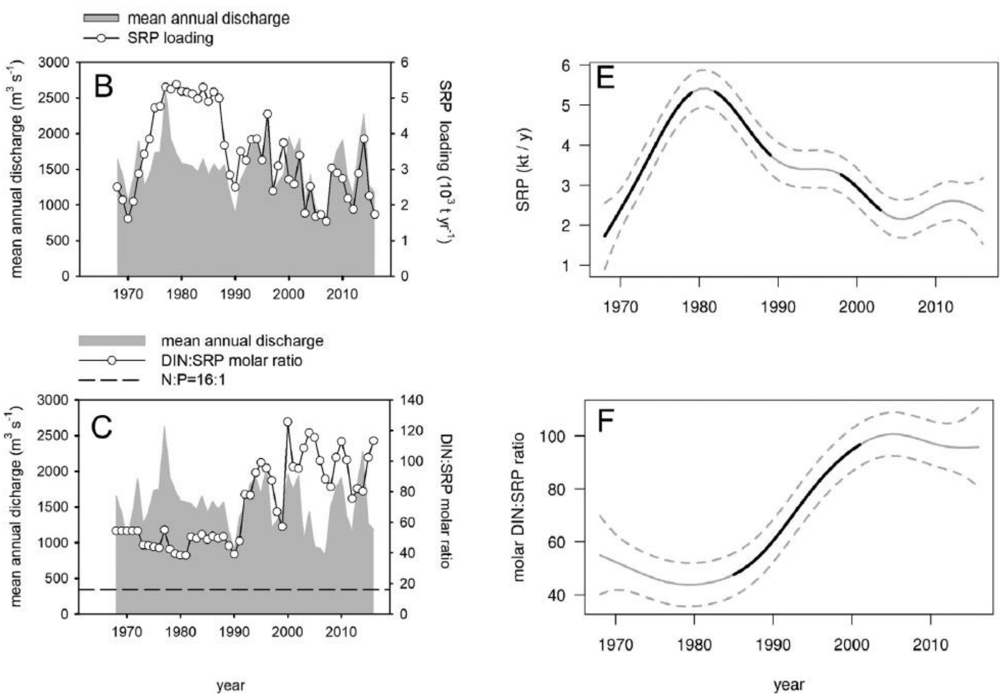


Figure 3.5.28. Annual loadings exported from the Po river watershed at Pontelagoscuro. B – soluble reactive phosphorus (SRP); C – molar DIN:SRP ratio. The mean annual discharge is depicted as grey background. The bold lines represent the time extent of increase (line up) or decreas (line donw); E – SRP increased in 1968 -1978, decreased in 1982 – 1989 and 1998 – 2008; F – DIN:SRP molar ratio: increased in 1985 – 2001.

Estimates of nutrient loads have been also done in some coastal basins, such as the Po di Volano, which directly delivers large amounts of nitrogen to one of the two study sites, chosen within the macro-site of the Po delta, i.e. the lagoon of Goro. In the Po di Volano basin, declared in its entirety "vulnerable to nitrates of agricultural origin" (Leg.D. 152/2006), detailed studies were carried out, with analysis of the various terms of the balance sheet (Castaldelli et al., 2013) and of the most important reasons why nitrogen loads delivered to the Goro lagoon have changed in recent decades (Milardi et al., 2020).

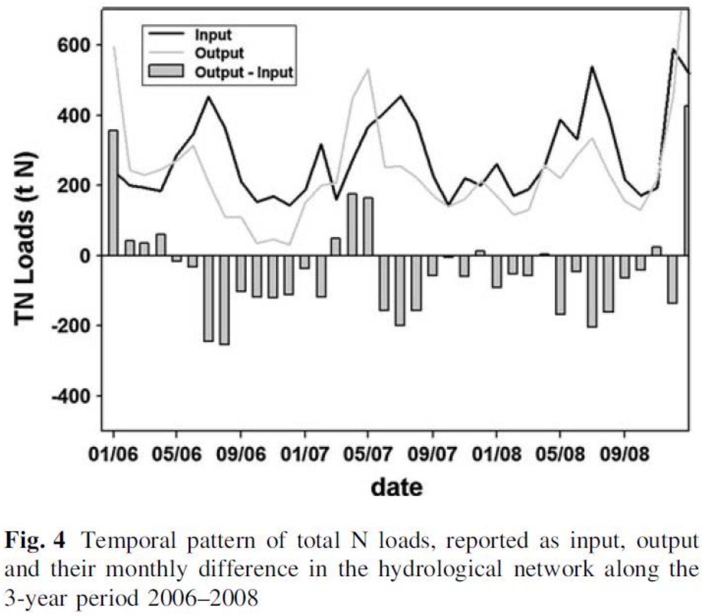


Figure 3.5.29. Monthly loads of total nitrogen (clear line) carried by the Po di Volano to the Sacca di Goro, in the 2006-09 period; from Castaldelli et al., 2013.

3.5.2. Excess fertilizers, herbicides and pesticides usage

3.5.2.1. <u>Surface waters</u>

The Legislative Decree no. 152 of April/03/2006, which implements the Directive 2000/60/CE, defines the classification system for the environmental status of the water bodies. Regarding the different categories of ***surface waters***, the Decree assesses the overall condition of the water bodies based on the worst result between the Ecological and Chemical Status within a temporal range of six years.

The Chemical Status is defined based on the quality standards for the pollutants listed in the Decree no. 172/15 (priority list of pollutants - Directive 2013/39/EU). These substances are potentially dangerous, presenting a significant risk to the aquatic environment, and for this reason they must be progressively reduced and removed. Among them there are metals, **pesticides, herbicides, nitrates,** and other micro-pollutants.

Since the **Environmental Status** of a water body is determined on the assessment both of the Ecological and Chemical Status, if one of them does not have a good quality valuation, the water body fails to reach the quality objective set by the Directive.

The monitoring network for the surface waters in the Veneto Region is active since 2000 and it includes overall 320 monitoring stations for the watercourses; the monitoring points that were operative in 2018 in the Po catchment and belonged to the Veneto Region were 11, and among them 8 were located in the Po Delta, between the main course and its branches of Po di Maistra, Po delle Tolle, Po di Gnocca and Po di Goro (see Figure 3.5.30).

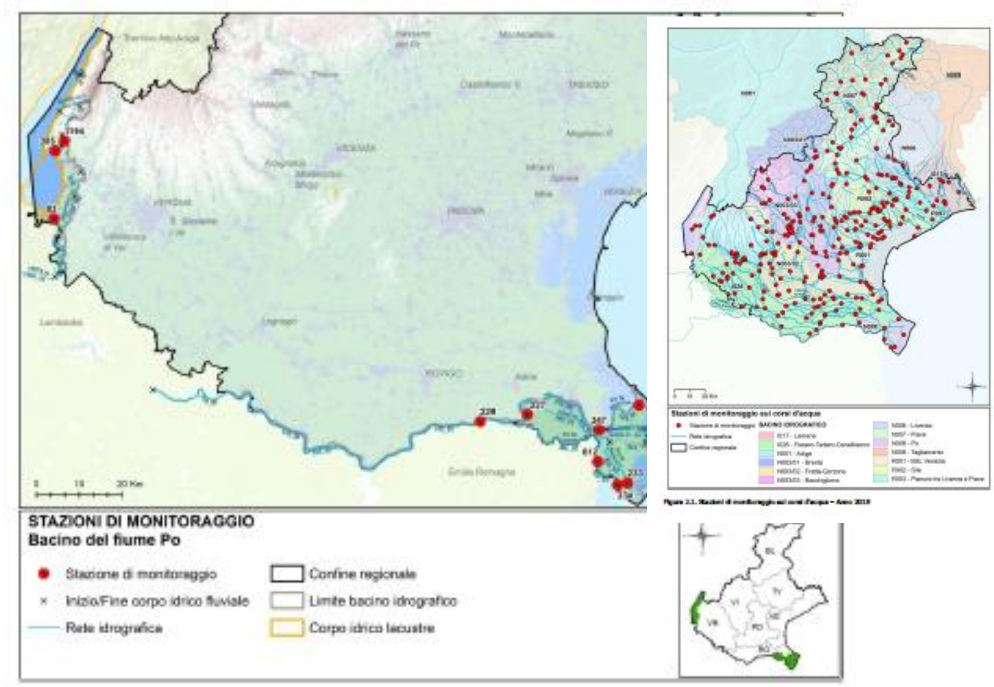


Figure 3.5.30. On the left: map of the monitoring points falling in the Po basin and belonging to the Veneto Region; on the right: all the monitoring stations active along the watercourses in the Veneto Region – Year 2018.

*Table 3.5.7. Monitoring plan for the quality assessment – of the Veneto Region- on the Po River (main river channel and deltaic branches) – **Year 2018**. Station numbers correspond to those specified in Figure 3.5.30.*

Stat.	Name of the watercourse of the station	Prov	Municipality	Location	Frequency (no per year)	Destination (*)
227	FIUME PO DI VENEZIA	RO	Corbola	Sabbioni	12	EQ DW
229	FIUME PO	RO	Villanova Marchesana	Canalnovo	4	EQ DW
230	PO DI MAISTRA	RO	Porto Tolle	Po di Maistra	4	EQ
232	PO DI TOLLE	RO	Porto Tolle	Po di Tolle	4	EQ
233	PO DI GNOCCA	RO	Taglio di Po	Po di Gnocca	4	EQ
234	PO DI GORO	RO	ArianonelPolesine	Po di Goro	4	EQ
347	FIUME PO DI VENEZIA	RO	Taglio di Po	Ponte Molo	8	EQ DW

612	SCOLO VENETO	RO	Taglio di Po	Polesine-Ponte Liè	4	EQ

(*) in some sites the monitoring plan aims at the environmental quality control (EQ), while in others the station serve also for the evaluation on the conformity of drinking waters (DW)

*Table 3.5.8. List of the excesses of the Environmental Quality Standard (EQS) determined from **2014 to 2018** (D.L.gs. 172/15).*

Year	Water body	Prov.	Municipality	Element	Type of excess	Value of the EQSμg/L	Measured valueμg/L
2015	FIUME PO DI VENEZIA	RO	Corbola	Pesticides	AMPA (Herbicides)	0,1	0,2
2015	FIUME PO	RO	Villanova Marchesana	Pesticides	Azoxystrobin (Fungicides)	0,1	0,2
2017	FIUME PO DI VENEZIA	RO	Corbola	Pesticides	AMPA (Herbicides)	0,1	0,4
2018	FIUME PO DI VENEZIA	RO	Corbola	Pesticides	AMPA(Herbicides)	0,1	0,2
2018	FIUME PO	RO	Villanova Marchesana	Pesticides	AMPA(Herbicides)	0,1	0,4

Regarding the **pesticides**, the Decree no. 172/15 considers 64 types in 2018 (including herbicides, biocides and fungicides); in 2019 they were extended to 90 types. Following the calculation procedure, the first steps involve the determination of the mean relative concentration for each pesticide and for each hydrographic basin, which is obtained as the ratio between the mean concentration and the quality standard, expressed as annual mean (Environmental Quality Standard [EQS] - annual mean [AM]), as defined in D.Lgs 172/15:

$$mean\ relative\ concentration = \frac{mean\ concentration}{EQS - AM}$$

For the assessment of the current status of the indicator the mean concentration of the single pesticides is compared to the respective environmental quality standard, with the aim of giving an overall evaluation of the risk correlated to the pesticide's presence in the watercourses. When the value of mean relative concentration is less than one, it means that the concentration of the pesticides measured in the basin generally does not exceed the limit set by the law.

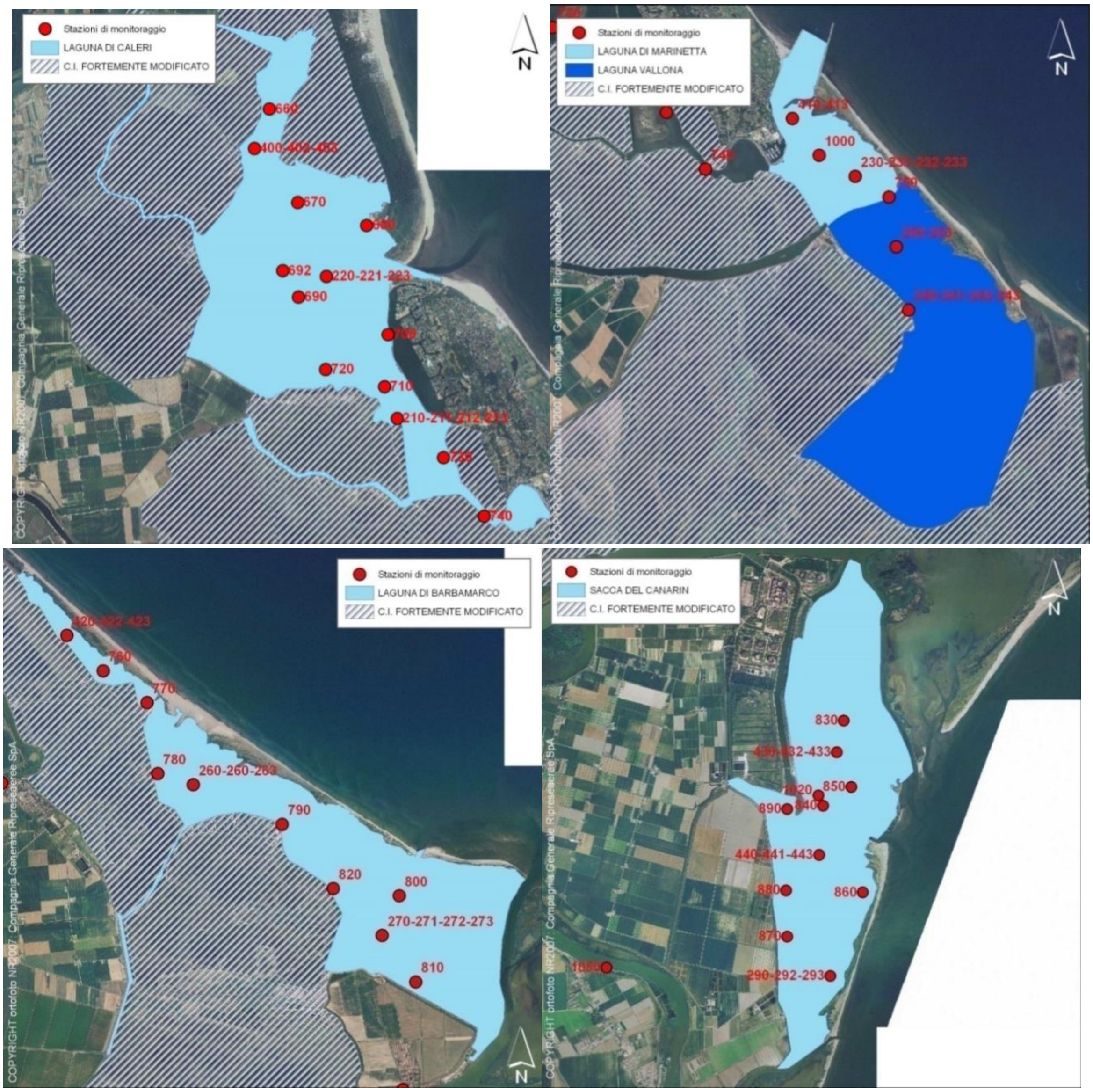
The analysis of the data shows that, although the number of the searched substances has increased, the trend of the relative mean concentration (RMC) remains stable **from *2009 to 2019***.

3.5.2.2. Transitional waters

As regards the ***transitional waters*** (lagoon areas in the Delta Po region), the monitoring network of the Veneto Region, set in accordance with the D.Lgs 152/2006, is active since 2008. The control and measuring activities, aimed at assessing the quality of the transitional waters, can be distinguished in activities for the evaluation of the ecological status (phytoplankton together with elements of physical-chemical quality and hydro-morphology), of the chemical status (water matrix, sediment and biota) and of the conformity of the water body to the life of shellfishes.

There are 15 monitoring stations in the network: 1 in the Lagoon of Baseleghe, 1 in the Lagoon of Caorle, 1 in the Lagoon of Caleri, 2 in the Lagoon of Marinetta, 1 in the Lagoon of Vallona, 1 in the Lagoon of Barbamarco, 1 in the **Sacca del Canarin**, 2 in the Sacca di Scardovari and 5 in the five branches of the Delta. The 95% of the samples collected for the chemical analysis on the water have shown values below the quantification limit, while only the remaining 5% have presented quantifiable values of the tested substances.

The chemical status of the water in the transitional water bodies, following the introduction of the new classification criteria (D.Lgs. 172/2015), proves to be good for all the water bodies; the Triphenyltin (fungicides) has been detected above the limits set by the law in the lagoon of Caleri, Marinetta and Scardovari and in the mouths of the Delta, except for the mouth of Maistra. In addition, some pesticides such as Azoxystrobin, Bentazone and Dimetomorf are almost ubiquitous in the area, even though present at low concentration.


Stazioni di monitoraggio
LAGUNA DI CALERI
C.I. FORTEMENTE MODIFICATO
N
660
400-402-403
670
692
220-221-223
690
720
710
740
Stazioni di monitoraggio
LAGUNA DI MARINETTA
LAGUNA VALLONA
C.I. FORTEMENTE MODIFICATO
N
1000
230-231-232-233
Stazioni di monitoraggio
LAGUNA DI BARBAMARCO
C.I. FORTEMENTE MODIFICATO
760
770
780
260-260-263
790
820
800
270-271-272-273
810
N
Stazioni di monitoraggio
SACCA DEL CANARIN
C.I. FORTEMENTE MODIFICATO
N
830
850
890
440-441-443
880
860
870
290-292-293

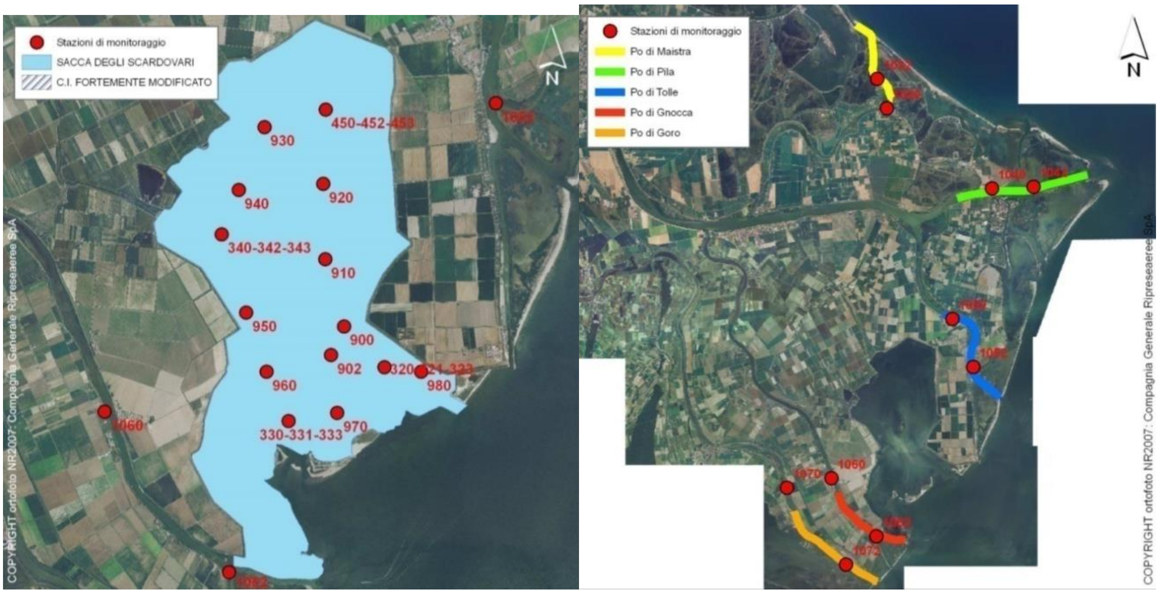


Figure 3.5.29: Localization of the sampling stations (ARPA Veneto; continued from the previous page).

Regarding the station 430_CA located in the **lagoon of Canarin**, the table reports the pesticides that have been monitored in the period ***2016-2018***.

Table 3.5.9: Presence of pesticides in the water matrix for the lagoon of Canarin, ***2016-2018***

Water body **CANARIN**	**2016**	**2017**	**2018**
Station no.	430 - CAN	430 - CAN	430 - CAN
2-4' DDT (°)			
4-4' DDD (°)			
4-4' DDE (°)			
4-4' DDT (°)			
Alachlor			
Aldrin (°)			
Dieldrin (°)			
Endrin (°)			
Isodrin (°)			
Atrazina			
Azinfos-Metile			
Chlorpiriphos			
Chlorpiriphosmetile			
Clorfenvinfos			
Desetilatrazina			
Terbutilazina			
Desetilterbutilazina			
Dimetenamide			
Dimetoato			
Endosulfano (miscelaisomerialfa, beta			

Endosulfan (sommaisomerialfa e beta)			
Esaclorocicloesano (isomeri) (HCH's) (°)			
Malathion			
Metolachlor			
Metribuzina			
Molinate			
Pendimetalin			
Procimidone			
Propanil			
Propizamide			
Simazina			
Terbutrina (°)			
Trifluralin			
2,4 - D			
Acetochlor			
Acido 2,4,5-triclorofenossiacetico (2,4,5			
Azoxystrobin			
Bentazone			
Boscalid			
Clomazone			
Cloridazon			
Dicamba			
Dimetomorf			
Diuron			
Etofumesate			
Flufenacet			
Isoproturon			
Lenacil			
Linuron			
Mcpa			
Mecoprop			
Metalaxil-M			
Metamitron			
Metossifenozide			
Nicosulfuron			
Oxadiazon			
Penconazolo			
Quizalopof-etile			
Rimsulfuron			
Tebuconazolo			
Mecoprop			
Metalaxil-M			
Metamitron			
Metossifenozide			
Nicosulfuron			

Legend

- Substance that is not under investigation
- Substance never above the limit of quantification
- Substance for which an exceedance of the quantification limit has been observed
- Substance for which an exceedance of the EQS – AM has been observed (D.Lgs 172/2015)

3.5.2.3. Coastal waters

Besides the stations for the environmental monitoring for the surface and transitional waters, the monitoring network also covers the coastal sea waters (D.Lgs. 152/06, D.M. 131/08).

The current monitoring network of the Veneto Region, active since 2010, involves 9 transects perpendicular to the coastline, each of them composed of several sampling stations that are located in the proximity of the main source pressures.

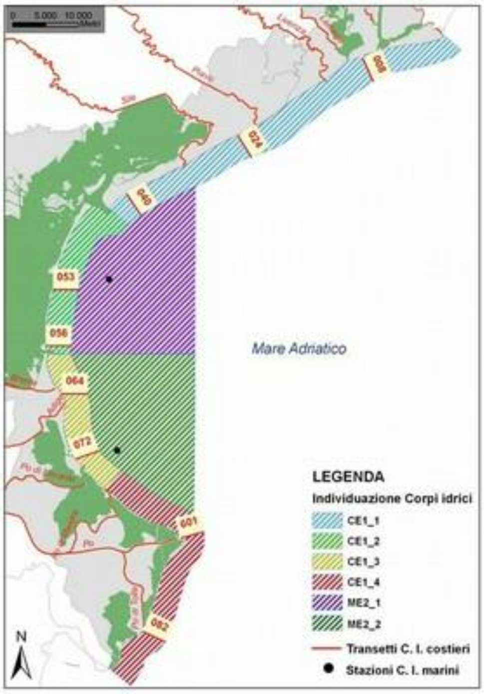


Figure 3.5.30. Map of the water bodies for the coastal sea waters and location of the monitoring areas (transects and stations). Transects covering the Delta Po region are CE1_4 and CE1_3.

The Chemical Status is defined based on the pollutants included in the priority list of the Ministerial Decree no. 260/2100. The water body that satisfies the expected quality standards is classified in the Good Chemical Status.

Regarding ***the 4-year period 2010-2013***, the Chemical Status has resulted “good” in the northernmost transect C1_3 and “not good” in thetransect in front the Delta Po. However, the assignment of the “not good” chemical status to the waters does not depend on the presence of pesticides and herbicides, but it is influences by the detection of other substances that are included in the priority list.

Regarding the ***three-year period 2014-2016***, the Table3.5.10reports the presence and exceedances in the water matrix of the substances of the priority list and of other elements not belonging to this list for the coastal sea waters.

Table3.5.10. Exceedances for the substancesbelonging (and not) to the priority list in the coastal seawaters (2014-2016).

Water body	Water matrix > EQS-AM	Chemical Status	NOTE
CE1_3		GOOD	
CE1_4	Benzo(ghi)perilene + Indeno(123-cd)pirene; lead	NOT GOOD	Exceedance of the EQS.MA in water due to IPA (2014) and lead (2016)

Finally, it should be noted that substances such as **fungicides, herbicides**, and **degradation products from DDT** mainly come from diffuse sources, while most of those that originate from an industrial production cycle have a punctual release (for example the solvents, the substances present in metal alloys, those for medical usages or for the production of surfactants). They can originate in the entire catchment basin of the delta area.

Other types of pesticides that are considered relevant in the Po Valley district (though not detected in the Sacca del Canarin) such as DDD, DDE, DDT, Endosulfan, Hexachlorobenzene, Hexachlorobutadiene, have been off-market since years. For this reason, the sources are considered mainly of diffused origin, since the localized use of these substances has not been in place for years.

In fact, some substances, or their metabolites, are found in water bodies even if for years they can no longer be sold and used, this highlights their high persistence in certain types of water bodies.

3.5.3. Grease, oil, chemicals and salt input (from energy production, mining activity, irrigation and urban runoff)

3.5.3.1. Grease, oil and chemicals

Regarding the concentration of the micro-pollutants the Italian legislation considers 42 chemical compounds belonging to the following groups, which are set by the Decree n. 172/15 (that substitutes the D.M. 260/10 used for the classification until 2015): Phenols, Polycyclic Aromatic Hydrocarbons, volatile organic micro-pollutants, Perfluoroalkyl substances (PFOS, PFOA PFBA PFBS PFPeAPFHxA), Nonylphenol, Di-ethylhexyl phthalate, Octylphenol and since 2017 Triphenyltin (that is monitored only along the Po branches). The Decree n. 172/15 lowered the standard for three Polycyclic Aromatic Hydrocarbons (Benzo(a)pyrene, Fluoranthene and Naphtalene) adding the perfluoroalkyl substances.

As seen in the previous paragraph, the calculation procedure determines initially the **mean relative concentration** (MRC) for each organic micro-pollutant and each hydrographic basin. This quantity is obtained as the ratio between the **mean concentration** and the **quality standard**, expressed as annual mean (EQS-AM), as defined in Decree n. 172/15:

$$mean\ relative\ concentration = \frac{mean\ concentration}{EQS - AM}$$

Regarding the mean concentration, the values lower than the quantification limit (LOQ) are considered equal to half of their measured value, while the values (LOQ) higher than EQS-MA of the substances are excluded from the computation.

For the evaluation of the current status of the indicator, the mean concentration of the micro-pollutants is compared to their respective environmental quality standard, with the aim of providing an overall assessment of the risk related to the presence of these pollutants in the watercourses. A mean relative concentration below one means that the concentration that are observed in the basin are below the limits set by the legislation.

In February 2010 there was a fraudulent **spill of oil** that flowed in huge quantities into the Lambro River, which is an important tributary of the Po River, and which was already heavily polluted at the time. Besides the Lambro River, the disaster involved the Po River too, and a small portion of the hydrocarbons arrived to the Adriatic Sea, however without causing important damages. Against all the odds, in fact, the Delta Po region and the Adriatic Sea were not affected significantly by this spill, although their ecosystems are extremely fragile. The reason relies on the fact that the oil arrived at the Po mouths in reduced amounts and very diluted.

Infact, in ***2010*** in the transitional waters in the province of Rovigo, which includes **Sacca del Canarin**, Sacca di Scardovari and Lagoon of Barbamarco, the monitoring system did not detect any trace of the **hydrocarbons of oil origin**, and it did not highlight any type of anomalies in other investigations (https://www.arpa.veneto.it/arpavinforma/comunicati-stampa/archivio/comunicati-dal-2000-al-2010/fiume-po.-aggiornamento-sui-controlli-di-arpav-nelle-lagune-del-delta-e-nei-fiumi-non-si-rilevano-idrocarburi).

Table 3 shows that in the **Lagoon del Canarin**, in the years **2016, 2017 and 2018**, the concentrations for the investigated **micro-pollutants** were always below the limits. The reported values refer to the substances such asPhenols, Polycyclic Aromatic Hydrocarbons, volatile organic micro-pollutants and other compounds (Nonylphenol, Bis(2-ethylhexyl) phthalate, Octylphenol) and PFAS.

Table 3.5.9. Analysis of the results from the monitoring station located in the Lagoon of Canarin between 2016-2018 concerning some micro-pollutants.

Water body **CANARIN**	**2016**	**2017**	**2018**
STATION	430 - CAN	430 - CAN	430 - CAN
Metalli			
Arsenicodisciolto (As)			

Cadmiodisciolto (Cd)			
Cromototaledisciolto (Cr)			
Mercuriodisciolto (Hg)			
Nicheldisciolto (Ni)			
Piombodisciolto (Pb)			
IPA			
Antracene			
Benzo(a)pirene (°)			
Benzo(b)fluorantene			
Benzo(ghi)perilene (°)			
Benzo(k)fluorantene			
Fluorantene			
Indeno(123-cd)pirene			
Naftalene			
Organometalli			
Tributilstagno (°)			
Trifenilstagno (°)			
Alchilfenoli			
4(para)-Nonilfenolo			
Para-terz-ottilfenolo			
Compostiorganici			
1,1,1 Tricloroetano			
1,2,3 Triclorobenzene			
1,2,4 Triclorobenzene			
1,3,5 Triclorobenzene			
1,2 Diclorobenzene			
1,3 Diclorobenzene			
1,4 Diclorobenzene			
1,2 Dicloroetano			
Benzene			
Clorobenzene			
Cloroformio (CHCL3)			
Cloruro di vinile (conteggio della			
concentraz. monomerica Di(2etilesilftalato) residua			
Diclorometano			
Esaclorobenzene (HCB) (°)			
Esaclorobutadiene (HCBD) (°)			
Pentaclorofenolo			
Pentaclorobenzene (°)			
Tetracloroetilene (Percloroetilene)			
Tetracloruro di carbonio			
Toluene			
Tricloroetilene (Trielina) (C2HCl3)			

Xilene (o+m+p)			

Legend

	Substance that is not under investigation
	substance never above the limit of quantification
	Substance for which an exceedance of the quantification limit has been observed
	Substance for which an exceedance of the EQS – AM has been observed (D.Lgs 172/2015)

3.5.3.2. Salt intrusion

The salt intrusion is a process that affects significantly the Delta Po region. The general causes comprise the reduced water discharges of the Po River due to the lower water releases from the mountain and hydropower basins; the fluid extraction from the subsoil; the subsidence, and the eustatism. Overall, the salt ingression is strictly connected to the water usage in the entire basin, which, being one of the richest in Italy, hosts a large population and numerous working activities. The extent of salt-water intrusion causes damages for the territories, preventing irrigation of some deltaic areas, with large impacts to the ecosystems.

The process has affected the entire territory for a long time, as highlighted in Figure 3. The salt intrusion was small during the period between ‘50s and ‘60s, when it reached the first 2-3 km inland from the river mouths. The phenomenon is quite ordinary in the transitional space between fresh and salt water of the estuarine environment, where the sea processes interact with the fluvial ones, especially in front of the coast. In the presence of other factors, the salt intrusion tends to increase, as it happened during the ‘70s and ‘80s, when it spread until 10 km far from the mouths, making it impossible to irrigate a portion of territory having an extension of 20,000 ha and comprising the Isola di Camerini, della Donzella and Ca’ Venier. Finally, in 2000 the salt intrusion reached its maximum, moving up to 24-30 km into the Delta Po from the mouths. This trend led to the formation of a water-deprived area of .ca 30,000 ha, preventing the irrigation also in the Island of Porto Viro and Ariano (Colombo and Tosini, 2009).

According to the most recent data, the salt intrusion has reduced, reaching 15-20 km from the mouth.

Figure 3.5.31. Salt intrusion extension: from left to right during '50s-'60s, during the period of 70s-'80s and at the beginning of 2000.

The salt intrusion is object of investigation by the "permanent observatory for the hydraulic use" in the Po River basin. This institution has the aim of strengthening cooperation and dialogue between the subjects belonging to the governance system of water resources within the district, promoting the sustainable use of water resources in implementation of Directive 2000/60 /EC and coordinating the actions necessary for the proactive management of extreme dry events, both of district and sub-basin value.

During the years, the permanent observatory has proposed a series of actions for the management of the drought, in particular in the Delta Po Region. Among these actions, there was also a measuring campaign of the water flux and salinity in the different branches of the Delta, which was carried out in 2017, since the salt intrusion is considered one of the most severe process during drought.

The monitoring activities were a collaborative investigation among Arpa Emilia Romagna, Arpa Veneto, CNR ISMAR of Venezia, Consorzio di Bonifica Delta del Po e Genio Civile (di Rovigo) of the Veneto Region.

The measuring campaigns on the Po River included salinity measurements, realized with regular intervals and during an entire cycle of the tide, along the water columns in the main branches of the Delta, every 600 m during low tide, and every km during high tide. The sampling, carried out with multi-parameters gauges, extended 15-18 km far from the mouths. In the same time, the campaign measured the water discharge by means of Doppler instrumentations, with the aim of verifying the water discharge partitioning among the Po branches. The collected measurements have highlighted the extension of the salt intrusion in the five branches of the Po River.

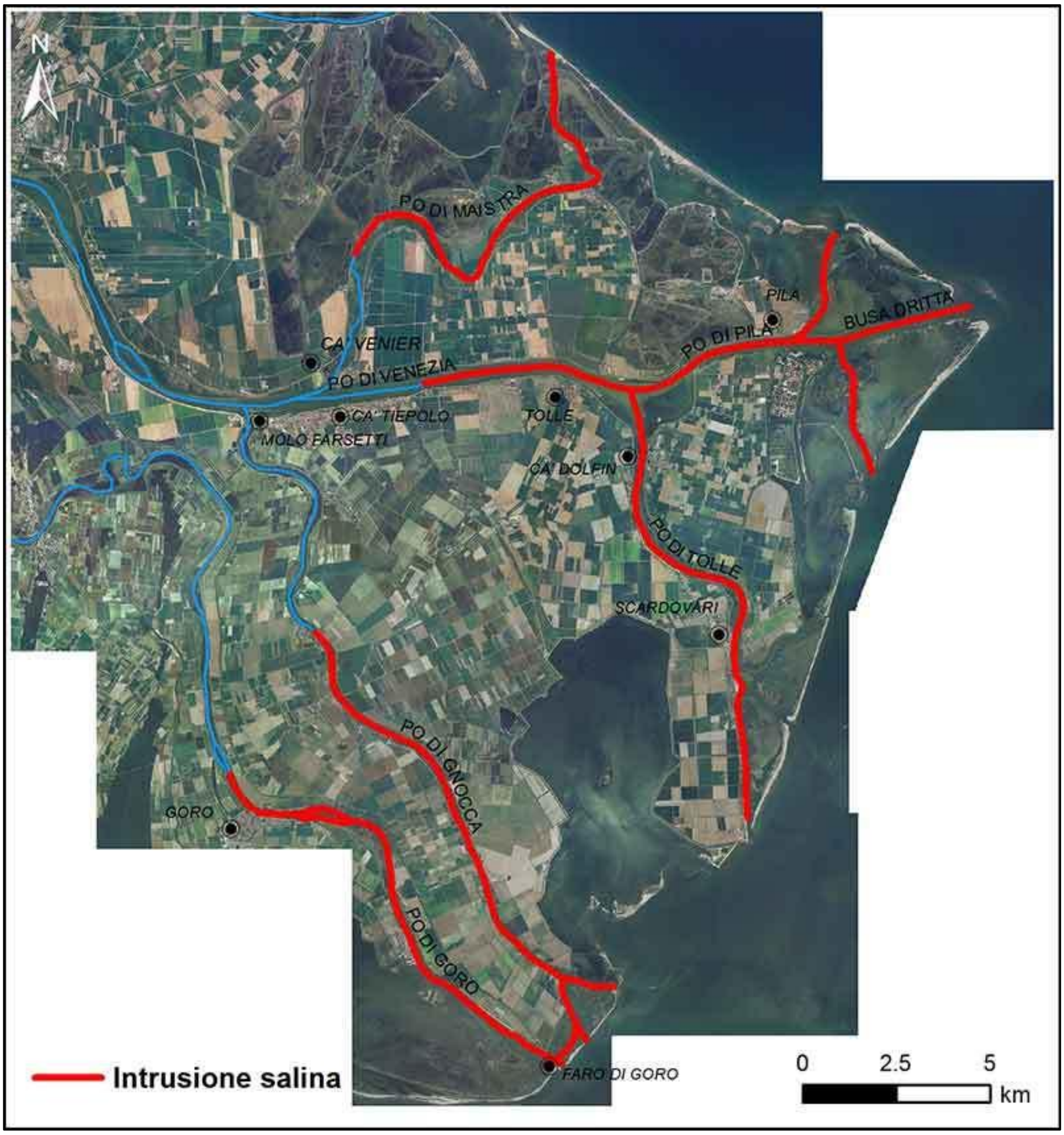


Figure 3.5.31. Extension of salt intrusion in the branches of the Po River.

The analysis of the sampling showed the presence of the salt intrusion 12-15 km from the mouth in the branch of Po di Pila during high tide, in accordance with the mathematical models that are currently used. These values confirmed a situation of risk in all the sampling points that are affected by the salt intrusion, creating problems of water supply that can be aggravated following a decrease of the water discharge. The extension of the salt intrusion seems in line with the measuring campaign of 2007.

As mentioned before, the process can become more severe with the decrease of fresh water coming from upstream and it can jeopardize the water supply (for both irrigation and drinking usage) in the coastal area. Additionally, it can cause severe damages to the ecosystems, leading, for example in regard tosediments, to the creation of zones and micro-zones of desertification, to drying of the littoral areas and salinization of costal lands.

The recent low water conditions combined with the salt intrusion inland have highlighted a critical situation for the Delta region, which is highly vulnerable to the climate changes.

Regarding the Po River discharges and the measurements at Pontelagoscuro station, the analysis considered a maximum of 12 000 m^3/s and a minimum of 189 m^3/s (Colombo e Tosini, 2009). The study asserted that, with the aim of avoiding the salt intrusion, the minimum discharge flowing at Pontelagoscuro should not be lower than 450 m^3/s (G. Mantovani, 2019).

Further analysis of the collected data and their usage for the prediction through mathematical models can be directed to improve the understanding of the salt intrusion, supporting the decision and interventions needed to reduce the salt water ingression, thus preventing the worsening of the water resource and guarantying its protection

3.5.3.3. Urban runoff

Regarding the run-off waters that can contain pollutants, a reconstruction of the released amounts of pollutant from this source has not been possible, since its analytical contribution (measures of the pollutant loads) cannot be easily distinguished from others sources, such as natural (watercourses, drainage canals and multi-purpose waterways) and artificial receptors (sewage and drainage network). Moreover, the releases are extremely variable both during the year and in connection with the meteorological events.

In this regard, the Veneto Region has proposed a series of measures to manage the releases and the treatment of the run-off waters, storm-water first flush and washing water, within the Piano di Tutela delle Acque. This is a technical and management instrument to achieve goals of quali-quantitave protection according to the Directive 200/60/CE (Italian actuation by the Decree 152/2006).

From the monographic page “Obiettivi di qualità ambientale e principali misure per il sottobacino Delta Po”, 2016 of the “Piano di Gestione delle Acque”, which is the operative instrument according to the Directive 200/60/CE (Italian actuation by the Decree 152/2006) to achieve a sustainable policy for the polluted water, it is evident that the run-off waters are not among the pressure elements threatening the transitional waters and with them **Sacca del Canarin** (Table 30).

This depends on the fact that the entire area is scarcely urbanized (Figure 3) and hosts mostly farming and fishing activities, which contribute very little to polluted run-off waters, storm water first flush and washing water.

Table 3.5.10. List of the pressure threating the coastal and transitional waters: number of the impacted water bodies distinguished according to their natural status (natural, artificial, highly impacted) and type of pressures.

Sea coastal waters and transitional waters: NUMBER OF SURFACE WATER BODIES						
Pressures	**Sea-coastal**			**Transitional**		
	Natural status			**Natural status**		
	Natural	Artificial	Highly modified	Natural	Artificial	Highly modified
Urban wastewater	1	-	-		-	-
Urban run-off	**1**	-	-	-	-	-
Not treated wastewater	1	-	-	-	-	-
Run-off from farmlands	1	-	-	3	-	-
Coastal infrastructure (naval building sites, ports)	1	-	-	-	-	-
Barriers for the coastal protection	1	-	-	2	-	-
Coastal nourishment	1	-	-	-	-	-
Industrial water release	-	-	-	3	-	-
Intake hydraulic works (for civil and industrial purpose)	-	-	-	1	-	-
Sluice gate	-	-	-	3	--	-
Urban wastewater	-	-	-	0	-	-
Dredging	-	-	-	3	-	-
Water bodies without pressure	0			5		

Discontinuous urban texture, with mixed use (art. Surface 50-80%)
Arable land in irrigated areas
Riparian vegetation
Fishing valleys
Lagoons or waterways

Figure 3.5.33. Land cover in the coastal area of the Delta Po.

3.5.4. Sediment as a pollutant

Starting from 2008, the Regional Agency for the Prevention and Protection of the Environment in the Veneto Region (ARPAV), in collaboration with the Veneto Region, follows the environmental monitoring of the lagoons in Veneto, in accordance with the Decree n. 152/2006 (and further modifications and integrations).

The control activities and measures aimed at assessing the environmental quality of the lagoons involves the evaluation both of the ecological status (in conformity of the life of shellfishes) and of the chemical status of the water matrix, **sediments** and biota (in accordance with Decree n. 152/2006 and further modifications).

The Legislative Decree no. 172, 13/October/2015, presented important modifications, adding quality standards for the sediment with the aim of selecting appropriate sites where evolutionary trends for the pollutants can be inferred. The sampling of the sediment matrix to investigate the synthetic pollutants should have at least annual frequency, both for the substances belonging and not belonging to the priority list according to the Decree 172/15.

The sampling conducted in 2016 involved overall 17 stations belonging to the Delta Po region: 3 in the Lagoon of Caleri, 1 in the Lagoon of Marinetta, 1 in the Vallona Lagoon, 2 in the Lagoon of Barbamarco, 2 in the **Sacca del Canarin**, 3 in the Sacca di Scardovari, 5 distributed in the 5 branches of the Delta.

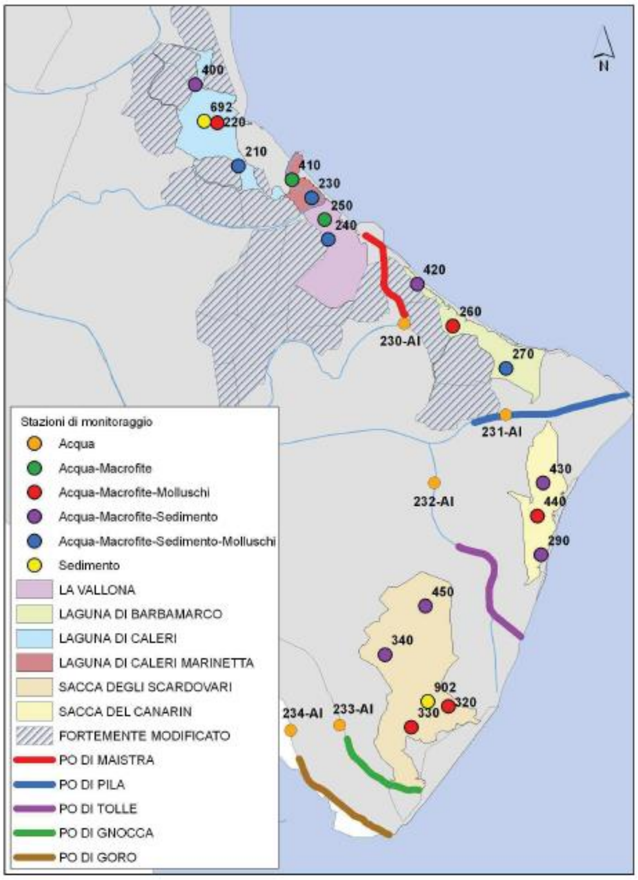


Figure 3.5.34. Localization of the sampling stations (from Valutazione di statoecologico e chimicodeicorpiidricisuperficialidel Veneto).

DETERMINAZIONI ANALITICHE	UDM	DETERMINAZIONI ANALITICHE	UDM
Metalli		DD's Totali	µg/kg s.s.
Arsenico (As)	mg/kg s.s	Dieldrin	µg/kg s.s.
Cadmio (Cd)	mg/kg s.s	Esaclorobenzene (HCB)	µg/kg s.s.
Cromo VI	mg/kg s.s	alfa HCH (esaclorocicloesano)	µg/kg s.s.
Cromo (Cr)	mg/kg s.s	beta HCH (esaclorocicloesano)	µg/kg s.s.
Mercurio (Hg)	mg/kg s.s	delta HCH (Esaclorocicloesano)	µg/kg s.s.
Nichel (Ni)	mg/kg s.s	gamma HCH (esaclorocicloesano)	µg/kg s.s.
Piombo (Pb)	mg/kg s.s	***Policlorobifenili***	
Organo metalli		PCB-28	µg/kg s.s.
Tributilstagno	µg/kg s.s.	PCB-52	µg/kg s.s.
Policiclici Aromatici		PCB-77	µg/kg s.s.
Acenaftene	µg/kg s.s.	PCB-81	µg/kg s.s.
Antracene	µg/kg s.s.	PCB-101	µg/kg s.s.
Benzo(a)antracene	µg/kg s.s.	PCB-118	µg/kg s.s.
Benzo(a)pirene	µg/kg s.s.	PCB-126	µg/kg s.s.
Benzo(b)fluorantene	µg/kg s.s.	PCB-128	µg/kg s.s.
Benzo(ghi)perilene	µg/kg s.s.	PCB-138	µg/kg s.s.
Benzo(k)fluorantene	µg/kg s.s.	PCB-153	µg/kg s.s.
Crisene	µg/kg s.s.	PCB-156	µg/kg s.s.
Dibenzo(ah)antracene	µg/kg s.s.	PCB-169	µg/kg s.s.
Fenantrene	µg/kg s.s.	PCB-180	µg/kg s.s.
Fluorantene	µg/kg s.s.	PCB totali (3)	µg/kg s.s.
Fluorene	µg/kg s.s.	**GRANULOMETRIA**	
Idrocarburi Policiclici Aromatici (PAH)	µg/kg s.s.	Ghiaia	%
Indeno(123-cd)pirene	µg/kg s.s.	Sabbia	%
Naftalene	µg/kg s.s.	Pelite	%
Pirene	µg/kg s.s.	**ANALISI BIOLOGICHE**	
Pesticidi		***Saggi ecotossicologici***	
DDD(2)	µg/kg s.s.	*Vibrio fischeri* (fase liquida) - EC50	testo
DDE(2)	µg/kg s.s.	*Vibrio fischeri* (fase solida)	STI
DDT(2)	µg/kg s.s.	*Dunaliella tertiolecta*	TU
Aldrin	µg/kg s.s.	*Brachionus plicatilis*	%

Figure 3.5.325. List of the investigated parameters for the sediment matrix in the lagoons of the Delta Po- 2016.

The analysis of the results, carried out in a single sampling campaign, as set by the law, have shown a 66% of the values below the quantification limit, while only 34% of the values as measurable. The exceedances of the limits set by the Decree 172/2015 were reported for Cadmium and Mercury, Polycyclic Aromatic Hydrocarbons (PAH), Chrome and Polychlorinated biphenyls.

*Table 3.5.111. Analysis of the results of the monitoring stations located in the Delta Po in **2016** concerning sediments.*

Water bodies	Caleri			Marinetta	Vallona	Barbamarco		Canarin		Scardovari			Po di Maistra	Po di Pila	Po di Tolle	Po di Gnocca	Po di Goro
Station	212-CAL	402-CAL	692-CAL	232-MAR	242-VAL	272-BAR	422-BAR	292-CAN	432-CAN	342-SCA	452-SCA	902-SCA	1032-Maistra	1042- Pila	1052- Tolle	1062-Gnocca	1072-Goro
Metalli																	
Arsenico (As)																	
Cadmio (Cd)																	
Cromo VI																	
Cromo (C r)																	
Mercurio (Hg)																	
Nichel (Ni)																	
Piombo (Pb)																	
Organometalli																	
Tributilstagno																	
PoliciclciAromatici																	

Acenaftene																	
Antracene																	
Benzo(a)antracene																	
Benzo(a)pirene																	
Benzo(b)fluorantene																	
Benzo(ghi)perilene																	
Benzo(k)fluorantene																	
C risene																	
Dibenzo(ah)antracene																	
Fenantrene																	
Fluorantene																	
Fluorene																	
IdrocarburiPoliciclici																	
Indeno(123-cd)pirene																	
Naftalene																	
Pirene																	
Pesticidi																	
2-4' DDD																	
2-4' DDE																	
2-4' DDT																	
4-4' DDD																	
4-4' DDE																	
4-4' DDT																	
Aldrin																	
DD's Totali																	
Dieldrin																	
Esaclorobenzene (HCB)																	
alfa HCH																	
beta HCH																	
delta HCH																	
gamma HCH																	
Policlorobifenili																	
PCB (somma o totale)																	

Legend:

- Substance that is not under investigation
- Substance never above the limit of quantification
- Substance for which an exceedance of the quantification limit has been observed
- Substance for which an exceedance of the EQS – AM has been observed (D. 172/2015)

Additionally, eco-toxicological tests can be conducted on the sediment matrix. In fact, when the matrix used for the chemical classification is the water column, but the sediments show exceedances in the pollutant concentrations, eco-toxicological tests are necessary to assess possible eco-toxicological effects – of short and long period. Moreover, any other useful investigation is undertaken to assess the risk for the human health posed by the pollutants whose value is above the limit.

Regarding the eco-toxicological analyses (see Table3.5.122), those of a chronic type with Dunaliella terctiolecta did not show toxicity in any station, instead showing an eutrophicating effect in some stations (Caleri, Barbamarco, Scardovari, Po di Maistra) (Data from 2016).

The test with Vibriofischeri (solid phase) showed a light toxicity in some stations, such as Vallona and Scardovari, and a medium toxicity at Barbamarco, while the test with Brachionus plicatilis did not exhibit any type of toxicity. It should be noted that the spatial distribution of the eco-toxicological signals cannot be related to the spatial distribution of the pollutants detected in the sediments.

Table3.5.12. Table of the eco-toxicologicalanalysis carried out different sediment matrices.

Punto prelievo	Test Dunaliella tertiolecta fase liquida		Test Brachionus plicatilis		Test Vibrio fischeri fase solida		Saggio di tossicità acuta con Vibrio fischeri - EC50
	TU	Valutazione	%	Valutazione	STI	Valutazione	Valutazione
392 - BAS	0	tossicità assente	0	tossicità assente	0.272	tossicità assente	negativo
382 - CAO	0	tossicità assente	0	tossicità assente	0.261	tossicità assente	negativo
402 - CAL	0	tossicità assente	0	tossicità assente	0.356	tossicità assente	negativo
212 - CAL	0	tossicità assente	0	tossicità assente	0.271	tossicità assente	negativo
692 - CAL	0	**effetto eutrofizzante**	0	tossicità assente	0.424	tossicità assente	negativo
232 - MAR	0	tossicità assente	0	tossicità assente	0.002	tossicità assente	negativo
242 - VAL	0	tossicità assente	0	tossicità assente	**1.324**	**tossicità lieve**	negativo
422 - BAR	0	**effetto eutrofizzante**	0	tossicità assente	**4.756**	**tossicità media**	negativo
272 - BAR	0	tossicità assente	0	tossicità assente	0.795	tossicità assente	negativo
292 - CAN	0	tossicità assente	0	tossicità assente	0.110	tossicità assente	negativo
432 - CAN	0	tossicità assente	0	tossicità assente	0.723	tossicità assente	negativo
902 - SCA	0	tossicità assente	0	tossicità assente	0.557	tossicità assente	negativo
342 - SCA	0	tossicità assente	0	tossicità assente	0.418	tossicità assente	negativo
452 - SCA	0	**effetto eutrofizzante**	0	tossicità assente	**2.454**	**tossicità lieve**	negativo
1032 - Maistra	0	**effetto eutrofizzante**	0	tossicità assente	0.622	tossicità assente	negativo
1042 - Pila	0	tossicità assente	0	tossicità assente	0.358	tossicità assente	negativo
1052 - Tolle	0	tossicità assente	0	tossicità assente	0.237	tossicità assente	negativo
1062 - Gnocca	0	tossicità assente	0	tossicità assente	0.223	tossicità assente	negativo
1072 - Goro	0	tossicità assente	0	tossicità assente	0.132	tossicità assente	negativo

Some pollutants seem to be ubiquitous, such as Cadmium and Chrome, while others are abundant in some areas with respect to others, such as thePolycyclic Aromatic Hydrocarbons in the Lagoons of Caleri and Marinetta. Moreover, among the five branches of the Po River, the branch of Pila is characterized by a lower concentration of the pollutants on the sediments. Actually, the composition of the sediment that is mainly sand, together with the low concentration of the organic matter that can be observed in the riverbed, could have limited the absorption of the pollutants (see the grain size distribution in Figure 3.5.336).

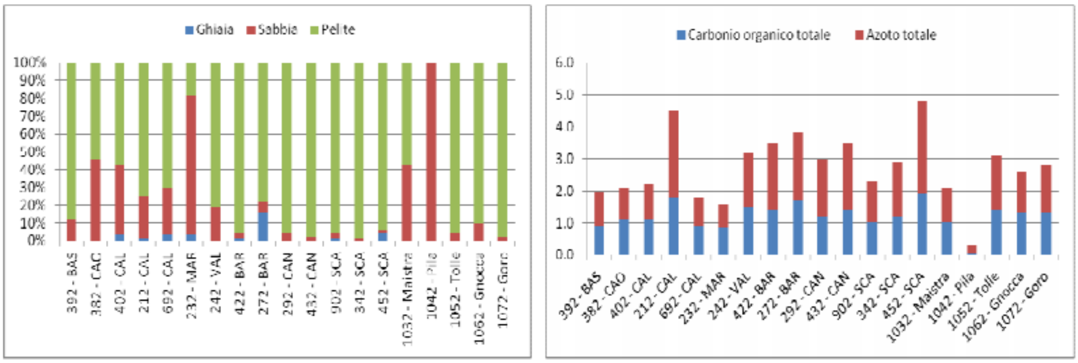


Figure 3.5.33. Grain size distribution of the sediments collected in the sampling stations (Left); concentration of organic carbon and total nitrate in the sediment matrix (Right).

The chemical analysis carried out on the sediments in *2018* show some exceedances of the listed limits for Cadmium and Chrome almost in all the water bodies, for Pesticides (DD's in table) exclusively in the Po di Pila, dioxins/furans and Polychlorinated biphenyls in the Lagoons of Barbamarco, **Canarin**, Scardovari and in the Po di Maistra.

The eco-toxicological results (*data from 2018*) show few positivity: the inhibition test for the algae growth with Phaeodactylum tricornutum show only two cases with low toxicity in the branches of Gnocca and Goro, while the test with Vibriofischeri (solid phase) exhibits two cases of slight toxicity, one in the **Lagoon of Canarin** and one in the Lagoon of Scardovari.

To interpret the recent chemical conditions of the Delta Po, it is necessary to consider the fact that the territories included into the Po catchment, are ones of the most industrialized in Italy.

Since the 1960, with the development of the big chemical industries and the increasing usage of the hydrocarbons, the environmental condition of the rivers has worsened exponentially, until the '70s, when the first environmental law was adopted in Italy concerning waters (Merli law).

Therefore, the Po River, crossing a large part of the northern regions in Italy, has been, and still it is, a conveyor of pollution, besides sediments and nutrients.

In its final part, in the low and medium plain, the Po River is generally dammed and suspended on the level of the plain, and this feature limits the entry of pollutants, which flow into the river mainly through its tributaries and wide network of secondary channels.

3.5.5. Acquisition of new in-situ data and analysis of recent trends of water and sediment fluxes

Water and sediment fluxes are crucial factors in the evolution of estuarine regions, and the accretion and retreat of a delta depend both on the amount of sediments reaching the river mouth from the hydrological catchments and on the erosive power of the sea processes. The occurrence of floods and surges in the area contributes to shape the Delta: a single exceptional flood is able to retain, transport and deposit large volumes of sediments towards the river outlets, while a single storm-surge can erode wide sectors of shores and destroy submerged bed-forms. Recently, two important events have affected the Po Delta, in November 2018 with the "Vaia" storm and at the beginning of November 2019. Due to their high intensity, they caused important changes in the littoral area of the Po Delta, with the removal of sand bars and deposits along the river channels and erosion of large coastal areas.

Monitoring activities are expected withing the project Change We Care to acquire new in-situ data along the main branches of the Po River, with the aim of reconstructing the morphological changes occurred in these recent years. However, these experimental campaigns are still in progress. Here we report some recent studies conducted to visualize the latest trends by means of satellite images.

Satellite images offer a great opportunity to observe continuously the Po Delta area and to monitor some interesting aspects, such as changes in the emerged lands and sediment plumes during floods. The first satellite products have been available since the '70s with the Landsat mission 1 and 2, and the pool was augmented by the successive Copernicus Program that launched Sentinel-2 in 2015 and Sentinel 2-b in 2017.

Figure 3.5.347, Figure 3.5.358 and Figure 3.5.369 (master thesis of Trampe (2016), written under the supervision of the CNR-national research center) shows turbidity plumes during normal and exceptional conditions and they come from elaborations of Sentinel-2 acquisitions. The plumes coming from the northern tributaries spread at both sides of the emerged bar in front of the Pila mouth. At south a small plume enters into the sea through Po di Tolle and a denser, wider plume can be identified between Tolle and the spit at the southern end. The main branch of the Po river shows a higher turbidity in comparison to the others.

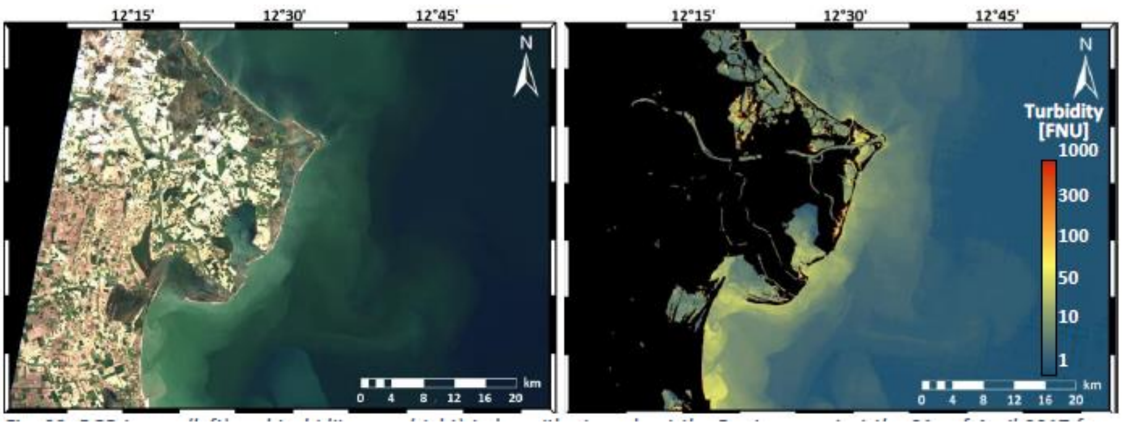


Figure 3.5.347. RGB image (left) and turbidity map (right) in logarithmic scale at the Po river coast at the 21th of April 2017 from Sentinel-2 acquisition (Trampe, 2016).

Figure 3.5.347. RGB image (left) and turbidity map (right) in logarithmic scale at the Po river coast at the 21th of April 2017 from Sentinel-2 acquisition (Trampe, 2016). refers to the typical Scirocco plumes

originating from the Po mouths. Their geometry follows the sea current direction and it is clearly directed and divided by the bar in front of the Pila mouth. As previously, the main branch of the Po river shows a higher turbidity in comparison to the others.

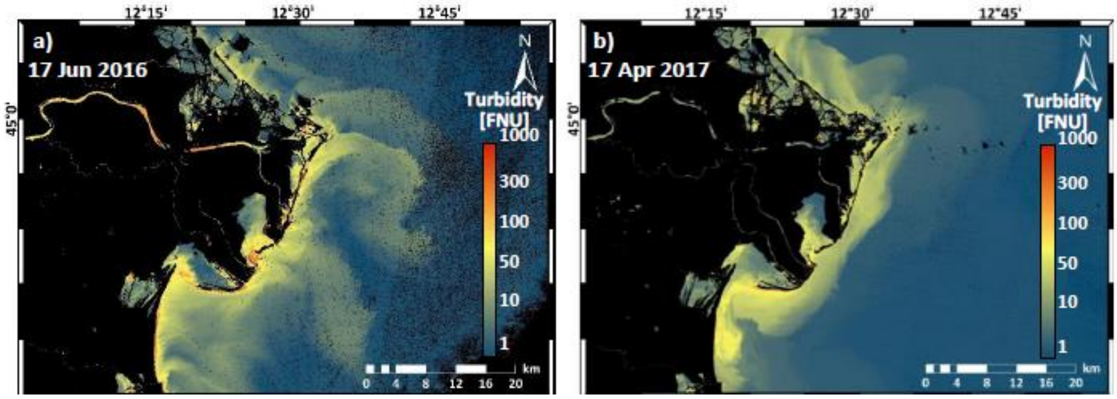


Figure 3.5.358. Turbidity maps (log scale) of typical Scirocco plumes: a) 17th of June 2016, b) 17th of April 2017.

During floods, the turbidity plumes are different and extensively larger and denser.

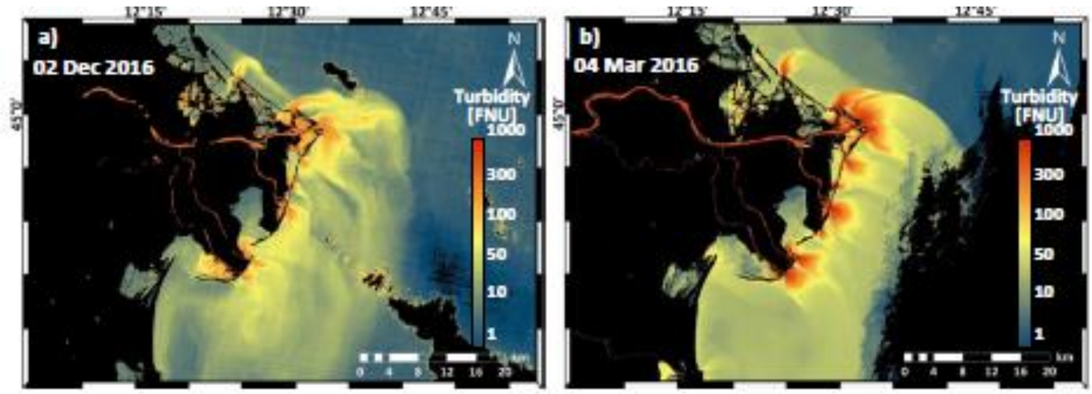


Figure 3.5.369. Turbidity maps (log scale) in high discharge conditions: a) 17th of June 2016, b) 17th of April 2017.

Generally speaking, the images display a strong connection between the fluvial flux, the sea-current and the turbidity plumes. In the north of the Pila mouth the sediments are transported near the coast, as it is shown by Figure 3.5.369, while the plumes coming from the main Pila mouth and from the southern outlets are transported towards south and dispersed in a wider area offshore, where they settle down when their velocity start reducing.

It is important to highlight that the fate of the turbidity plume is not easy to predict. The suspended sediments entering into the sea during floods can be both deposited near the coast and transported farther away from the river mouths. The process is highly dependent on the mutual strength of the sea currents and sediment fluxes coming from the river. Therefore, the sediment particles dispersed in the plume settle down with different times and distances according to the prevailing forces acting on them, and they can lead to dissimilar responses for different flood events. The correlation between the plume-spreading and the formation of subaqueous bedforms is not straightforward and is still matter of research.

However, as seen before, satellite observations are useful to clearly depict the pattern circulation at the mouth and the possible trajectories of the sediments.

Moreover, the satellite images confirm the observations carried out on the water and sediment fluxes partitioning. According to the measurements, the southern branches deliver more amount of fresh water and sediments with respect to the northern ones (Maestra 1%, Pila 74%, Tolle 7%, Gnocca 11% e Goro 8%). This leads to the observation of much denser and larger plumes in at the main Pila mouth and in the southern part of the Po Delta.

A recent work shows the evolution of the Delta Po cusp starting from 1970 by comparing satellites imageries of different years (see figures below elaborated by Ninfo et al. 2018).

The Sentinel-2 images acquired in 2017 clearly show the growth of a small bar in front of the main Pila mouth of the Po River. According to Ninfo et al (2018), its formation is connected to a series of floods occurred between 2013 and 2015. It was originally visible only during low tides, but then it grew quickly and became stabler during the years. In the same period, the satellite images display the creation of new half-moon spits in proximity of the secondary, northern mouth, where new deposits emerged clearly in the summer/winter 2016 and they were visible both at low and high tides. The trend seems continuing as shown by the Sentinel-2a images of May 2017.

Figure 3.5.40. Landsat satellite images: (a) L1MSS-12 August 1972 (60 m); (b) L5TM 8 May 1987 (30 m); (c) L5TM - 14 July 1994 (30 m); (d) L7ETM 23 April 2002 (30 m); (e) L5TM 17 April 1991 (30 m); (f) L8OLI 3 April 2015 - (30 m). Elaborations by Ninfo et al. (2018).

The growing direction of the bars is N-NW, and it is very likely that it is influenced by the SE waves (Scirocco winds), which is the direction of the longshore sediment transport and it is opposite to the northern dominant wind (Bora). The same direction characterizes the main outlet of the channel and the bar of the subaqueous mouth.

The interpretation of the satellite images should be taken with caution, since the shores at the cusp sides are subject to rapid changes, being continuously eroded and re-deposited, depending on the prevailing forces between the sea-currents and the river flow.

3.5.6. Conclusion

The analysis of the data and studies reported in the previous chapters confirms that the Po Delta is a sensitive and vulnerable area, as it develops at the closure section of the Po River, whose water and sediment fluxes are key factors at shaping the delta morphology, but also at conveying pollutants and nutrients to the coastal areas. Moreover, transition environments such as lagoons and river mouths are delicate environments highly influenced by tides, river supplies, weather conditions and exchanges with the sea.

Some of the aspects considered in this report are subject of institutional monitoring, such as water fluxes and concentrations of pollutants, and they are observed continuously through measuring gauges at specific river sections and sampling stations located in the most vulnerable sites. Conversely, information on sediment fluxes and nutrient loads are not systematic and come mostly from specific studies conducted both by regional and research institutes.

- As regards water fluxes measured at the Po final section of Pontelagoscuro, the historical series available since the 1920s show that the monthly average and annual average flow of the Po River tend to decrease. However, the observed trends cannot be attributed only to the ongoing climate changes, since the water fluxes measured at the closure section are heavily affected by the withdrawals from the rivers in the Po catchment, occurred in the same period for drinking and irrigation purposes. Therefore, the observations can be taken with caution.

- Concerning sediment transport, historical and recent studies have shown that solid discharge has dropped consistently over the time along the Po River. This trend is attributed to the construction of dams and hydraulic powerplants along the river course, which have trapped sediments preventing them from reaching the sea. Moreover, change of land use and excavation along the river bed have contributed to reduce the sediment fluxes. The amount of sediment transported by the Po river to the coastal areas is mostly derived by indirect methodologies, based on mass balance, on the assessment of the eroded volumes and the changes in morphologies of the Delta mouths, or on numerical simulations, while direct measurements are rare, especially concerning the bedload.

  Important measuring campaigns have regarded the Po branches in the Po delta, with the aim of assessing the water and sediment flux partitioning and its evolution in time. The studies have confirmed the predominant role of the central Pila branch, which also shows the highest hydraulic capacity and consequently the highest growing rate.

- Nutrients represent a relevant aspect in the Po Delta, due to its location at the end of a high populated and exploited area, and due to its configuration, characterized by a flat territory with diffuse mechanical drainage. Therefore, the entire delta is considered vulnerable for nitrates used in agriculture and important measures are taken to limit their emission within the area.
  Regarding the nutrients 'concentration, in the last years (2017-2018) the **lagoons** have shown several differences connected to the variability of their chemical-physical parameters (such as dissolved oxygen, temperature). In general, in 2018 the comparison between the state of the water bodies clearly differentiates Vallona, which has the highest values, from all the other lagoons for all the concentrations of nutrients analyzed, both in terms of average and maximum values. Caleri, on the other hand, has always appeared in good condition. On the contrary, the concentrations of dissolved nutrients measured in the **delta (branches**) are very homogeneous in the different water bodies, both in median terms and in terms of variability, as well as the related physico-chemical parameters.

  In 2018 nutrient concentrations, with some exceptions, do not show a clear seasonal trend. Otherwise, the data relating to previous years showed more the presence of a maximum in the autumn-winter period and a minimum in the spring-summer period. As regards the seasonal trend of nutrients in the delta mouths, the most evident characteristics are the rather high values of ammonia nitrogen in the summer and, on the contrary, the marked increase in the concentrations of nitric nitrogen and phosphorus from orthophosphate in the winter months

  Concerning the nutrients' loads, the studies have highlighted that they are not homogeneously distributed over the year but follow the frequency, duration and extent of the floods. Moreover, it would be strategic to acquire more information, in order to highlight important aspects such as:
  - how the load of nutrients of the individual branches of the Po is distributed, influencing the various lagoons of the delta, through direct inlets and, indirectly, from the sea, through the lagoons' mouth, especially in flood,
  - the relative importance of nutrient loads from coastal basins, especially in the summer season,
  - the trend of cited terms in a climate change scenario and relative mitigation strategies.

- Regarding excess fertilizers and pollutants, the monitoring stations present in the lagoons, in the coastal waters, and in the Po branches have seldom shown some criticalities, which eventually depended on the industrial activities located in the upper part of the Po basins.

- Finally, salt intrusion has become one of the most severe threat in the Po Delta, especially following the recent decrease of fresh water.

4. SUMMARY AND CONCLUSION

This report focuses on water and sediment flux within five Pilot areas as well as nutrient and nonpoint sources of pollution sources related to them. The main differences between Pilot areas were recognized in the Introduction and refer to a general difference in sediment and water flux along the Adriatic Sea. Considerably higher quantities of water and sediment are being discharged from the Italian coast, resulting in more complex coastal environments with problems generally proportional to the size of each Pilot Site. Complexity of all three Pilot sites along the Croatian coast can be recognized in unknown quantities and less predictable behaviour of groundwater compared to surface runoff.

Three out of five Pilot sites reported decrease in sediment flux, mostly due to the activities related to river damming, sediment mining and land use change during the 20th century. The most common feature of all Pilot sites refers to seawater intrusion. This problem is being related to decrease in precipitation and surface runoff, negative fresh water budget, increase of air temperature over the coastal Adriatic and actual sea-level rise. Negative changes in freshwater budget led or may lead to extended time of flushing and enhanced accumulation of contaminants.

Amount and availability of sediment/ water flux and quality data showed significant differences between Pilot sites. Sufficient and comprehensive data sets are necessary to understand how the system works. Understanding of the system functioning and knowledge about its current ecological state provides a rational basis for predicting system behavior under new conditions such as extreme weather episodes (e.g. droughts), increasing anthropogenic demands and climate changes. In order to describe this behavior during additional demands, Hashimoto (1982) proposed a comprehensive analysis of the system performance. System performance can be described from three aspects: how often the system fails (reliability), what is the recovery rate of the system from unsatisfactory state (resilience) and how severe the damage caused by a system failure may be (vulnerability). Thus, the analysis based on these three criteria: reliability, resilience, and vulnerability (RRV analysis). This analysis focuses on system failure, defined as any output value reaching the predefined failure threshold. Measurement of these three criteria should be used in water resources management and operating policies.

Due to the anthropogenic causes and climate changes, functioning of water resource systems are becoming increasingly complex with increasing number of possible risks. In order to manage these risks determination of system baseline conditions is needed, however, baseline performance analysis for most of water systems is not set. Furthermore, the RRV concept requires determination of failure thresholds as well as the criterion for satisfactory state. In case of five Pilot sites baseline condition are not clear or do not exist, while failure thresholds and satisfactory are not completely set yet. In general, collected data compiled within this activity gave an insight into overall picture of sediment and water fluxes within each Pilot site, however, further data should be collected and analysed for ecological state assessment.

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