WP3 – Activity 3.2

Characterization of the marine water bodies and sediments quality of marine and tourist port areas

Deliverable 3.2.1

Report of hydrogeochemical quality and hydrogeological features: I) the hydrogeological features of the coastal aquifer and the description of the salinization processes during the seasonal cycle; II) the analysis of the karstic Aquifers; III) the analysis of the waters drainage of the Ancona landslide; IV) analysis of rivers and channels in proximity to the port areas investigated

Deliverable 3.2.2

Report of freshwater discharges features: the geochemical survey will extend to marine areas to characterize the freshwater discharges along the studied coastal zones and their influence on the geochemical quality of marine water, sedimentation and biodiversity

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Introduction

This final report represents one of the three activity deliverables belonging to Work package 3, Activity 2. This report will describe the characteristics of the rivers and channels near the port areas investigated the characteristics of the karst aquifers in the study areas and the characteristics of the salinization processes of aquifers.

Moreover, the characteristics of the submarine freshwater springs, which are typical of the Split and Podstrana area, and more generally of the whole of Kaŝtela Bay will be discussed below.

Analysis of rivers and channels in proximity to the port areas investigated.

Introduction

The purpose of the study was to evaluate, through a monthly or bi-monthly monitoring activity, the quality of the surface waters of the main rivers that flow near the test sites of the Interreg Italy-Croatia ECOMAP project, focusing both on the assessment of the state ecological and chemical state of the water following national and European Community regulations. Specifically, data deriving from monitoring activities that have affected the Esino river, adjacent to the Ancona test site, the Tagliamento river, adjacent to the Bibione test site, and the Jadro and Žrnovnica rivers, adjacent to the tests site of Split and Podstrana.

Tagliamento river, Bibione site (Italy)

Description of the hydrographic basin

The Tagliamento river rises at the Mauria pass (1195 m asl), near the border between Veneto and Friuli-Venezia Giulia, and flows into the Adriatic Sea between Lignano Sabbiadoro and Bibione cities (Figure 1).

Figure 1 - Geographical collocation of the Tagliamento river (Google Earth).

The total hydrographic basin of approximately 2920 km^2 and it extends between Friuli-Venezia Giulia and Veneto. In detail it borders to the west the hydrographic basin of the Piave and Meduna; to the north, it is bordered by the Carnic Alps chain; to the east, finally, it borders the basin of the Torre stream. In particular, the river marks the border between the Veneto region and Friuli-Venezia Giulia and in Veneto; it develops a catchment area on the left hydrographic of

3368 ha, mostly in the province of Venice. The plain originating from the Tagliamento river has a very large extension that goes from the river's current course up to the Lemene basin.

The Tagliamento river is the largest river in Friuli and the twelfth Italian river by length. The main riverbed of the river extends for a length of 178 km, reaching a very variable width ranging from a maximum of about 1500 m (Pinzano) to 150 m in some sections. The characteristic of its bed and that of the territory it passes through, which passes from the mountain slopes to the karst rocks, makes the river assume a predominantly torrential flow with very variable flow rates (average flow rate 92 m3 / s, ARPA 2020).

Overall, there are 18 types of water bodies in the Tagliamento river basin (Figure 2). Its most important tributaries, located on the left bank are the Lumiei, the Degano, the But, the Fella and the Ledra; the tributaries on the right bank are the Leale, the Arzino and the Cosa.

In the mountainous region, which can be identified with the part of the basin upstream of Venzone (at the confluence with the Fella River), the spatial trend of the reliefs makes it possible to precisely fix the line of the watershed. Downstream of the aforementioned confluence, however, the delimitation of the catchment basin is difficult as the hydrography is modified by man-made works such as drainage, reclamation and irrigation channels.

Within the Tagliamento river basin, two transitional water bodies have been identified, the Baseleghe lagoon complex and the mouth of the Tagliamento river. The Baseleghe lagoon has a surface greater than 0.5 km2 and a tidal excursion greater than 50 cm, therefore according to the Ministerial Decree 131/2008, it is classified as microtidal (Figure 3).

There are 88 municipalities placed inside within the Tagliamento basin, none of which have a population greater than 20,000 inhabitants. The largest centre is Gemona, with about 13,000 inhabitants.

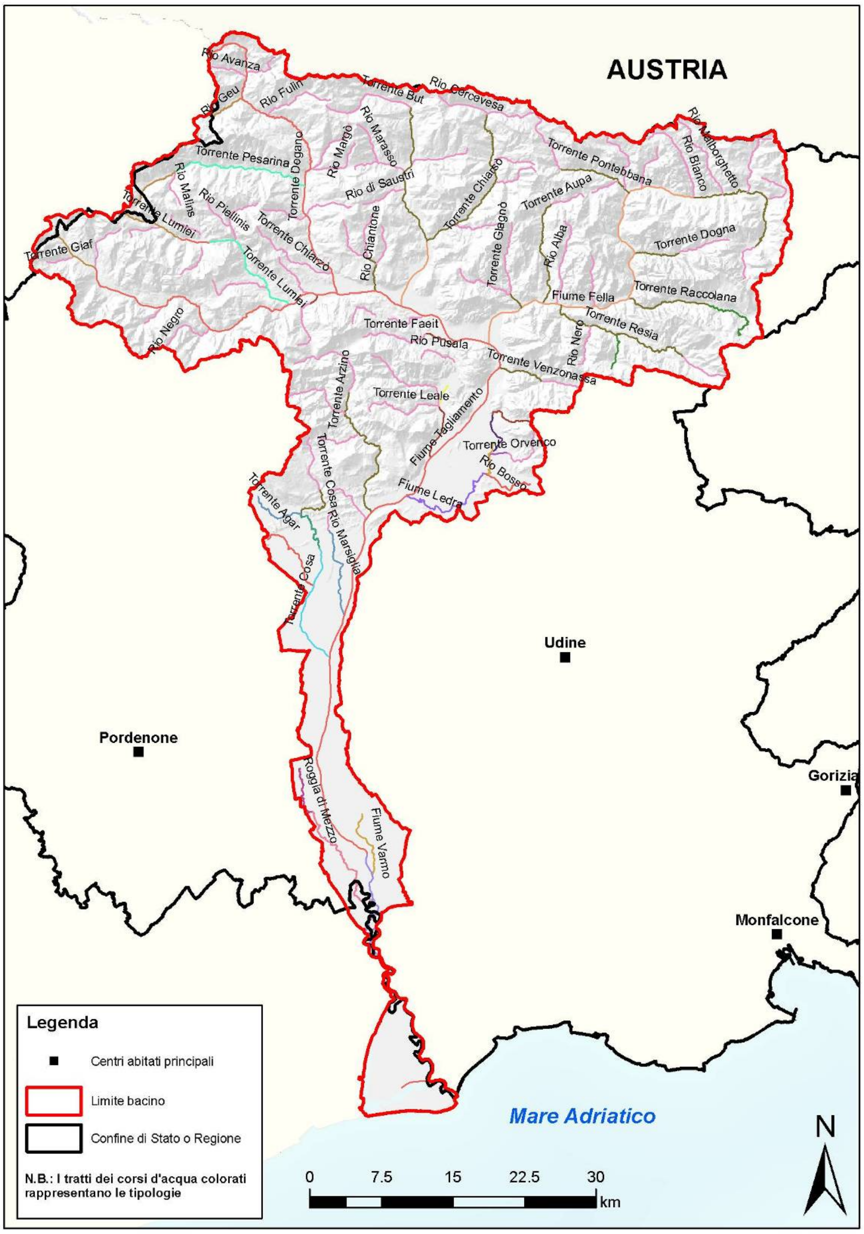

Figure 2 - Types of water bodies in the Tagliamento river basin (Autorità di bacino Distrettuale delle Alpi Orientali, 2010).

Figure 3 - Water bodies of transitional waters identified near the mouth of the Tagliamento river: the lagoon of Caorle and Baseleghe (ARPAV, 2009).

Areas designated for the protection of habitats and species

SIC e ZPS zones

The Council of the European Communities with Directive 92/43 / EEC of 21 May 1992 (the "Habitats" directive) outlined the directives for the conservation of natural and semi-natural habitats and wild flora and fauna, to help safeguard the biodiversity. The EU has promoted the establishment of a European ecological network of special areas of conservation (Z.S.C.) called "Natura 2000", to ensure the maintenance, or, if necessary, the restoration, in a satisfactory state of conservation of the types of natural habitats and the habitats of the species in their natural range. In particular, the Natura 2000 Network, under the "Habitat" Directive (Article 3), is made up of the Special Conservation Areas (ZSC) and Special Protection Areas (ZPS). Currently, the "network" is made up of two types of areas: the Special Protection Areas (ZPS), envisaged by the "Birds" Directive, and the proposed Sites of Community Importance (SIC); these areas can have different spatial relationships between them, from total overlap to complete separation.

In Figure 4 the SCI and ZPS zones present in the Tagliamento river basin are visible. Analyzing the study area in more detail, Table 1 and Figure 5 show the prestigious natural areas that fall (even partially) into the territory. The areas listed above, SIC or ZPS, falling within the territory of San Michele al Tagliamento are almost totally concentrated in the town of Bibione.

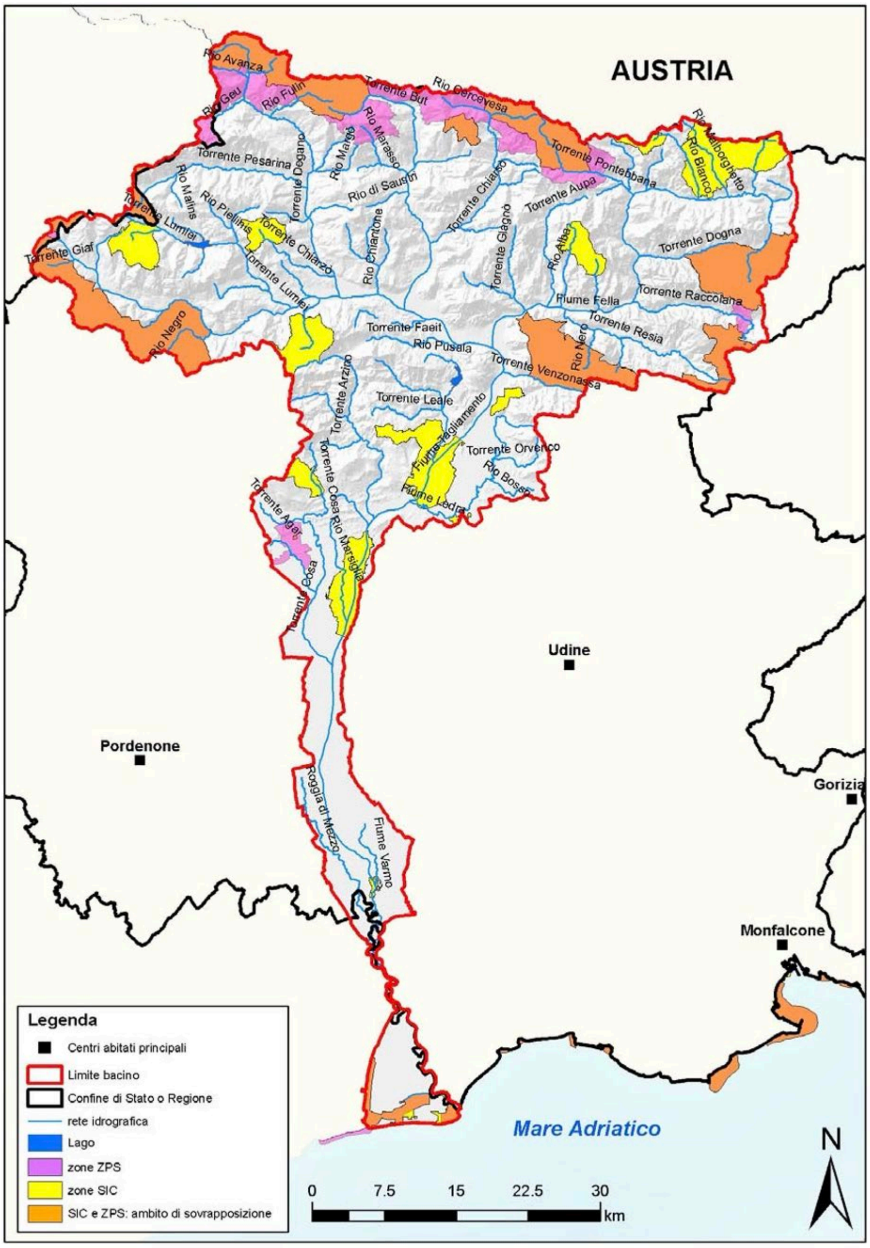

Figure 4 - SIC and ZPS zones in Tagliamento basin.

TYPE	CODE	NAME	AREA (HA)	CITY
SIC	IT3250033	Caorle lagoon - Tagliamento mouth	4386	San Michele al Tagliamento - Caorle
ZPS	IT3250040	Tagliamento mouth	280	San Michele al Tagliamento
ZPS	IT3250041	Valley Vecchia - Zumelle - Valleys of Bibione	2089	San Michele al Tagliamento - Caorle
SIC	IT3250044	Reghena and Lemene rivers - Taglio channel and near irrigation channel - Caves of Cinto Caomaggiore	640	Cinto Caomaggiore – Fossalta di Portogruaro – San Michele al Tagliamento

Table 1 - SIC and ZPS zones in Tagliamento basin falling within the territory of Bibione.

Aree SIC di Bibione

AREE ZPS di Bibione

Figure 5 - Located SIC and ZPS zones in the territory of Bibione.

Hydrogeochemistry of the downstream waters of the Tagliamento river

By comparing the geochemical characteristics of water sampled in the downstream portion of the Tagliamento river, through qualitative diagrams (Piper), the different chemical facies were identified, including the dominant one. In Figure 6 the results obtained by various authors are reported, including Grassi, (1994), Bortolan, (2008), and Saccon et al., (2013), who highlighted how the waters of the Tagliamento belong to the sulphate-calcic facies with a slight increase in magnesium (Mg) and an important enrichment in SO_4^{2-}. Results are in full agreement with Martelli and Granati (2010), which correlated the sulphate-calcium nature of the water with the dissolution of the gypsum from the Bellerophon formation located in the recharge area of the Tagliamento river. This unit crops out in the Carnic Alps in the western sector of the plain.

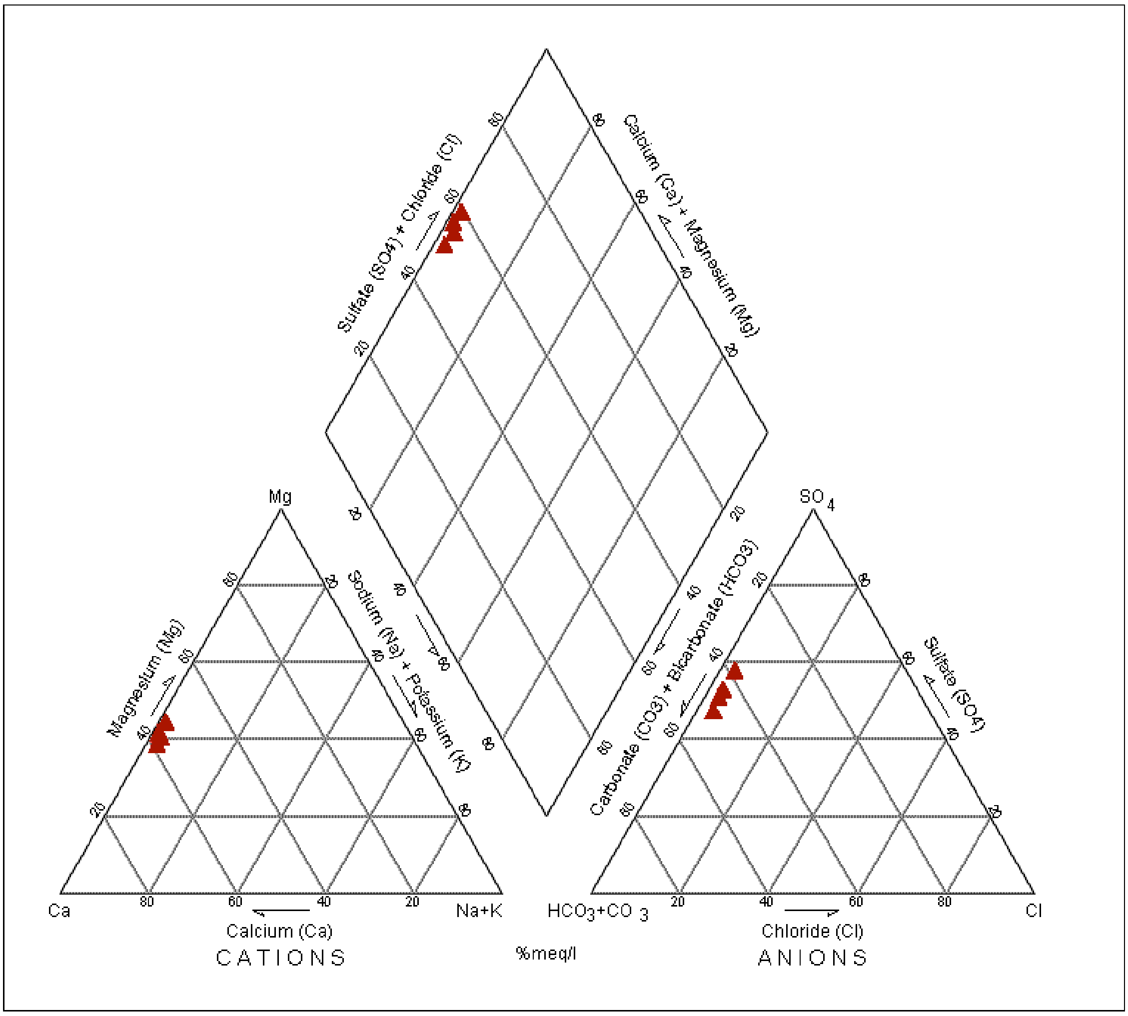

Figure 6 - Piper diagram showing the geochemical composition of the different Tagliamento river water samples analyzed by Grassi, (1994), Bortolan, (2008), and Saccon et al., (2013).

Water pollution of the downstream portion near the mouth

Estimates of pollution from point sources

From the processing of the data, provided by the Autonomous Region of Friuli-Venezia Giulia it appears that as regards the hydrographic basin of the Tagliamento river, there are 15 sites with point discharges.

While as regards the four municipalities belonging to the Veneto Region, which includes the Bibione test site, there is a single urban wastewater treatment plant (Figure 7).

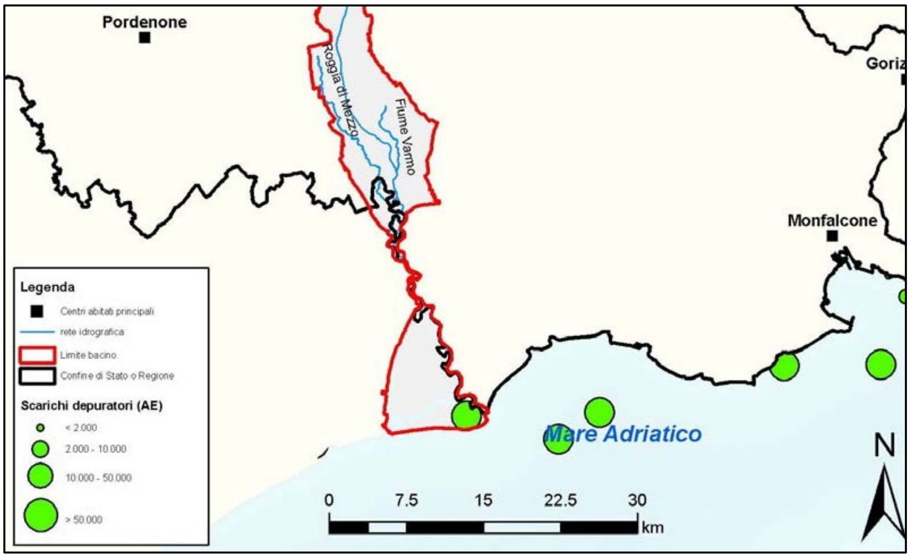

Figure 7 - Localization of discharges from urban purifiers in the Tagliamento river basin (Autorità di bacino Distrettuale delle Alpi Orientali, 2010).

In Table 2 the values of the potential loads of nutrients and deoxygenating substances estimated for the Tagliamento river basin are reported by Autorità di Bacino Distrettuale delle Alpi Orientali 2010.

Hydrographyc basin	N TOTAL Resident + floating + industrial (ton/yy)	P TOTAL Resident + floating + industrial (ton/yy)	BOD_5 TOTAL Resident + floating + industrial (ton/yy)	COD TOTAL Resident + floating + industrial (ton/yy)
Tagliamento (Veneto)	102	14	494	1,063
Tagliamento (Friuli)	1,504	200	7,336	15,773

Table 2 - Potential loads related to the purifiers that deliver to the Tagliamento river basin.

Estimates of pollution from diffuse sources

To estimate land use, the CORINE LAND COVER 2000 Project database was used, which is the most up-to-date with homogeneous coverage for the hydrographic basin of the Tagliamento river. The land use mapping carried out in this project has a minimum cartographed area of 25 hectares. The classes are divided into 5 increasingly detailed hierarchical levels.

To get an idea of the impact of agricultural activities on the assessment of the theoretical contributions of nitrogen and phosphorus in the downstream part of the Tagliamento river, a reference was made to the data, provided by the Veneto Region, as part of the survey activities for the preparation of "Water Protection Plans".

Figure 8 and Figure 9 show the basin-scale representation of the spatial distribution of the theoretical agro-zootechnical load of nitrogen and phosphorus in kg/ha of the Utilized Agricultural Area (SAU).

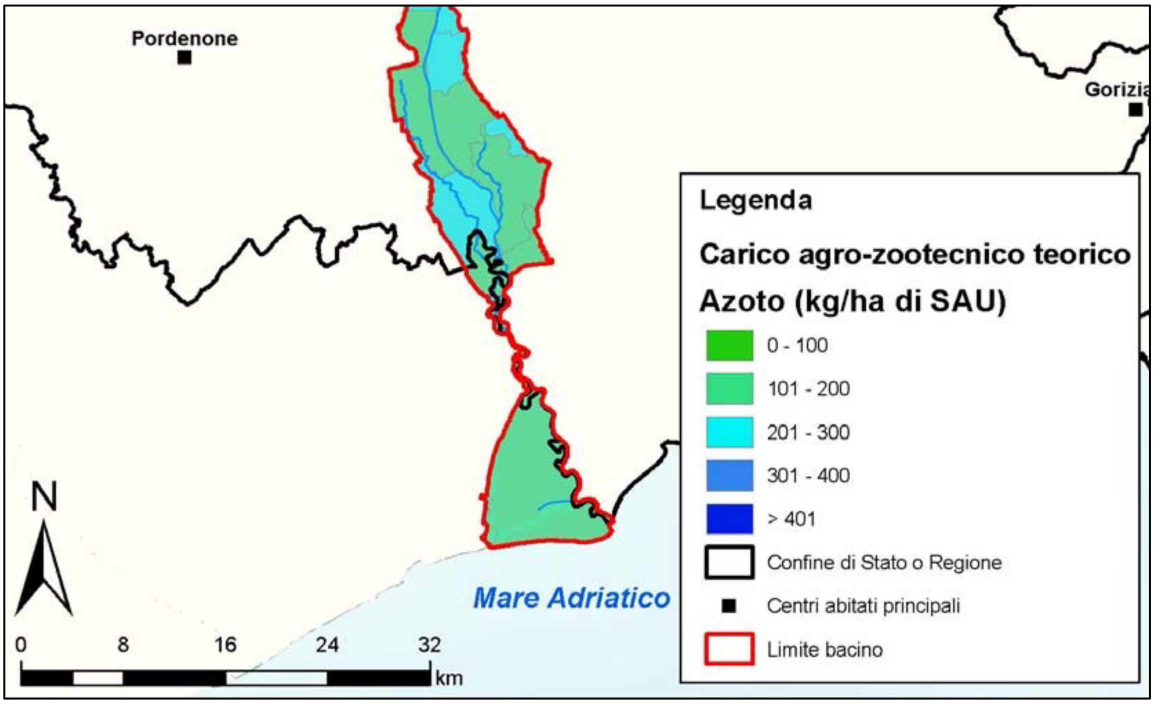

Figure 8 - Theoretical agro-zootechnical influence of nitrogen for the Tagliamento river basin (Autorità di bacino Distrettuale delle Alpi Orientali, 2010).

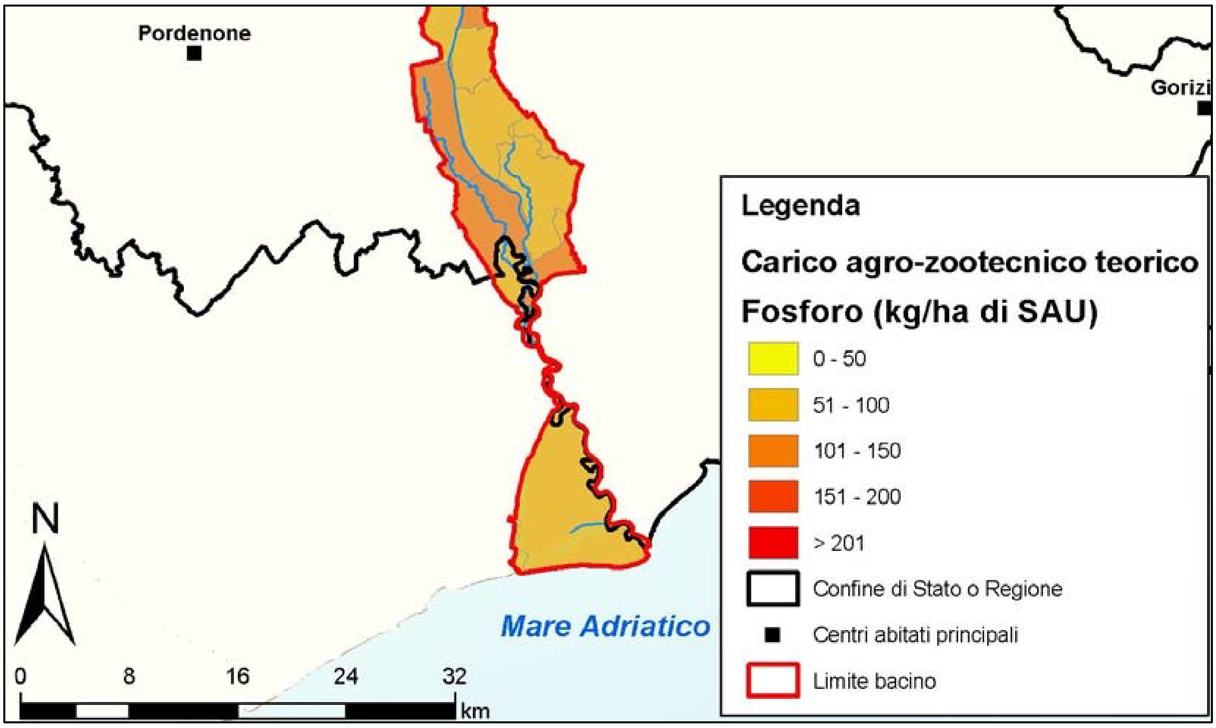

Figure 9 - Theoretical agro-zootechnical influence of phosphorus for the Tagliamento river basin (Autorità di bacino Distrettuale delle Alpi Orientali, 2010).

To get an idea of the impact of the population on the assessment of the theoretical contributions of nitrogen and phosphorus in the downstream part of the Tagliamento river, reference was made to the data, provided by the Veneto Region, as part of the survey activities for the preparation of the " Water Protection Plans "by the provisions of the relative" Annex H ". The procedure described in this document considers the contribution of both the resident population and the floating fraction.
Figure 10 and Figure 11 show the basin-scale representation of the spatial distribution of the theoretical nitrogen and phosphorus load due to the activities of the civil sector in kg/year.

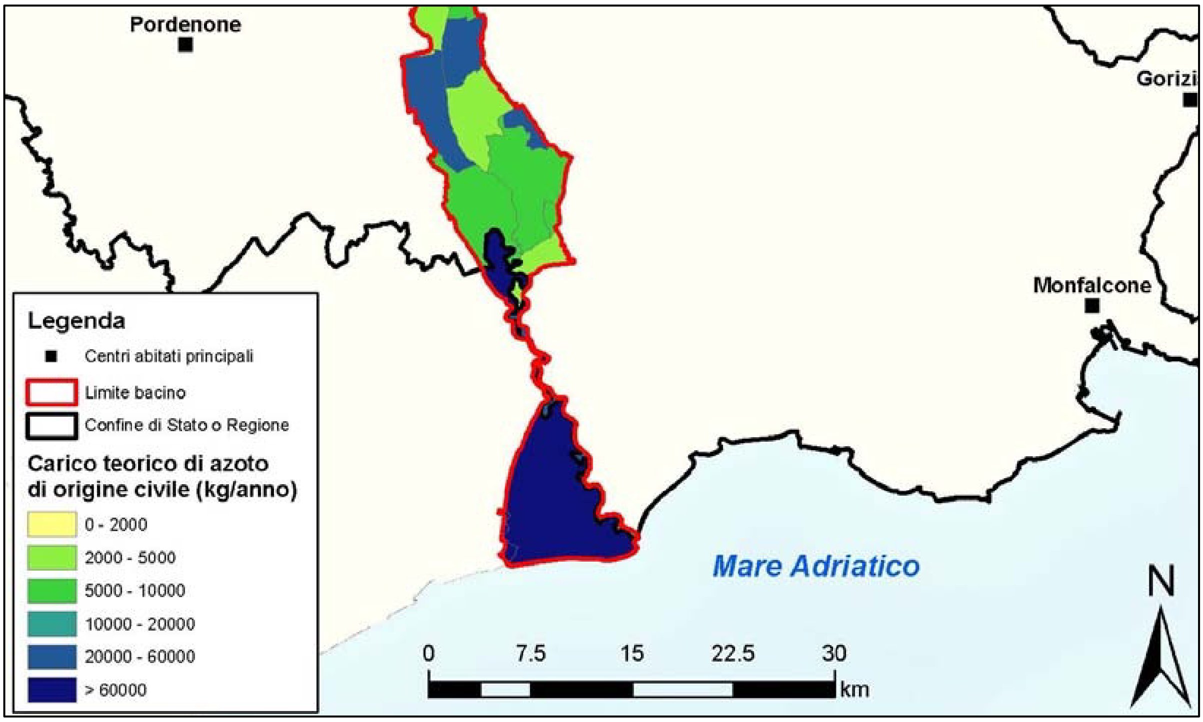

Figure 10 - Theoretical civil sector activities influence of nitrogen for the Tagliamento river basin (Autorità di bacino Distrettuale delle Alpi Orientali, 2010).

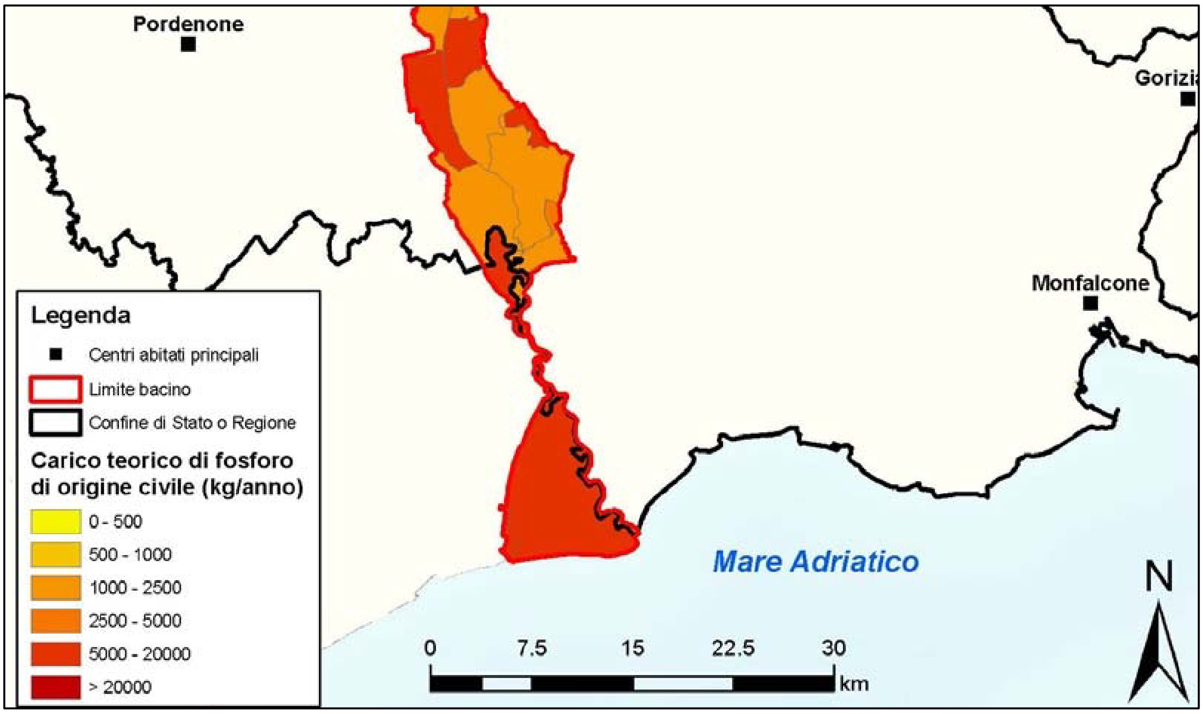

Figure 11 - Theoretical civil sector activities influence of phosphorus for the Tagliamento river basin (Autorità di bacino Distrettuale delle Alpi Orientali, 2010).

Finally, to get an idea of the impact of industrial activities on the evaluation of the theoretical contributions of the Biochemical oxygen demand (BOD) and phosphorus in the downstream part of the Tagliamento river, reference was made to the material, supplied by the Veneto Region, as part of the survey activities for the preparation of the "Water Protection Plans". The data that was provided to us already presented the calculation of industrial equivalent inhabitants.

Figure 12 and Figure 13 show the basin-scale representation of the spatial distribution of the theoretical load of BOD and phosphorus due to the activities of the industrial sector in kg/year.

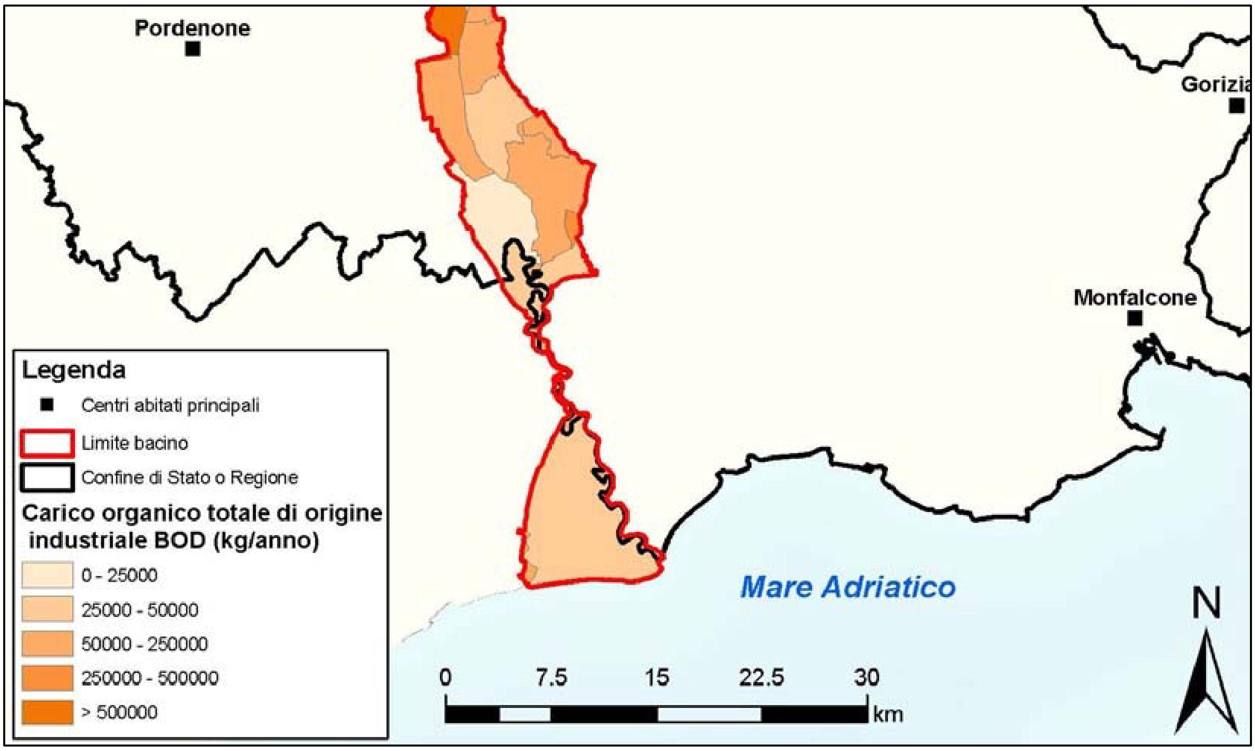

Figure 12 - Theoretical industrial activities influence of BOD for the Tagliamento river basin (Autorità di bacino Distrettuale delle Alpi Orientali, 2010).

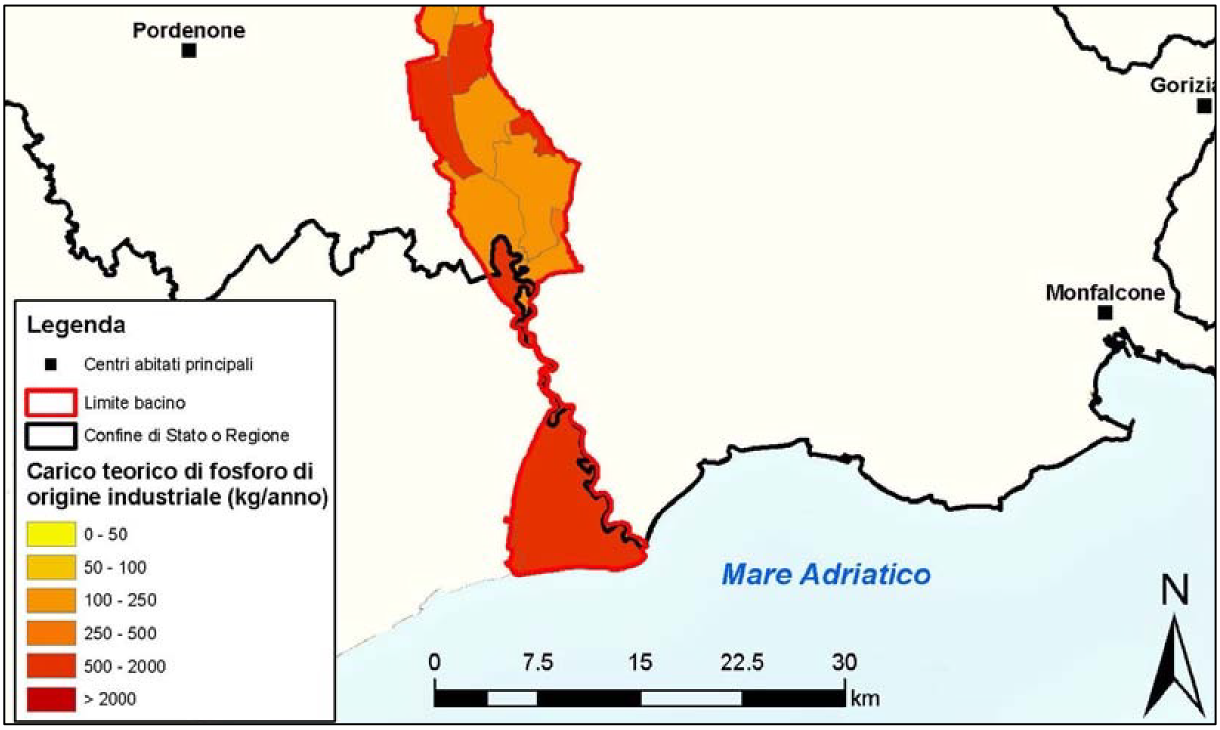

Figure 13 - Theoretical industrial activities influence of phosphorus for the Tagliamento river basin (Autorità di bacino Distrettuale delle Alpi Orientali, 2010).

Water quality monitoring

The monitoring of river water bodies, by the Friuli-Venezia Giulia Regional Agency for Environmental Protection (ARPA FVG), is carried out following Legislative Decree 152/06 ss. mm. and ii., updated by Legislative Decree 172/2015, which incorporates the criteria defined by Directive 2000/60/EC and Directive 2013/39/EU, modifying the basic setting of environmental quality monitoring of inland waters both in terms of approach and setting.

The general purposes are the prevention and reduction of pollution and the rehabilitation of surface and underground water bodies, and the protection and improvement of strictly aquatic ecosystems. By focusing on annexed wetlands and terrestrial ecosystems dependent on aquatic environments themselves, together with sustainable water use aimed at long-term protection of available water resources that can help mitigate the effects of floods and drought.

ARPA FVG, in collaboration with the Friuli Venezia Giulia Region, is engaged in the execution of various activities provided for by the European and Italian regulatory frameworks.

In particular, the structure responsible for assessing the state of inland waters deals with the organization of monitoring networks aimed at defining the environmental status of significant surface and underground water bodies and water with a specific functional purpose, water used by man and which they must meet particular quality requirements.

Monitoring results in 2014-2019 and comparison with the period 2010-2012

The results shown in this section are related to the monitoring activities carried out by ARPA FVG of the downstream waters of the Tagliamento River through two stations, station 06AS5F1 and station 06AS5F2 (Figure 14).

La valutazione della qualità del corpo idrico superficiale si basa sulla valutazione dello stato ecologico e dello stato chimico.

The assessment of the quality of the surface water body is based on the assessment of the ecological status and the chemical status.

The Ecological Status defines the quality of the structure and functioning of aquatic ecosystems, by monitoring the biological quality elements, the specific pollutants, the physical-chemical parameters in support and the hydro morphological elements in support.

There are five Ecological Status classes for natural water bodies: high (blue), good (green), sufficient (yellow), poor (orange), and bad (red).

Specifically, the biological elements analyzed for the evaluation of inland surface freshwaters (rivers) are benthic diatoms, macrophytes, benthic macroinvertebrates and fish.

The physicochemical elements supporting the EQBs are summarized in the LIMeco (Pollution Level by Macrodescriptors for ecological status), a synthetic index that describes the quality of running waters about nutrients and oxygenation. The parameters considered for the definition of LIMeco are Oxygen in% saturation (deviation from 100%), Ammonia nitrogen, Nitric nitrogen and total Phosphorus.

Ministerial Decree 260/10, which was partially amended by Legislative Decree 172/2015, provides that the Chemical Status is assessed based on the presence or absence of the polluting substances included in the priority list of Ministerial Decree 260/10 (tab . 1 / A), partially amended by Legislative Decree 172/2015. To achieve a Good status, the concentrations of these substances must be lower than the Environmental Quality Standards in terms of annual average or maximum permissible concentration, where applicable. It is sufficient that a single element exceeds these values for the failure to achieve the Good status. The quality classes of the chemical state are two: Good (blue) and not Good (red).

Figure 14 - Location of the two monitoring stations ARPA FVG downstream of the Tagliamento River.

Figure 15 and Figure 16 show summary sheets of the ARPA FVG containing the results obtained on the ecological and chemical status in the two stations examined.

In detail, station 06AS5F1 (located to the north) is located in a large stretch of the Tagliamento river with a conformation of braided canals, with a floodplain, and the area is highly natural. The main anthropogenic pressure is constituted by the extractive activities of the territory and by the mainly agricultural use of the surrounding territory. The sampled stretch is characterized by good fluvial functionality, despite the hydro-morphological simplification given by the presence of simplified riparian formations. The monitoring results show that the ecological status of the water body is sufficient in the second three years of the 2014-2019 monitoring period, therefore the quality objective is not maintained. While the analysis of priority substances led to the assignment of good status. Figure 15 shows the results obtained for each class examined.

Ecologic status		Monitoring (2010-2012)	Monitoring (2014-2019) (I three years)	Monitoring (2014-2019) (II three years)
	EQB	Diatoms	Diatoms	Diatoms
	EQB	Macrophytes	Macrophytes	Macrophytes
	EQB	Macroinvertebrates	Macroinvertebrates	Macroinvertebrates
	EQB	Fish fauna	Fish fauna	Fish fauna
	EQ	LIMeco	LIMeco	LIMeco
	EQ	Supporting chemicals parameters (1/B)	Supporting chemicals parameters (1/B)	Supporting chemicals parameters (1/B)

Legend	Trend	Objective
High, Good, Sufficient, Scarse, Bad, n.a, n.d	⟺	

Chemical status	Monitoring (2010-2012)	Monitoring (2014-2019) (I three years)	Monitoring (2014-2019) (II three years)
	Priority substances (1/A)	Priority substances (1/A)	Priority substances (1/A)

Legend	Trend	Objective
Good, No good, n.d	n.d.	

Enviromental Status
No Good

n.a = not applicable; n.d. = unavailable

Figure 15 - Summary sheets of the ARPA FVG containing the results obtained on the ecological and chemical status in station 06AS5F1 (data from ARPAFVG).

While station 06AS5F2 (located towards the mouth) is located in the portion of the Tagliamento river, which begins with the introduction of the Varmo river and ends with the beginning of the saline wedge, where it assumes a potamal character and a monocursal course. The main anthropogenic pressures are attributable to the agricultural use of the territory, the impressive bank works and the profound morphological changes of the riverbed, both longitudinally and transversally, which strongly affect the fluvial functionality. The monitoring results show that the ecological status of the water body is sufficient in the monitoring period 2014-2019, therefore the quality objective is not achieved. While the analysis of the priority substances led to the assignment of a good chemical status. Figure 16 shows the results obtained for each class examined.

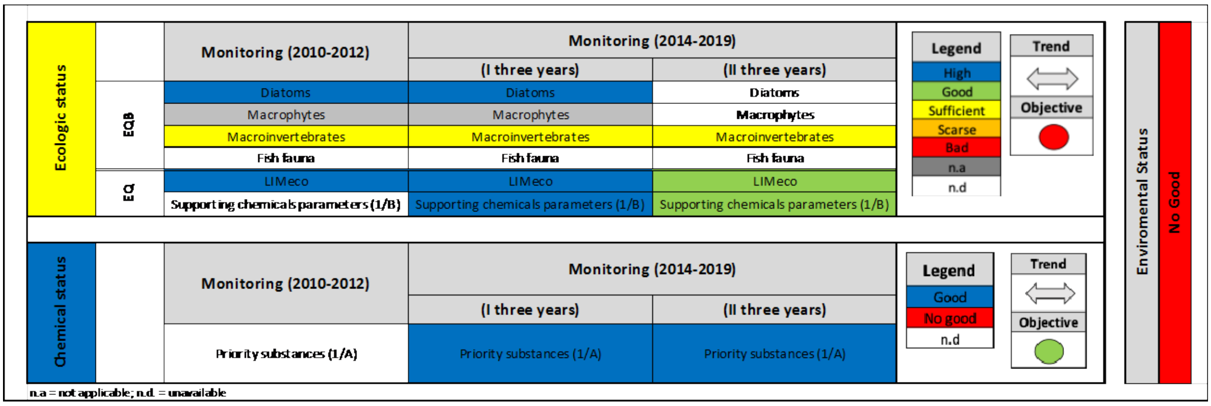

Figure 16 - Summary sheets of the ARPA FVG containing the results obtained on the ecological and chemical status in station 06AS5F2 (data from ARPAFVG).

Seasonal monitoring results in 2018-2019

Although the chemical state of the waters of the Tagliamento river downstream was good for the three years 2014-2016 and 2017-2019 no concentrations of priority substances were found higher than the regulatory threshold of Ministerial Decree 260/10. However, a more detailed focus was carried out on the temporal trend of some chemical / physical parameters and ions closely related to anthropogenic pollution which have shown a certain variability over time.

In Figure 17 and Figure 18 the trend of water temperature and pH is visible. The temperature varies from about 15 ° C in winter, although in March/April 2018 the values were around 10 ° C, and above 20 ° C in the summer months with a similar trend for the two monitoring stations. The pH for both points varies from 7.6 to 8.2, with average values close to 8.0.

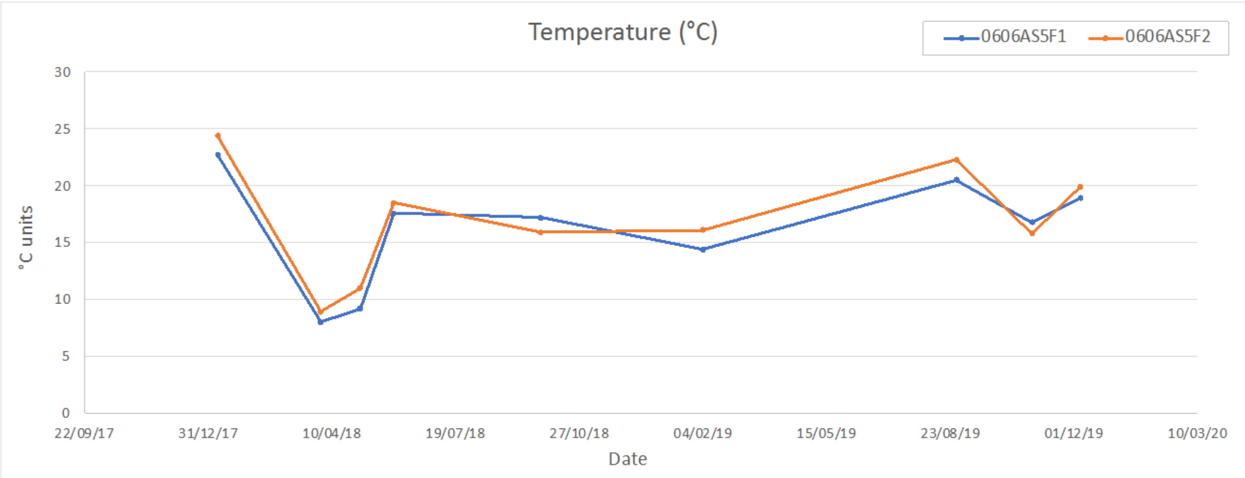

Figure 17 - Trend of temperature values in the period 2018-2019 in the two stations examined (data from ARPAFVG).

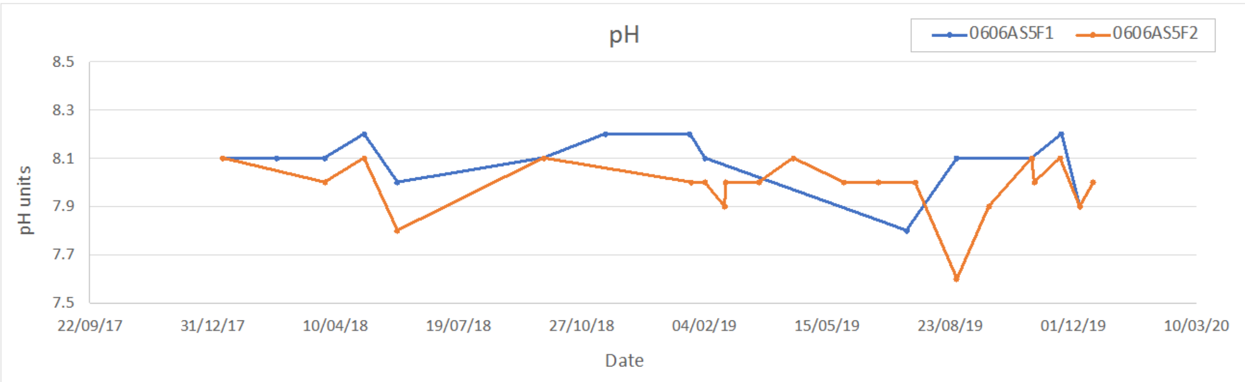

Figure 18 - Trend of pH values in the period 2018-2019 in the two stations examined (data from ARPAFVG).

Figure 19 and Figure 20 show the time course of the concentration as a percentage of dissolved oxygen in the water and the electrical conductivity. The waters of the Tagliamento river in both stations have good oxygenation, over 90%, and the point towards the mouth (0606AS5F2) in the summer months, due to a few more degrees of water, has greater oxygenation. The electrical conductivity, on the other hand, varies from 350 to 500 uS/cm with an average value of 400 uS/cm. Values above 500 uS/cm are observed only in July 2019 in the most upstream station (0606AS5F1), most likely due to the increase in nitrate concentrations in the water.

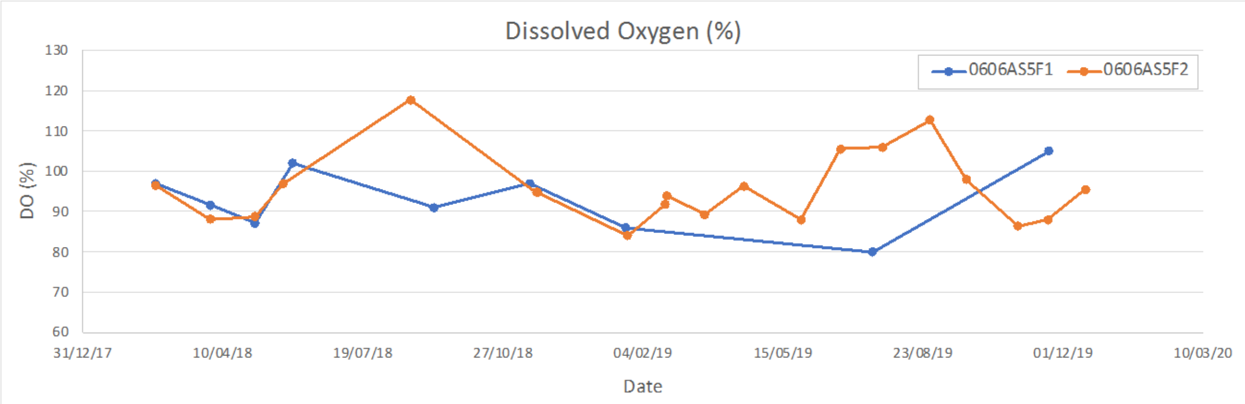

Figure 19 - Trend of DO values in the period 2018-2019 in the two stations examined (data from ARPAFVG).

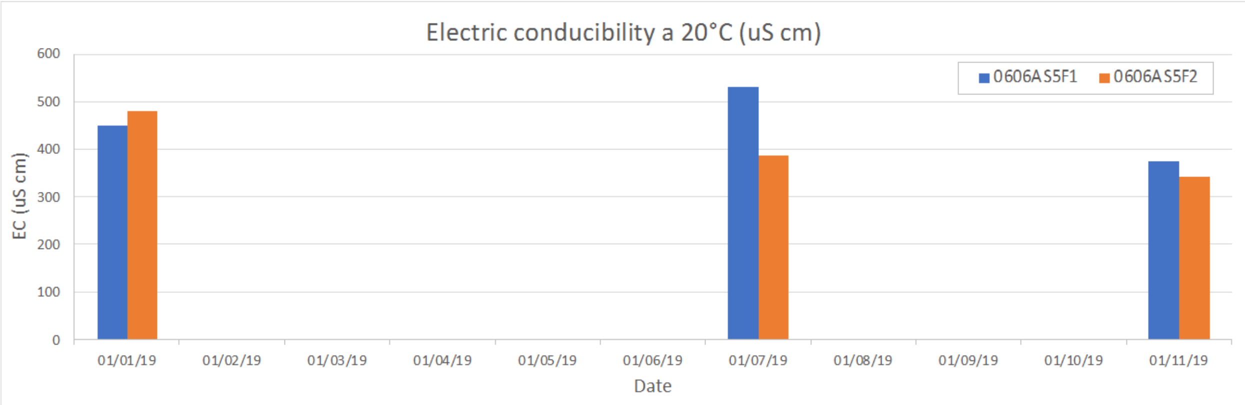

Figure 20 - Trend of EC values in the period 2018-2019 in the two stations examined (data from ARPAFVG).

Finally, nitrate and total phosphorus data were processed as main indicators of human activities and how the latter affect water quality. Although below the regulatory threshold, in the figure it is possible to observe how nitrates tend to have average values close to 5-7 mg/l, except in July 2019 when the values of station 0606AS5F1 reached 18 mg/l, and the total phosphorus values tend to be almost always lower than 0.016 mg/l; except September 2018, for station 0606AS5F1, with values close to 0.4 mg/l and December 2019, for both stations, with values close to 0.2 mg/l.

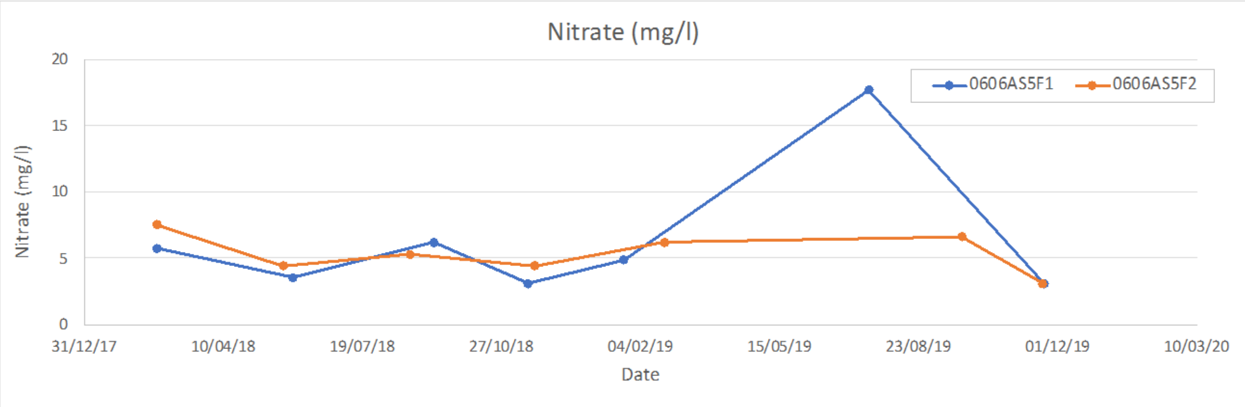

Figure 21 - Trend of nitrate concentration in the period 2018-2019 in the two stations examined (data from ARPAFVG).

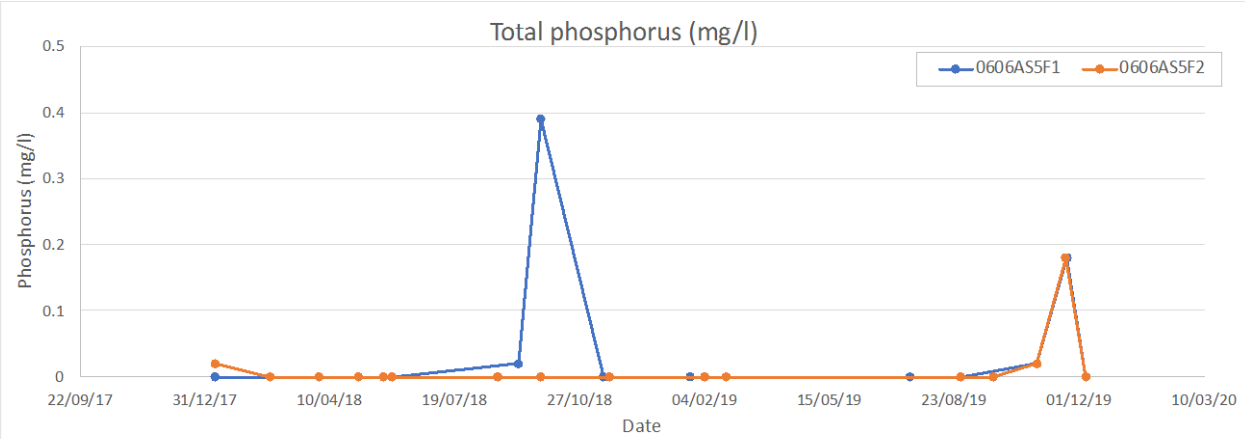

Figure 22 - Trend of total phosphorus concentration in the period 2018-2019 in the two stations examined (data from ARPAFVG).

Discussion

We have seen how the waters of the Tagliamento are greatly influenced and exposed to anthropogenic pollution, both of civil origin and agricultural/industrial origin.

Focusing on the downstream sector of the Tagliamento river, we have seen how the Bibione area has an important purifier discharge (> 50,000 AE) and, from the point of view of the estimated potential loads of nutrients and deoxygenating substances, it has an annual production of nitrogen, phosphorus, BOD and COD important. In the area of interest, it was seen how the greatest influence on phosphorus and nitrogen concentrations is linked to activities of civil and industrial origin, although the influence of agricultural activities should not be underestimated.

However, the monitoring activities of the downstream sector through two ARPA FVG control points have shown how the waters of the Tagliamento stretch of interest in the 2014-2019 semester have preserved a good chemical status, due to the absence of pollutants beyond the regulatory thresholds, and a steady ecological state, which should continue to be worked on.

Ultimately, the waters of the downstream stretch of the Tagliamento river, close to the Bibione test site, are of good quality both from a chemical and ecological point of view.

Esino river, Ancona site (Italy)

Description of the hydrographic basin

The Esino River is the main river of the Province of Ancona and its catchment area, which measures a total of 1,203 sq km, falls with an appreciable part in the province of Macerata and only marginally in the provinces of Pesaro and Perugia (Figure 23). It originates from Mount Cafaggio (1,116 m) in Esanatoglia (MC) and flows, after about 75 km, to Falconara Marittima in the locality of Fiumesino. The river has very particular characteristics; upstream it is characterized by a typically torrential regime, downstream and up to the mouth it looks much more like a classic plain river.

The entire river course of the Esino river is conditioned by the tectonics, lithology and stratigraphic structure of the formations; four sections with different morphological characteristics of the riverbed can be distinguished (Piano Tutela acque Regione Marche, 2008):

• from the spring in Matelica, the riverbed generally affects the carbonate formations of the Umbrian-Marche succession, sometimes the terraced alluvial deposits. More or less straight sections alternate with slight sinuosity;

• from Matelica to Cerreto d'Esi, the riverbed is meandering. The banks are well defined and sidebars emerge only during lean periods. In this section, the riverbed affects the Miocene terrigenous formations;

• from Cerreto d'Esi to Scisciano, the riverbed from irregular becomes straight, affecting the almost all of the path of the carbonate formations. Numerous sidebars not very durable over time are observed;

• from Scisciano to the mouth, the riverbed is anastomosed, rather large, with gravelly and pebbly alluviums furrowed by canals that give rise to numerous bars.

Figure 23 - Geographical collocation of the Esino river (Google Earth).

From a hydrographic point of view, the basin of the Esino river has an amphitheatre-like head, a medium trunk of almost uniform width and a terminal trunk, from Moie downstream, which progressively expands to the mouth. The upper part, in reality, is a pseudo-amphitheatre, which gives rise to a substantially binary system (Sentino torrent and Esino river proper), the second of which with complex hydrography, is the Giano stream, a tributary to the left of the Esino river, more important than the mainstream.

The major tributaries of the Esino river, the Giano and Sentino torrents flow entirely between the internal Umbrian-Marchigiana ridge and the external Marchigiana ridge, carving the same lithological sequences of the main course, while the Esinante torrent, a smaller tributary than the others by extension and water supply, cuts the Mio-Pliocene formations of the external Marche basin.

The intermediate part of the Esino river has a modest average total width, with a shallow watershed and with very asymmetrical draining slopes since those on the right predominate over those on the left. The terminal part is typical of a plain watercourse, with slopes that become more and more extensive and less steep. The meandering of the channel is manifested only in the high and medium-high parts and then alternates with anastomosed sections in the medium-low and low parts.

In the catchment area of the Esino river, the most significant underground water resources are found in the carbonate succession of the Umbrian-Marchigiana and Marchigiana ridges and the aquifer of the alluvial plain (Figure 24).

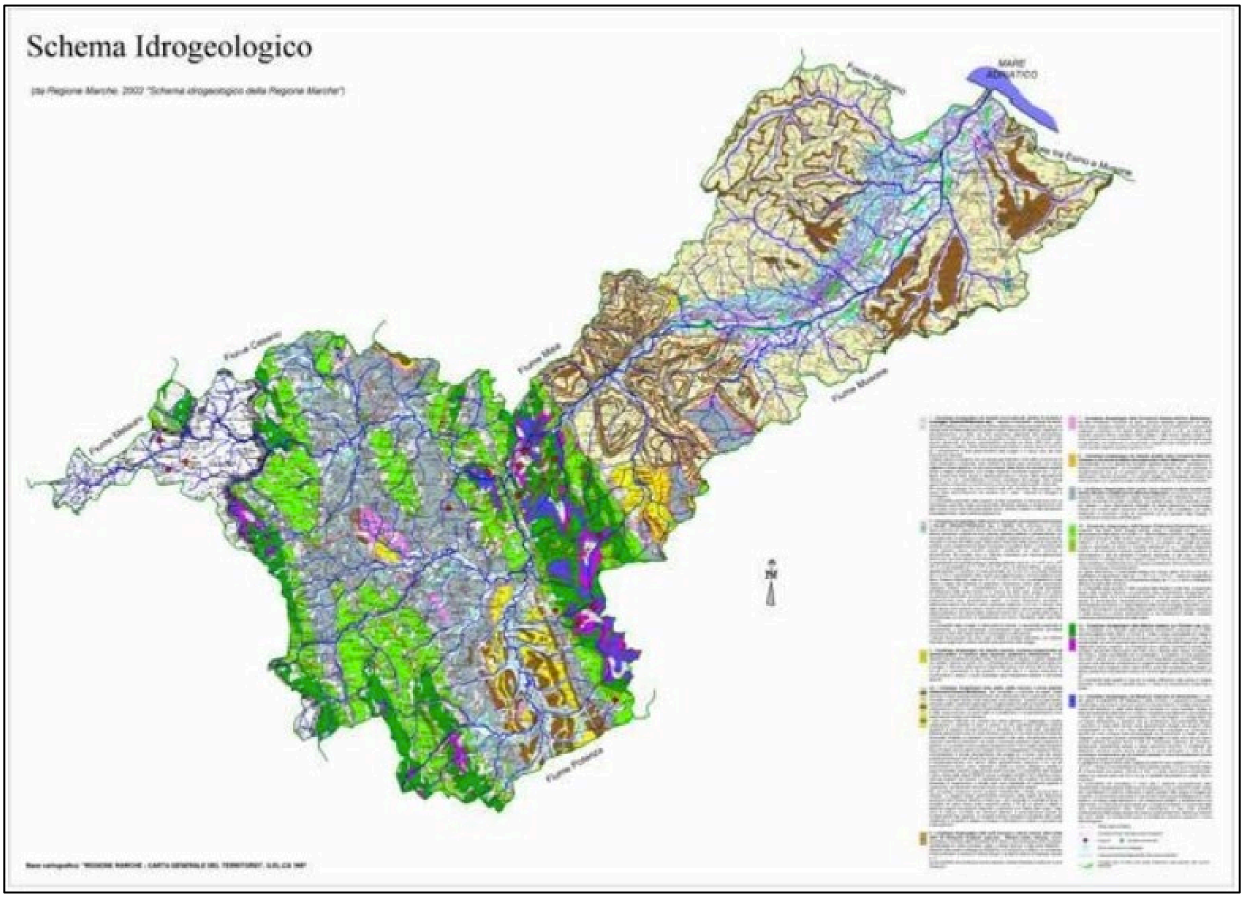

Figure 24 - Hydrological scheme of the Esino River basin (Piano Tutela acque Regione Marche 2008).

Areas designated for the protection of habitats and species

SIC e ZPS zones

The creation of the 2000 network with Special Areas of Conservation (ZSC) and Special Protection Areas (ZPS) satisfies a clear community obligation established in the framework of the United Nations Convention on Biological Diversity.

The "network" was structured based on two directives: n. 92/43 / EEC of the Council of 21 May 1992 on the conservation of natural and semi-natural habitats and wild flora and fauna, commonly known as the "Habitats" directive and the "Birds" directive (Dir. N. 79/409 / EEC) concerning the conservation of wild birds, replaced by Dir. 2009/147 / EC. "

In the downstream sector of the Esino river, within the catchment area, in Ripa Bianca, there is a Special Conservation Area (ZPS), which perfectly matches the Special Protection Area (ZSC), called " Fiume Esino in località Ripa Bianca" (Figure 25).

The area extends to 406 hectares and includes the Ripa Bianca Regional Nature Reserve in the province of Ancona. The ZPS-ZSC area is characterized by the river environment with riparian forests in a good state of conservation and by some humid areas of artificial origin.

The river geomorphological system is represented by the riverbed of the Esino river, with dynamics mainly conditioned by the presence of an ENEL traverse used for the derivation of water serving a hydroelectric plant, and by the alluvial plain, consisting of terraced Holocene and Pleistocene.

The vegetation on the banks of the river is characterized by a band of shrubby willows in the inner part of the river and by a tree band in the outer area with white willow, black poplar and white poplar.

The area represents the most important nesting, wintering and aestivation site for the aquatic avifauna of the region.

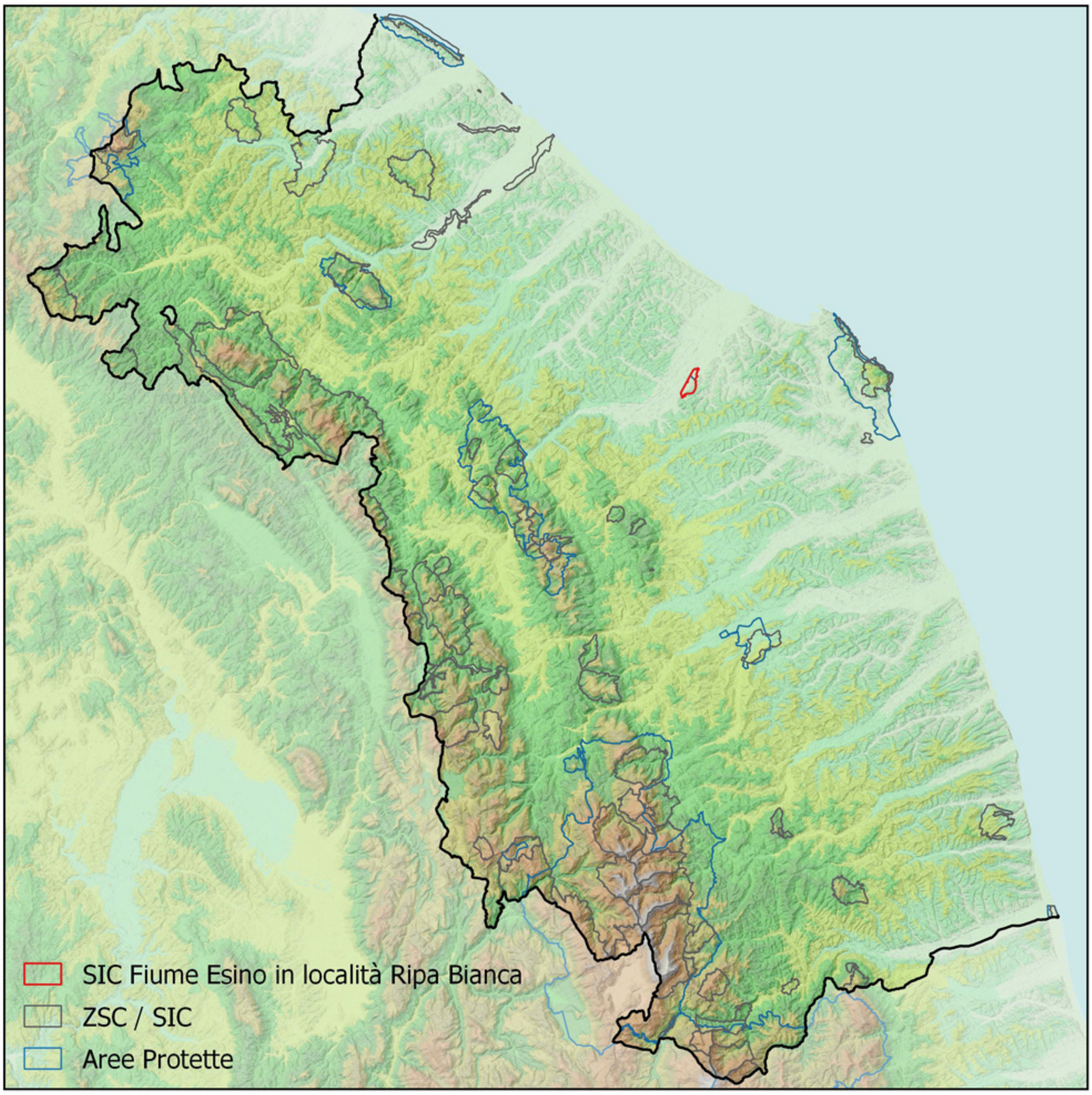

Figure 25 - Area ZSC / SIC Esino River in Ripa Bianca locality (Rete Natura 2000 Regione Marche).

Socio-economic characteristics: Estimation of the organic load and potential trophic load

The hydrographic area of the Esino extends for approximately 1299.44 square kilometres (approximately 13% of the regional territory) and is mainly characterized by the significant basin of the same name (89% of the territory).

The resident population in 2001 stood at 261,270 inhabitants (17.8% of the region) with a population density of 212 inhabitants per sq km (Figure 26), higher than the regional average (151 inhabitants / sq km). Density like the regional data can be found in the significant Esino basin (157 inhabitants / sq km).

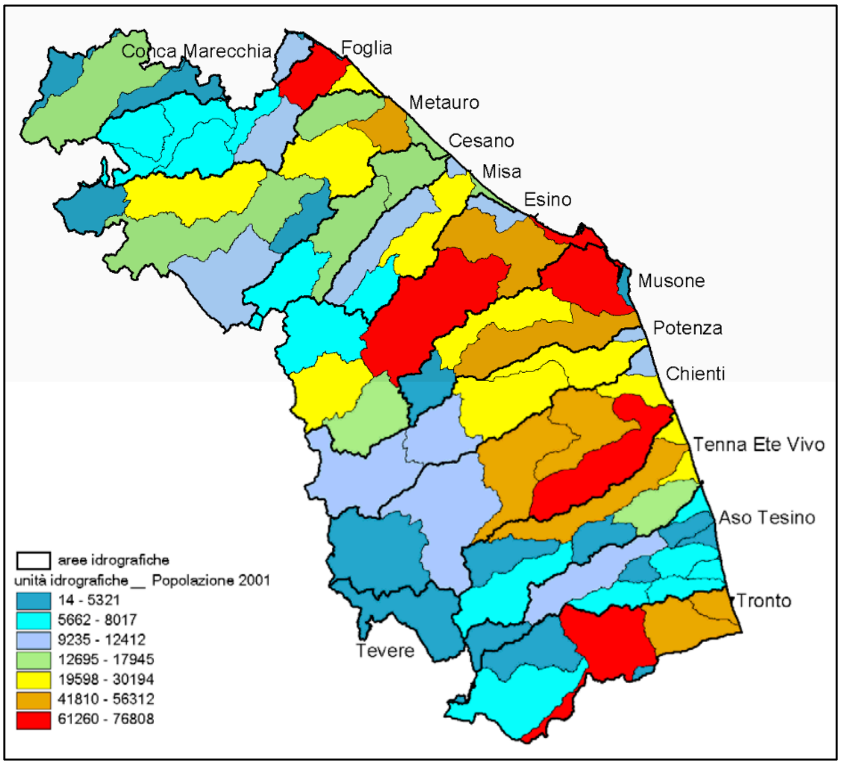

Figure 26 - The resident population in 2001: distribution in hydrographic units (Piano Tutela acque Regione Marche 2008).

As regards the characterization of land use, by comparing the percentages of land use of the four most significant macro-classes, the analysis carried out with the Corine Land Cover '90 elaboration reveals how the values of the hydrographic area and the significant basin do not deviate much from regional values (Figure 27). In the urban area: 2.9-2.4% hydrographic area-Esino basin versus 2.3% regional; arable land: 34.8- 36.2% against 33.9% regional; crops: 28.0-29.9% against 31.6% regional; woods-pastures: 25.6-28.4% against 29.4% regional.

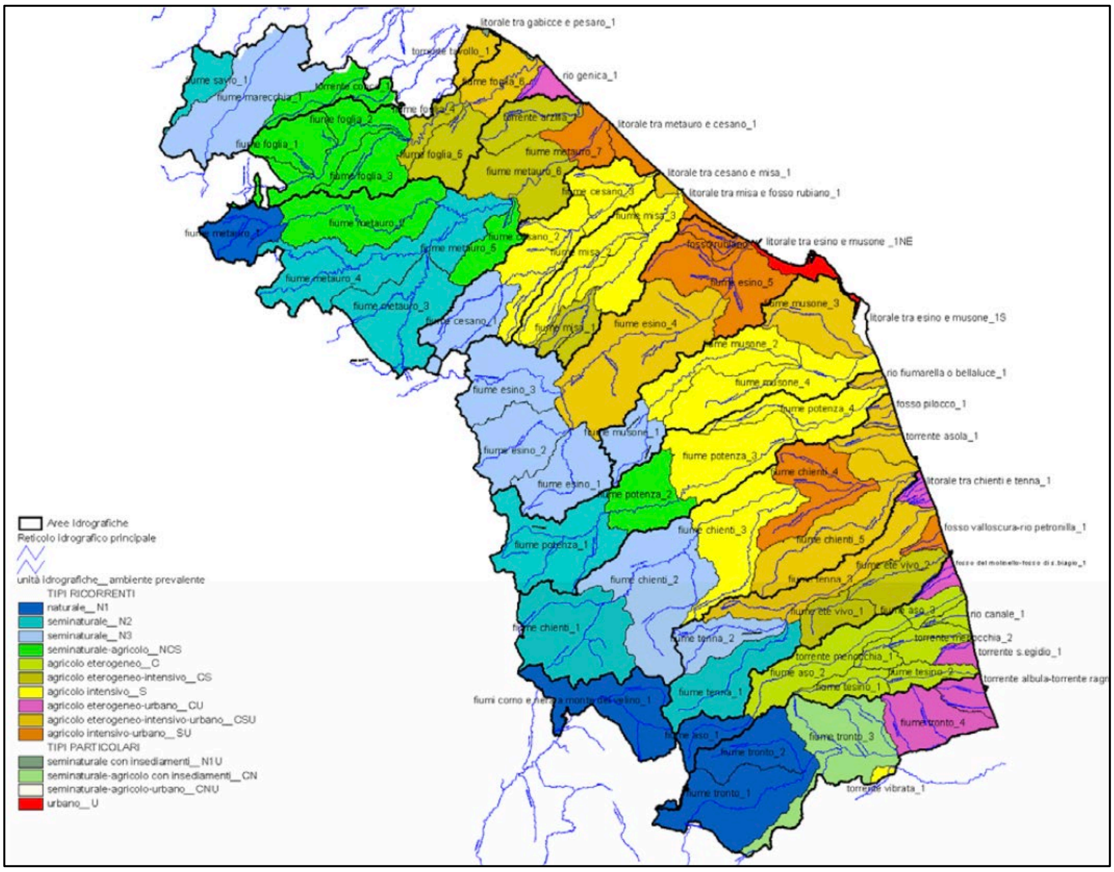

Figure 27 - The typing of hydrographic units concerning the dominant characters of land use. Corine Land Cover 2000 (Piano tutela acque Regione Marche 2008).

The estimated potential organic load in the hydrographic area can be estimated at 1,410,805 Equivalent Inhabitants, who represent about 19.1% of the regional load.

In the characterization concerning production sources both in the hydrographic area and in the Esino, percentages higher than the regional data relating to the zootechnical source are

highlighted: 44-49% against 38%. Values lower than the regional one regarding both the industrial component: 38-35% against 42%, and the civil component: 19-15% against 20%.
The AbEq / territorial surface ratio of 1,086 in the hydrographic area and 1,038 in the significant basin, is higher than the regional value of 761. The AbEq / resident population ratio is similar: 5.4-6.6 versus 5.0.
The high territorial density found in the Esino-Musone NE coast should be highlighted: 4,946 AbEq / Kmq.
The estimated potential trophic load in the hydrographic area can be estimated at 8,754 tons/year of nitrogen and 4,733 tons/year of phosphorus, respectively equivalent to 14.8% and 14.2% of the regional total. In the characterization concerning production sources, both in the case of nitrogen and phosphorus, the percentages of hydrographic area and basin are similar to the regional ones. Nitrogen: about 13-17% for the point source (civil industrial), 83-87% for the widespread (agricultural-zootechnical) source; Phosphorus: about 2-3% for the point source, 97% for the diffuse source (Figure 28).

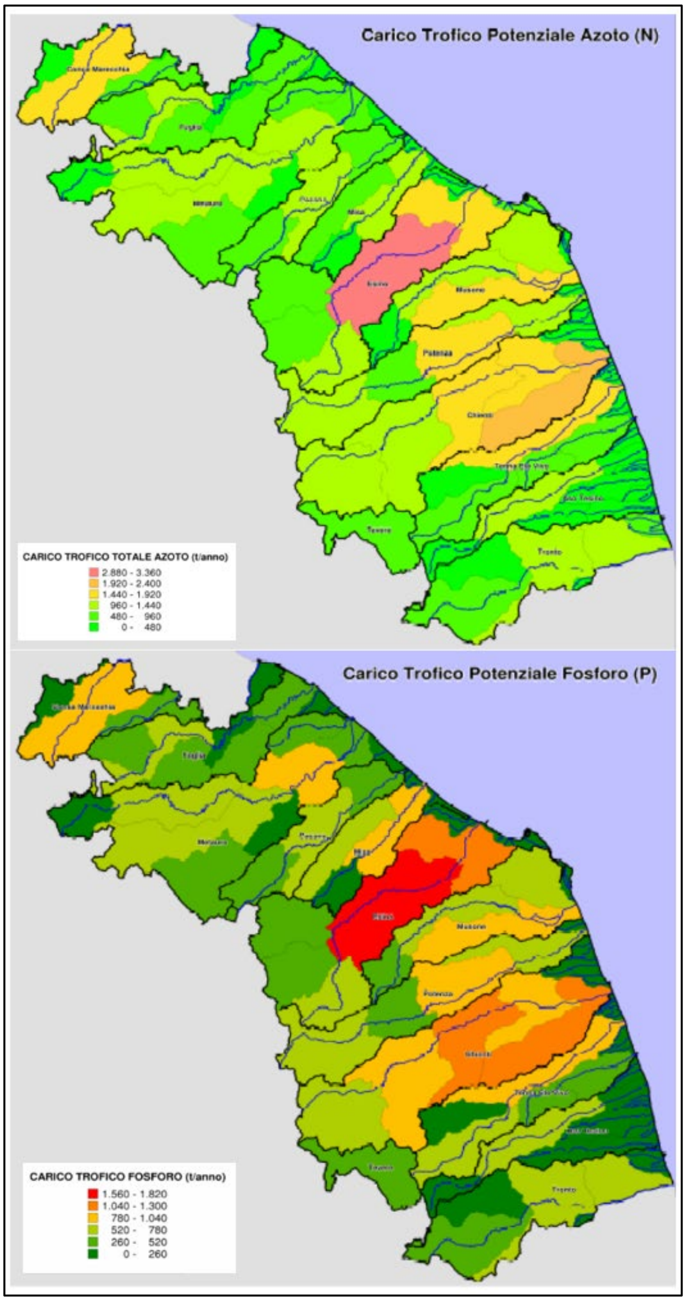

Figure 28 - The potential trophic load (nitrogen and phosphorus) in the hydrographic units (Piano Tutela acque Regione Marche 2008).

Water quality monitoring in Marche Region

The monitoring of river water bodies, by the Marche Regional Agency for Environmental Protection (ARPAM), is carried out following Legislative Decree 152/06 ss. mm. and ii., updated by Legislative Decree 172/2015, which incorporates the criteria defined by Directive 2000/60/EC and Directive 2013/39/EU, modifying the basic setting of environmental quality monitoring of inland waters both in terms of approach and setting.

The general purposes are the prevention and reduction of pollution and the rehabilitation of surface and underground water bodies, and the protection and improvement of strictly aquatic ecosystems. By focusing on annexed wetlands and terrestrial ecosystems dependent on aquatic environments themselves, together with sustainable water use aimed at long-term protection of available water resources that can help mitigate the effects of floods and drought.

ARPA MARCHE carries out, on behalf of the Marche Region, the monitoring of the 185 identified and typified river water bodies. The ARPAM monitoring network is made up of 124 sampling stations, 6 stations were used to assess the qualitative state of the downstream stretch of the Esino river (Figure 29).

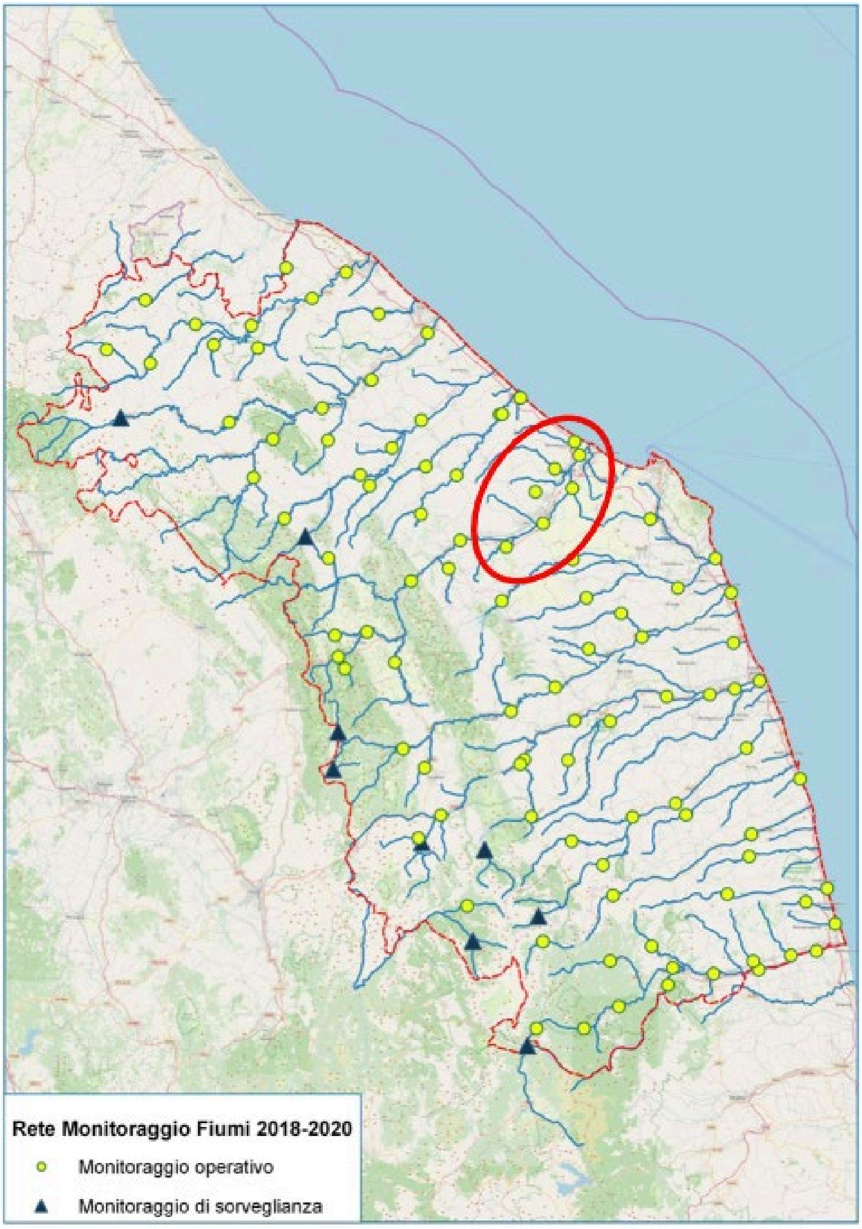

Figure 29 - ARPAM river water bodies monitoring network in period 2018-2020. The red circle highlights the 7 stations examined.

The D.M. 260/2010 provides for the definition of the chemical status and ecological status of natural water bodies and the ecological potential for artificial or heavily modified ones.
To classify the ecological status and the chemical status of river water bodies, the Ministerial Decree 260/2010 provides for the monitoring of biological quality elements, and physical, chemical, chemical and hydromorphological parameters.
In detail, the monitoring of the indicators from the legislation, carried out by ARPAM, has the purpose of evaluating the quality status of the river water body by determining: biological indicators; physical-chemical parameters; priority and non-priority chemicals.
The ecological state expresses the quality of the structure and functioning of the aquatic ecosystem through the monitoring of a series of indicators that come biological, chemical, physicochemical and hydromorphological representative of the different conditions of the river ecosystem. In detail, the biological elements analyzed are macroinvertebrates, diatoms, macrophytes, and fish fauna.
The monitoring of the Physico-chemical parameters, of the priority substances (table 1/A) and non-priority substances (table 1/B) was carried out on a quarterly, bimonthly or monthly basis depending on the characteristics of the monitoring site.
The ecological status is expressed in 5 quality classes: high, good, sufficient, poor, and bad, which represent a progressive departure from the reference conditions corresponding to the undisturbed state.
The chemical state is classified based on the presence of the priority chemical substances identified by the legislation (heavy metals, pesticides, industrial pollutants, etc.) in concentrations higher than environmental quality standards; the chemical state is evaluated in two classes, good and not good.
The definition of good chemical status of internal surface water bodies is defined based on compliance with the SQA defined for each substance referred to in table 1/A of Legislative Decree 172/2015. The SQA established for the substances in the priority list are expressed as an annual average (SQA-MA) and/or as maximum allowable concentrations (SQA-CMA). The chemical status can be classified as good/not good based on meeting or exceeding the SQA.
The results of the monitoring contribute to the definition of the ecological status and the chemical status.

Monitoring of river bodies located downstream of the Esino river

The results obtained from the monitoring carried out in the last three years will be shown below, and compared with the previous results, for the 6 stations examined for the characterization of the water quality downstream of the Esino river (Figure 30; ARPAM, 2021). Table 3 shows the coordinates in Gauss Boaga.

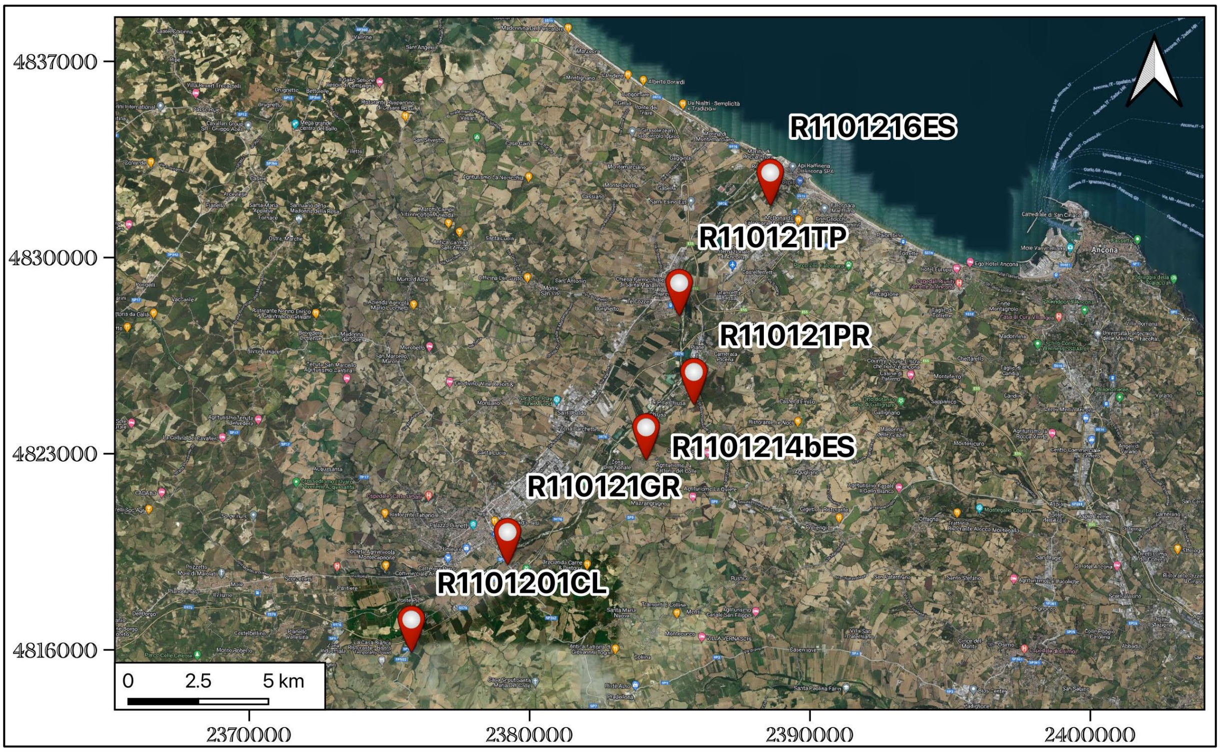

Figure 30 - Stations examined for the characterization of the water quality downstream of the Esino river.

Table 3 - The coordinates of the stations.

Station	Long X (m)	Lat Y (m)
R1101216ES	2388576.00	4833340.00
R110121TP	2385327.00	4829404.00
R110121PR	2385851.00	4826226.00
R1101214bES	2384146.00	4824249.00
R110121GR	2379203.00	4820513.00
R1101201CL	2375773.00	4817389.00

R1101216ES station

R1101216ES
Water body gainable macrotype: M2/Mc
Type: 12SS4F
Hardly changed water body
STATION: R1101216ES
x: 2388576 y: 4833340
Municipality: Falconara Marittima
Locality: Fiumesino mouth

The station is located near the mouth in Fiumesino (altitude 5 m a.s.l.), at a distance of about 75 km from the source. The watercourse has a very wide riverbed, a moderate current speed and a substrate mainly consisting of mud, sand and gravel. At this level, the river no longer presents the succession of mesohabitat pool and riffle but flows in a large run which, in terms of depth and type of flow, is closest to the characteristics of a pool. Peripheral vegetation is hygrophilous and well-diversified. The site is located near the API refinery which is located on the hydrographic right and the surrounding area is the man-made one of the coastal strips.
Figure 31shows the results obtained from the monitoring activity.

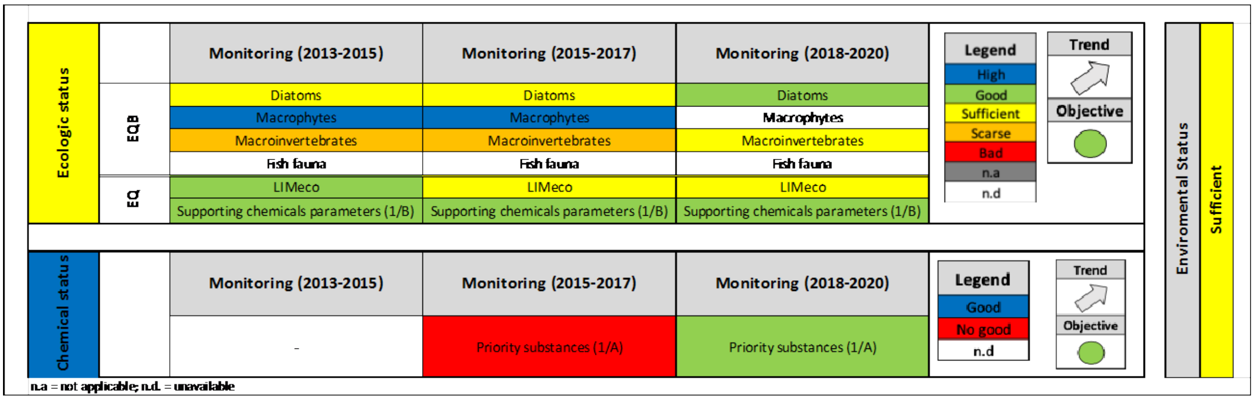

Figure 31 - Results obtained from the monitoring activity in the R1101216ES station (data from ARPAM).

The sufficient ecological status is determined by the state of the macrobenthic community and the chemical-physical parameters (limeco) and is improved compared to the previous monitoring cycle.
The objective of sufficient ecological quality has been achieved.
Both macroinvertebrates and chemical-physical parameters (limeco) have a sufficient quality class, with a stable trend for limeco and increasing for macroinvertebrates. They determine the overall class of the ecological status.
Diatoms improved the quality class from sufficient to good.
No criticalities were found in the monitoring of priority chemicals and therefore the water body is attributed to a good chemical status.
The objective of good chemical quality has been achieved.
In detail, we analyze:

- Pressures analysis 2019

Point pressures	Widespread pressures	Hydromorphological pressures
Contaminated sites	Urban washing	Physical alteration
	Agricultural use	Dams, barriers and locks
		Other alterations

- Pollution by organic and microbiological load

	2018	2019	2020
COD (avarage values mg/l)	11	12	n.d.
Escherichia coli (average values U.F.C./100 ml)	10183	2,185	2168

- Chemical pollution: Presence of pesticides

R110121TP station

N.D.	R110121TP Water body gainable macrotype: M1/Ma Type: 12SS2T Natural water body Station: R110121TP X: 2385327 y: 4829404 Municipality: Chiaravalle Location: Bridge of the cycle path

The station is located on the shaft of the Triponzio stream, downstream of the town of Chiaravalle (altitude 25 m a.s.l.), after the canalized section, at a distance of about 20 km from the source. At this point, the stream has already received the waters of the tributary Fosso Guardengo and shortly afterwards it flows into the Esino River.
The Triponzio stream flows in an area mainly used for agricultural purposes, but it also flows near some industrial areas (Ostra, Monte San Vito).
Figure 32 shows the results obtained from the monitoring activity.

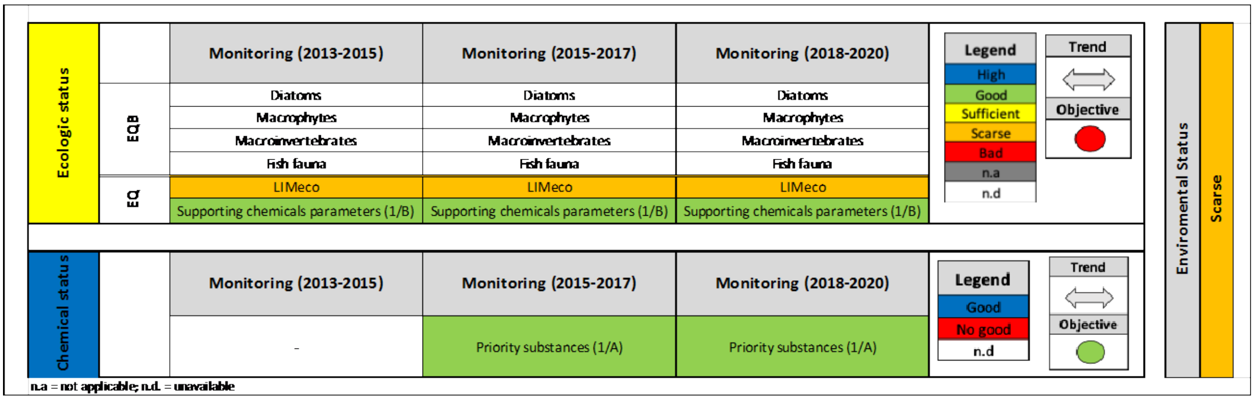

Figure 32 - Results obtained from the monitoring activity in the R110121TP station (data from ARPAM).

The water body is characterized by poor ecological quality and is unchanged compared to the previous monitoring cycle. The goal of good ecological quality is foreseen for 2027; at the moment it has not been achieved.

The chemical-physical parameters (limeco) stably show a poor quality class.

It is one of the sites with a limeco lower than the sufficient class, consequently, the monitoring of biological indicators was not conducted pending the observation of positive changes in the limeco (as required by the ISPRA guideline n.116 / 2014).

No criticalities were found in the monitoring of priority chemicals and therefore the water body is attributed to a good chemical status.

The objective of good chemical quality has been achieved.

In detail, we analyze:

- Pressures analysis 2019

Point pressures	Widespread pressures	Hydromorphological pressures
	Agricultural use	

- Nutrient pollution

	2018	2019	2020
Nitrate (avarage values mg/l)	47	25	71

- Pollution by organic and microbiological load

	2018	2019	2020
COD (avarage values mg/l)	26	12	n.d.
Dissolved Oxygen (%)	68	68	n.d.
Escherichia coli (average values U.F.C./100 ml)	229620	7,967	n.d.

- Chemical pollution: Presence of pesticides and metals

R110121PR station

R110121PR
Water body gainable macrotype: M5
Type: 12IN7T
Natural water body
Station: R110121PR
X: 2385851 Y: 4826226
Municipality: Camerata Picena
Location: Le Piane, via S. Giuseppe

The Pratacci ditch is a short stream that crosses the territories of the municipalities of Polverigi, Agugliano and Camerata Picena where, in the locality of Le Piane, it flows into the Esino river. Its waters are taken for irrigation purposes and its basin acts as a receptor for numerous discharges from industrial settlements.

The monitoring station is located not far from the confluence with the Esino river, in the locality of Le Piane.

Figure 33 shows the results obtained from the monitoring activity.

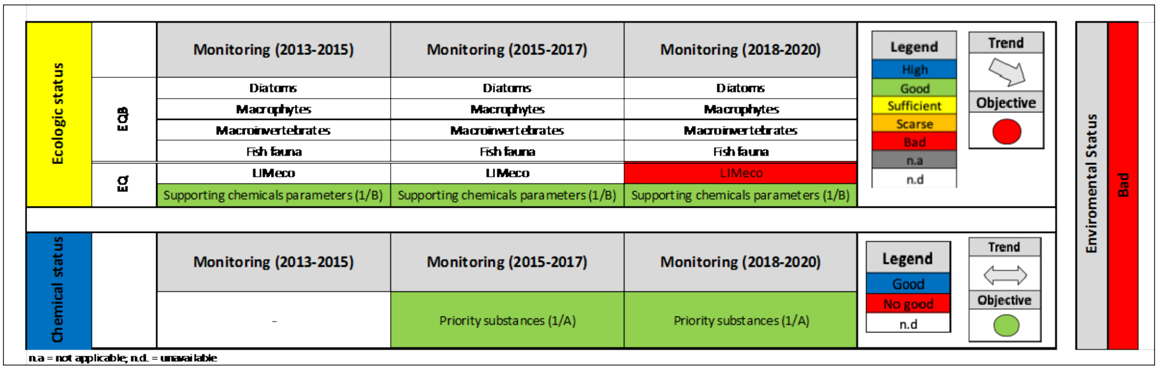

Figure 33 - Results obtained from the monitoring activity in the R110121PR station (data from ARPAM).

The water body is characterized by poor ecological quality. In the previous monitoring cycle, the water body was not directly monitored, and the ecological status class was obtained by merging. The goal of good ecological quality has not been achieved.

It is one of the sites with a limeco lower than the sufficient class, consequently, the monitoring of biological indicators was not conducted pending the observation of positive changes in the limeco (as required by the ISPRA guideline n.116 / 2014).

No criticalities were found in the monitoring of priority chemicals and therefore the water body is attributed to a good chemical status.

The objective of good chemical quality has been achieved.

In detail, we analyze:

- Pressures analysis 2019

Point pressures	Widespread pressures	Hydromorphological pressures
Spillways	Agricultural use	Physical alteration

- Nutrient pollution

	2018	2019	2020
Nitrate (avarage values mg/l)	19	41	86
Total phosphorus (avarage values mg/l)	0.86	0	0

- Pollution by organic and microbiological load

	2018	2019	2020
COD (avarage values mg/l)	46	17	n.d.
Dissolved Oxygen (%)	43	67	62
Escherichia coli (average values U.F.C./100 ml)	3650	18,100	5033

- Chemical pollution: Presence of pesticides and metals

R1101214bES station

R1101214bES
Water body gainable macrotype: M2/Mc
Type: 12SS4F
Natural water body
Station: R1101214bES
X: 2384146 Y: 4824249
Municipality: Agugliano
Location: La Chiusa

The station is located at 40 m a.s.l., at a distance of about 65 km from the source. In this section, the active riverbed widens considerably. The section of the wet riverbed is natural, with a bottom mainly made up of pebbles and gravel.
Peripheral vegetation is natural on both sides. The site is located downstream of the 60000 A.E.
The territory is mainly used for agricultural practices and animal breeding.
Figure 34 shows the results obtained from the monitoring activity.

Ecologic status		Monitoring (2013-2015)	Monitoring (2015-2017)	Monitoring (2018-2020)
	EQB	Diatoms	Diatoms	Diatoms
	EQB	Macrophytes	Macrophytes	Macrophytes
	EQB	Macroinvertebrates	Macroinvertebrates	Macroinvertebrates
	EQB	Fish fauna	Fish fauna	Fish fauna
	EQ	LIMeco	LIMeco	LIMeco
	EQ	Supporting chemicals parameters (1/B)	Supporting chemicals parameters (1/B)	Supporting chemicals parameters (1/B)

Legend
High
Good
Sufficient
Scarse
Bad
n.a
n.d

Trend	Objective
⟺	●

Chemical status	Monitoring (2013-2015)	Monitoring (2015-2017)	Monitoring (2018-2020)
	-	Priority substances (1/A)	Priority substances (1/A)

Legend
Good
No good
n.d

Trend	Objective
⇨	●

Enviromental Status
Bad

n.a = not applicable; n.d. = unavailable

Figure 34 - Results obtained from the monitoring activity in the R1101214bES station (data from ARPAM).

Sufficient ecological status is determined by the state of the biological communities investigated and by the chemical-physical parameters (lieco) and does not show class variations compared to the previous monitoring cycle.
The objective of sufficient ecological quality is foreseen for 2027; at the moment it has been achieved.
Biological indicators and chemical-physical parameters (limeco) have a sufficient quality class.
The trend is stable for macroinvertebrates and limeco, decreasing for diatoms.
In the year 2020, a maximum concentration value was detected for the mercury parameter (0.08 µg/l) higher than the SQA-CMA (0.07µg/l).
Consequently, the objective of good chemical quality was not achieved.
In detail, we analyze:

- Pressures analysis 2019

Point pressures	Widespread pressures	Hydromorphological pressures
Urban drains	Urban washout	
Contaminated sites	Agricultural use	

- Pollution by organic and microbiological load

	2018	2019	2020
Escherichia coli (average values U.F.C./100 ml)	1475	1,440	2417

- Chemical pollution: Presence of pesticides.

R110121GR station

N.D.	R110121GR Water body gainable macrotype: M5 Type: 12IN7T Natural water body Station: R110121GR X: 2379203 Y: 4820513 Municipality: Location: via Roncaglia

The Granita stream is a short 13 km long stream. It was born on the slopes of Mount Morello (243 m) and, after having crossed the territories of Belvedere Ostrense and San Marcello and having received the waters of the Gorgolungo canal, on the outskirts of Jesi, it enters the Esino river.

The monitoring station is located not far from the confluence, in the last stretch where the stream is channelled.

Figure 35 shows the results obtained from the monitoring activity.

Ecologic status		Monitoring (2013-2015)	Monitoring (2015-2017)	Monitoring (2018-2020)
	EQB	Diatoms	Diatoms	Diatoms
	EQB	Macrophytes	Macrophytes	Macrophytes
	EQB	Macroinvertebrates	Macroinvertebrates	Macroinvertebrates
	EQB	Fish fauna	Fish fauna	Fish fauna
	EQ	LIMeco	LIMeco	LIMeco
	EQ	Supporting chemicals parameters (1/B)	Supporting chemicals parameters (1/B)	Supporting chemicals parameters (1/B)

Legend: High, Good, Sufficient, Scarse, Bad, n.a, n.d — Trend — Objective

Chemical status	Monitoring (2013-2015)	Monitoring (2015-2017)	Monitoring (2018-2020)
	-	Priority substances (1/A)	Priority substances (1/A)

Legend: Good, No good, n.d — Trend — Objective

Enviromental Status: Good

n.a = not applicable; n.d. = unavailable

Figure 35 - Results obtained from the monitoring activity in the R110121GR station (data from ARPAM).

The water body is characterized by good ecological quality. In the previous monitoring cycle, the water body was not directly monitored and the ecological status class was obtained by merging.
The goal of good ecological quality has been achieved.
The chemical-physical parameters (limeco) show a good quality class.
As this is a new monitoring site, there is no information relating to the trend.
No criticalities were found in the monitoring of priority chemicals and therefore the water body is attributed to a good chemical status.
The objective of good chemical quality has been achieved.
In detail, we analyze:

- Pressures analysis 2019

Point pressures	Widespread pressures	Hydromorphological pressures
Spillways	Urban washout	
Contaminated sites	Agricultural use	

- Nutrient pollution

	2018	2019	2020
Nitrate (avarage values mg/l)	16	36	52
Total phosphorus (avarage values mg/l)	0.36	0.21	0.12

- Pollution by organic and microbiological load

	2018	2019	2020
COD (avarage values mg/l)	37	19	n.d.
Escherichia coli (average values U.F.C./100 ml)	465942	17,000	9833

- Chemical pollution: Presence of metals

R1101201CL station

N.D.	R1101201CL Water body gainable macrotype: M1/Ma Type: 12IN7T Natural water body Station: R1101201CL X: 2375773 Y: 4817389 Municipality: Monte Roberto Location: Pian del Medico

The station is located less than 1 km from the confluence with the Esino river, in Pian del Medico (altitude 86 m a.s.l. at about 11 km from the source).

The surrounding area is mainly for agricultural and livestock use but the stream also flows close to some industrial activities often linked to the transformation of local products (oil, wine, milk). Figure 36 shows the results obtained from the monitoring activity.

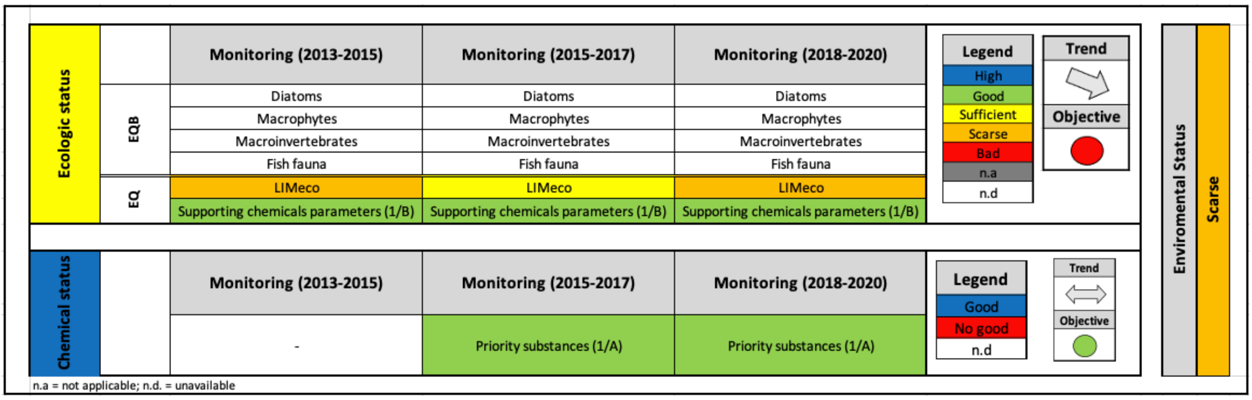

Figure 36 - Results obtained from the monitoring activity in the R1101201CL station (data from ARPAM).

The water body is characterized by poor ecological quality and has deteriorated compared to the previous monitoring cycle. The goal of good ecological quality is foreseen for 2027; at the moment it has not been achieved.

The chemical-physical parameters (limeco) worsened the quality class, passing from sufficient to poor.

It is one of the sites that in the previous period had a limeco lower than the sufficient class, consequently, the monitoring of biological indicators was not conducted pending the observation of positive changes in the limeco (as required by the ISPRA guideline n.116 / 2014).

No criticalities were found in the monitoring of priority chemicals and therefore the water body is attributed to a good chemical status.

The objective of good chemical quality has been achieved.

In detail, we analyze:

- Pressures analysis 2019

Point pressures	Widespread pressures	Hydromorphological pressures
	Agricultural use	

- Nutrient pollution

	2018	2019	2020
Nitrate (avarage values mg/l)	19	29	n.d.

- Pollution by organic and microbiological load

	2018	2019	2020
COD (avarage values mg/l)	17	17	n.d.
Escherichia coli (average values U.F.C./100 ml)	8375	6,975	n.d.

- Chemical pollution: Presence of metals

Discussion

We have seen how the waters of the Esino are strongly influenced and exposed to anthropic pollution, both of civil origin and agricultural/industrial origin.

Focusing on the downstream sector of the Esino river, the monitoring activities of the downstream sector through six ARPAM control points have shown how the waters of the Esino stretch of interest in the three years 2018-2020, compared to the previous three years, have kept a good chemical status and discreet ecological status. In detail, they have maintained a good chemical state due to the absence of pollutants beyond the regulatory thresholds, except for station R1101214bES due to the presence of mercury slightly above the threshold.

While ecological status should continue to be worked on to maintain or improve the status, several stations exhibit biological and chemical indicators ranging from poor to sufficient.

Ultimately, the waters of the stretch downstream of the Esino river, near the experimental site of Ancona, are of good quality from a chemical point of view and of good quality from an ecological point of view.

Jadro and Žrnovnica river, Split and Podstrana sites (Croatia)

Introduction

The Jadro and Žrnovnica rivers are streams that flow north of the Split test site and north of the Podstrana test site respectively (Figure 37). They are rivers that originate from the karst springs of Jadro and Žrnovnica which share the same catchment area.

The Jadro and Žrnovnica springs are located on the southwestern slopes of the Mosor and Kozjak mounts, in the contact zone between the carbonate sedimentary rocks of Splitska Zagora, with good permeability, and the coastal strip composed of flysch. The source of Jadro is 35 m above sea level while that of Žrnovnica is 90 m above sea level.

Precisely for this reason, the Jadro and Žrnovnica rivers, although adjacent to two different test sites, will be treated in a single chapter.

Figure 37 - Location of the Jadro and Žrnovnica rivers compared to the two Croatian test sites.

Description of the hydrographic basin

The catchment area of the Jadro and Zrnovnica springs before the 2000s had not been precisely defined, in fact, it varied between 300 and 500 km^2 depending on the authors (Bonacci, 1978) and (Fritz et al, 1988). This difficulty was encountered mainly due to the difficult definition of the hydrographic basins in the east and west limits, as the north and south boundaries of the basin are much easier to determine since the contact with impermeable sediments acts as a complete hydrogeological barrier.

According to more recent research (since 2000), and above all based on the results of the groundwater tracing tests, the hydrographic basins to the east and west of the catchment area of the Jadro and Zrnovnica springs have been redefined, determining the influence of the basins contiguous and the significant contribution of the contiguous rivers (Krka River from the west and the Cetina River from the east).

This is confirmed by the fact that the Žrnovnica spring, under natural conditions, was an intermittent spring, which dried up in periods of drought, but after the construction of dams on the Cetina River for HE Dale, it became a permanent spring.
The catchment area is mainly composed of carbonate, limestone and dolomitic rocks and flysch sediments, while other rocks are found more rarely. In the hydrogeological map of the catchment area, four main categories of rocks are distinguished based on their permeability (Figure 38; Kapelj, 2013):

- Carbonate rocks of the Permian, Mesozoic and partly Eocene - mainly permeable rocks (in dark green).
- Dolomite limestone rocks and Cenomanian dolomites and platey limestones from the Turonian period - moderately permeable rocks (in green),
- Clayey limestones of the Permian, Anisian dolomite, clastic rocks and breccias, marly limestones and calcareous marls of the Paleocene age - poorly permeable rocks (in light green).
- The clastic deposits of the Lower Triassic and Eocene flysch - impermeable rocks (in brown).

Furthermore, a subgroup of sedimentary rocks of alternating ownership has also been identified. These sediments originate from aerial erosion of source rocks or deluvional processes on the slope material. They contain silty-clayey materials with various limestone fragments.

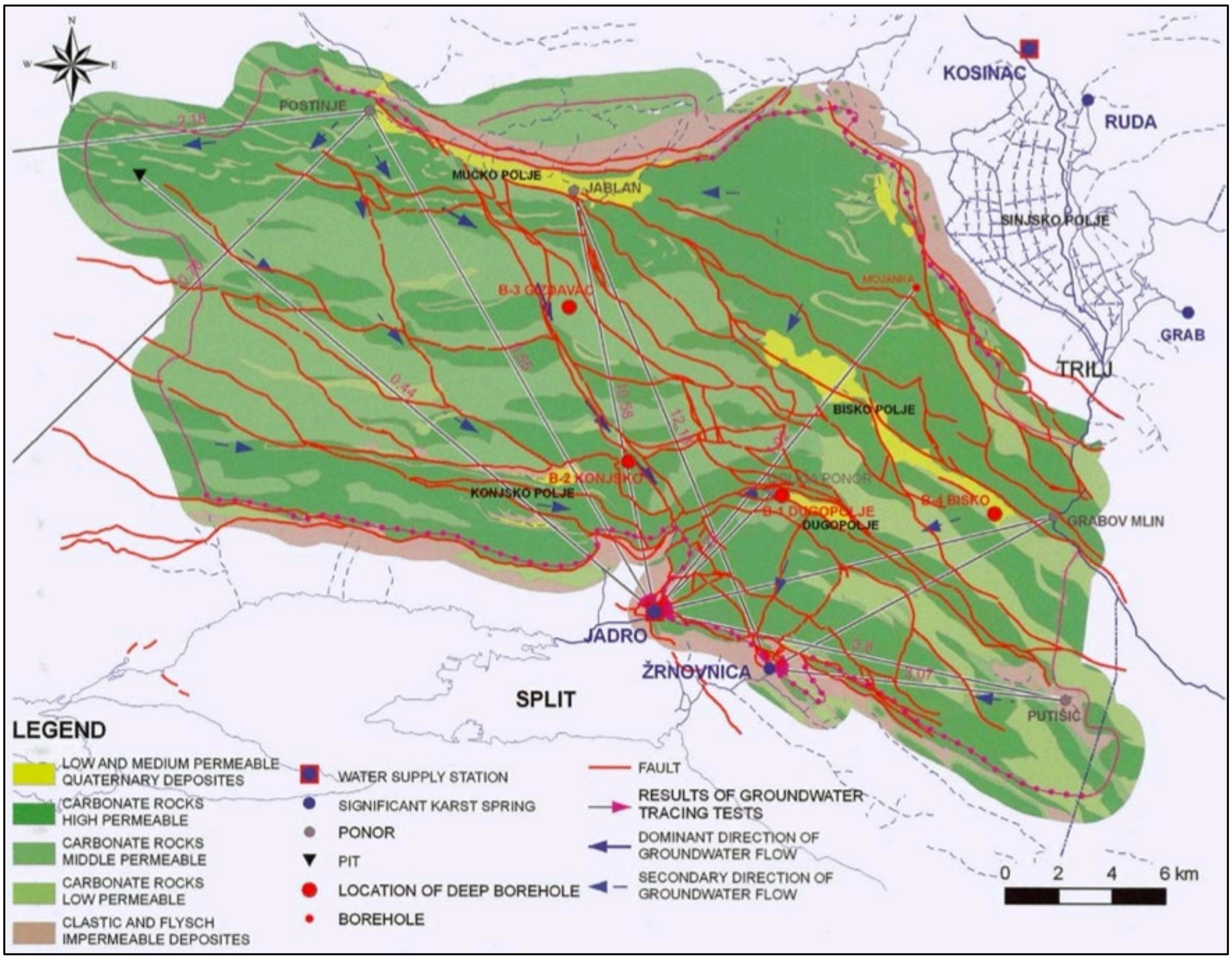

Figure 38 - Hydrogeologic map of the hydrographic basin Jadro and Žrnovnica springs (Kapelj, 2013).

In the interpretation of the Basic Hydrogeological Map of the Croatian Republic (Split and Primosten Sheets), Fritz and Kapelj (1998) provided a detailed description of the hydrogeological characteristics of the rocks observed in this area. A variety of different karst phenomena can be found in the catchment area. The sharp fracture of the ground paved the way for the intense karstification of the carbonate rocks. Perennial streams do not form on the carbonate bedrock, which means that all precipitation precipitates underground within a short period. In the parts of the basin where clastic rocks are present, there are intermittent surface water flows that converge rapidly in single sinkholes that occur in the karst poljes and then enter the horizontal circulation zones of groundwater kapelj et al. (2008).

Hydrology of the Jadro river

The Jadro spring is used for the water supply of Split, the surrounding settlements and the cities of Solin, Kastela and Trogir.

According to Kapelj et al., 2013, the minimum flow rate of the Jadro spring varies between 3.60 m^3/s (August 1995) and 3.90 m^3/s (September 1997, August and September 2003). And it is at its lowest level in the dry period, mainly in August and September, when the average monthly flow can decrease to just 4.0 m^3/s (August 1995 and September 2003). During the drought period, the withdrawal of water from the Jadro spring often exceeds the permitted 2.0 m^3/s, rising to 2.9 m^3/s, Kapelj et al. (2006).

The Jadro River flows from its source at the foot of Mosor through an alluvial valley and finally flows into the Adriatic Sea through the bay of Kaštela, near Split. The total length of the watercourse is 4.3 km (Figure 39). Several smaller streams and two larger tributaries, Poklinovac and Rupotina, contribute to the flowing discharge. However, the tributaries are generally torrential and, therefore, occasionally feed the Jadro, during the rainy season, bringing considerable quantities of sediments. During the summer, the Poklinovac and Rupotina streams are mostly dry.

The Jadro topographical basin is relatively small and covers about 22 km^2, although the current hydrological basin is probably much larger, its boundaries have not yet been reliably established. The complexity of the groundwater flow and the size of the basin guarantees the continuity of the river source throughout the year. The flow of the Jadro River is measured at the Majdan (hydrological) measurement station.

The average annual flow rate of the Jadro River measured at the Majdan station, as evidenced by Ljubenkov (2015), is 7.9 m^3/s (1961–2010), and the highest annual mean flow rate is 12.8 m^3/s (1970) and the minimum of 5.1 m^3/s (1983). Over a year there is a notable variation in the flow rate (Figure 40). Therefore, the largest flows occur from November to March, with averages above 10 m^3/s. The minimum monthly average flow rates are observed in summer (July, August and September) and reach values of 3.3 m^3/s, 2.9 m^3/s and 3.7 m^3/s respectively. It should be noted that even during the winter months relatively small flow rates can occur with monthly averages of less than 4 m^3/s (Ljubenkov, 2015).

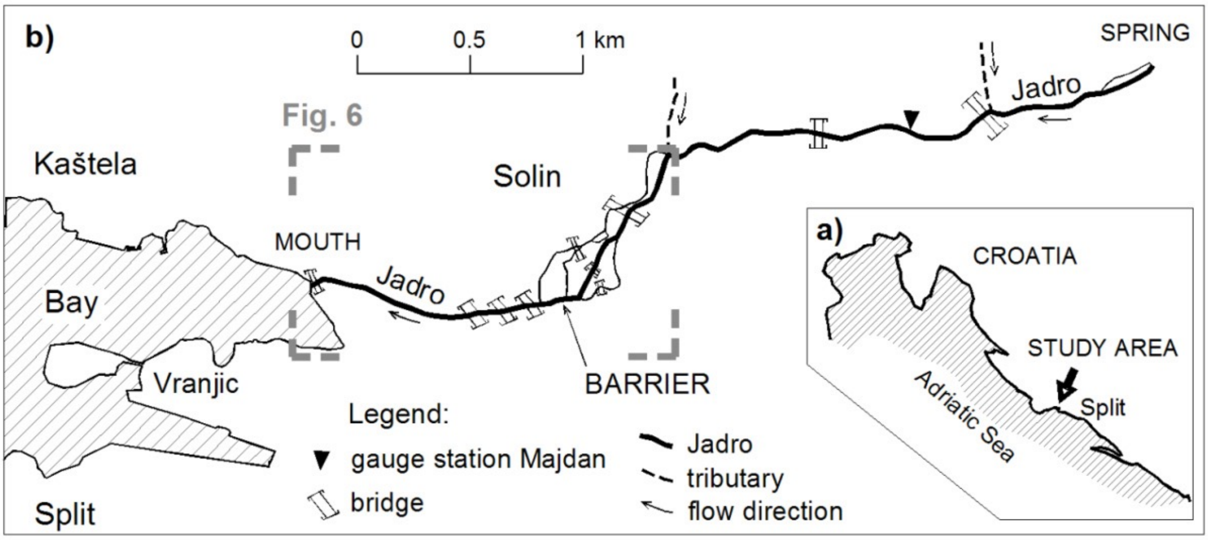

Figure 39 - Location map of the Jadro River (from Ljubenkov, 2015).

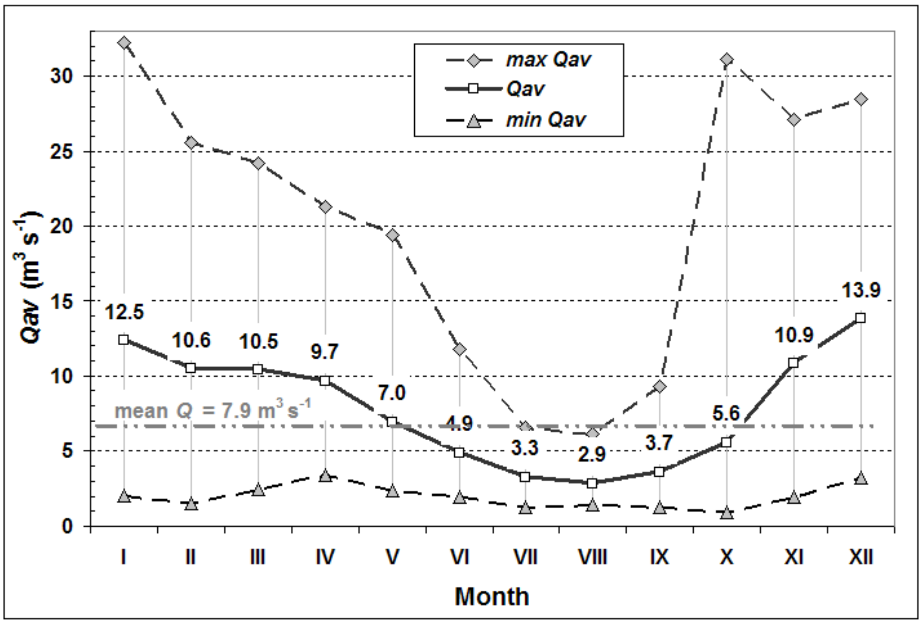

Figure 40 - Monthly discharges of the Jadro River at gauging station Majdan in the period 1961–2010 (form Ljubenkov, 2015).

Hydrology of the Žrnovnica river

The spring of Žrnovnica is used for the water supply of the village of Zrnovnica and the irrigation of agricultural areas.

The source of Žrnovnica joins several smaller springs that arise in the wider area, where the minimum measured flow rate of this spring area is up to 250 l/s (9 September 1993) while the maximum flow rate is up to 19, 1 m^3/s (18 December 2004).

The catchment area of the Žrnovnica River is located in the Dinaric Karst bare in the southern part of Croatia near Split. The maximum elevation in the relatively small basin is 1225 m above sea level (a.s.l.) and the average height of the basin is over 350 m a.s.l. The water emerges from a permanent karst spring at an altitude of 80 – 90 m a.s.l., depending on the level of the water table. Its canal is 5235 m long.

The catchment area of the Žrnovnica River consists mainly of carbonate rocks and partly of impermeable flysch. The carbonate layers differ in age, the lithological composition of the litter and structural-tectonic position. Quaternary sediments cover the lower basin, generally below 50 m a.s.l. Figure 41 shows the topographical boundary of the catchment area of the Žrnovnica River which has an area of 51.1 km^2. Using the hydrographic method of groundwater (Bonacci, 1987), the hydrogeological basin of the Žrnovnica karst spring is estimated at 40 km^2.

Along the watercourse, the morphology of the canal is extremely varied. The upper river is deep and narrow, in the middle portion it is wide (10 m on average) and relatively shallow with well-developed bedforms, basins and lateral bars (in this part of the river it has special habitat conditions important for the development and maintenance of the river and hydrographic biota) while near the sea the Žrnovnica river divides into several branches. The delta area is defined as the part of the catchment area downstream of this point (Valker, 1989). The Žrnovnica River Delta consists of fertile soil with nutrient-rich water bodies. The estuary provides the link between fresh water and the marine environment, making this small catchment area extraordinarily diverse from an ecological point of view.

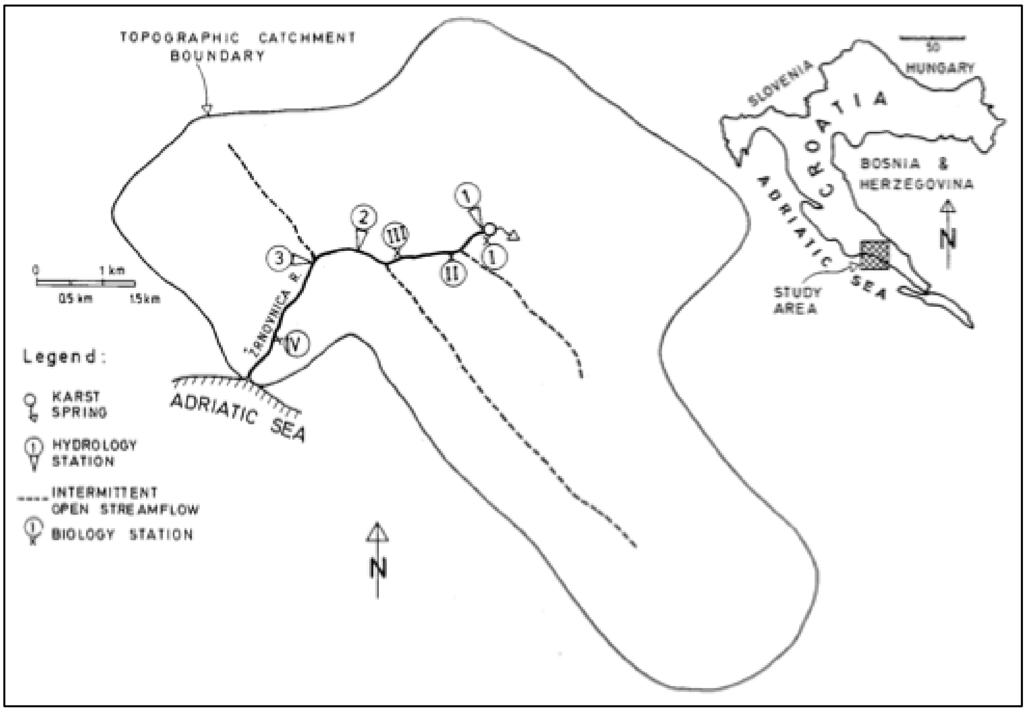

Figure 41 - Location map of the Žrnovnica River (from Bonacci et al., 1998).

There are three water level and flow measurement stations on the Žrnovnica River (Figure 41). Table II presents the characteristic discharges recorded between 1990 and 1994. The data shows the hydrological irregularity along the Žrnovnica river caused by karst phenomena. Less than 100 m downstream from measurement station 1 there is a sinkhole area where water is lost through the small karst crevices of the riverbed. After having drained the same water reappears about 100 m upstream of the measuring station 3. Consequently, the hydrological characteristics of measuring station 2 are critical for the determination of the maximum possible water extraction and the determination of ecologically acceptable flows.

Table 4 - Characteristic discharges recorded between 1990 and 1994 in 3 stations (Bonacci et al., 1998).

Gauging station	Discharge (m^3/s)		
	Minimum	Average	Maximum
1	0.201	1.64	11.3
2	0.146	1.58	31.1
3	0.320	1.80	42.0

The complexity of the hydrogeological situation caused by karst features along the Žrnovnica river is presented graphically in Figure 42.

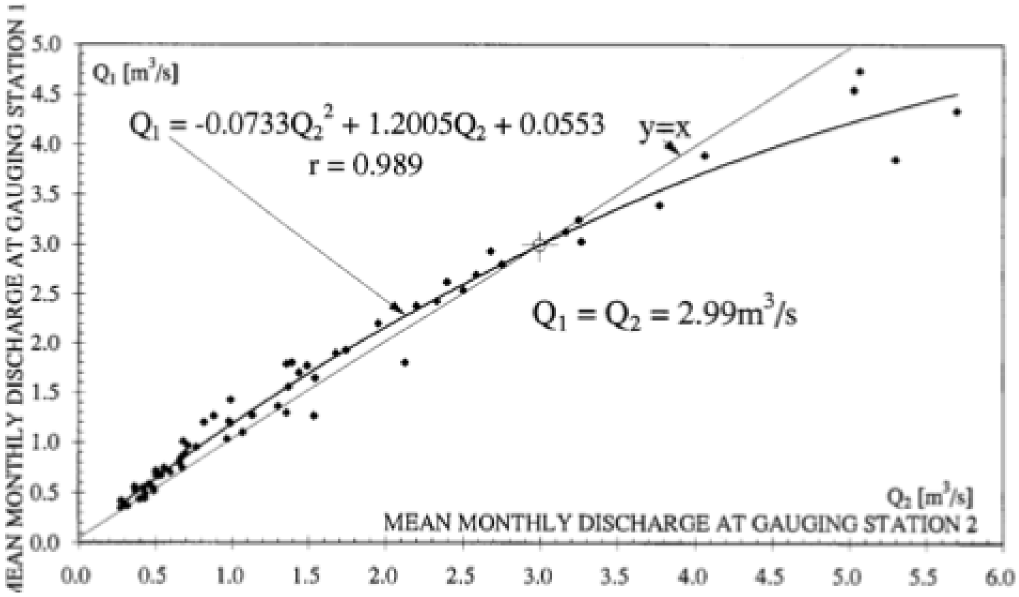

Figure 42 -Relationship between mean monthly discharge at gauging stations 1 and 2 (November 1989 - December 1994; from Bonacci et al., 1998).

The relationship between the monthly mean flows measured at measurement stations 1 and 2 is strong but hydrologically unusual. For spring discharges below 2.00 m^3/s, discharges at measurement station 1 are greater than at measurement station 2, downstream, due to water leaks through the sinkhole area. When the flow rate at station 1 is greater than 2.00 m^3/s, a generally normal hydrological situation arises, depending on the level of the water table. It should be remembered that the existence of water loss areas in open waterways in karst rivers can often complicate the determination of ecologically acceptable flows.

Hydrogeochemistry of the downstream waters of the Jadro and Žrnovnica rivers

By comparing the geochemical characteristics of water sampled in the downstream portion of the Jadro and Žrnovnica rivers, through qualitative diagrams (Piper), the different chemical facies were identified, including the dominant one. In Figure 43 the results obtained by results obtained from the monitoring of downstream waters for the Jadro and Žrnovnica rivers carried out throughout 2018 monthly, which highlighted how the waters of the Jadro and Žrnovnica rivers belong to the pure carbon-bicarbonate facies. Results are in full agreement with the geology of the area and above all the nature of the rivers, which originate from karst springs.

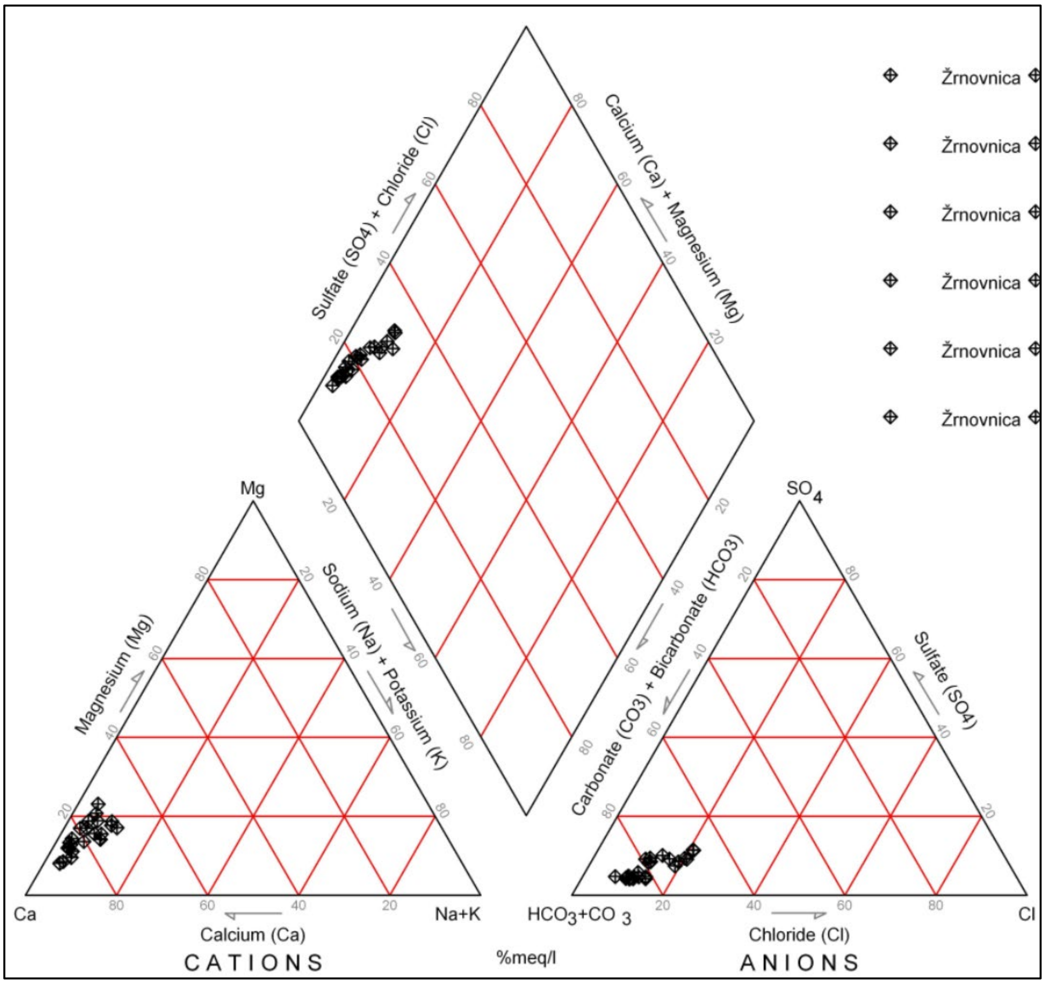

Figure 43 - Piper diagram shows the geochemical composition of the different Jadro and Žrnovnica rivers water samples.

Monitoring of river bodies located downstream of the Jadro and Žrnovnica rivers

The results obtained from the monthly monitoring carried out from January 2019 to May 2021 will be shown below for the 2 stations examined for the characterization of the water quality downstream of the Jadro and Žrnovnica rivers (Figure 45).

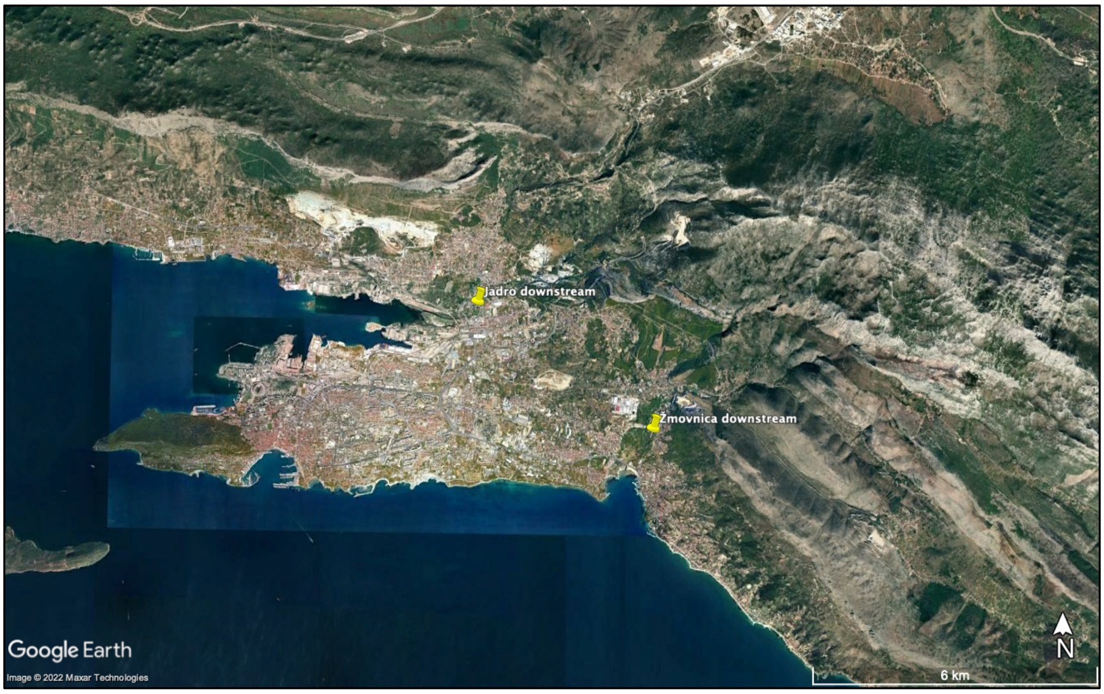

Figure 44 - Stations examined for the characterization of the water quality downstream of the Jadro and Žrnovnica rivers.

For the qualitative status of the waters belonging to the Jadro and Žrnovnica rivers, various chemical and biological parameters were monitored. The results of the main chemical and biochemical parameters, ions and indicators will be shown below.
The pH varies from values of 7 to 8 (Figure 46) following the geochemical nature of the water which presents itself with pure calcium bicarbonate facies, with a seasonal trend that generally follows the values of the water temperature (Figure 47).
They are oxygenated waters with dissolved oxygen values that vary a lot with seasonality and in different years, quite close to 9 to 14 mg/L, testifying that being waters of karst origin they are influenced by the amount of precipitation that supplies the waters of oxygen (Figure 48).
The electrical conductivity values, visible in Figure 49, are also very low with seasonal average values of about 400 uS/cm with a well-defined trend, values around 450 uS/cm in winter and values of 350 uS/cm in summer. The increase in electrical conductivity is hypothesized with the

increase of dissolved calcium in the water due to the dissolution of carbonates by rain in the wettest periods. In addition, slightly higher electrical conductivity values are recorded for the Žrnovnica river.

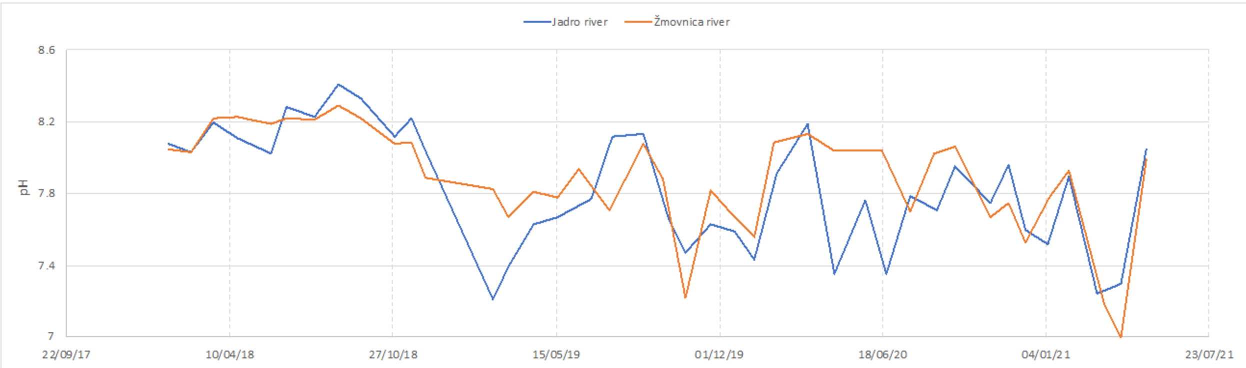

Figure 45 - Trend of pH values in the two monitoring stations for the period 2018-2021. In blue are the Jadro river values and in orange are the Žrnovnica values.

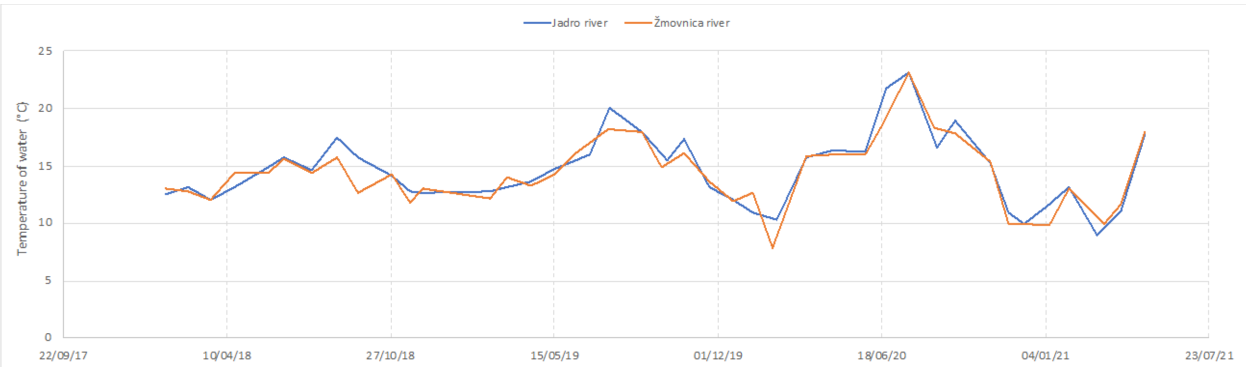

Figure 46 - Trend of temperature values in the two monitoring stations for the period 2018-2021. In blue are the Jadro river values and in orange are the Žrnovnica values.

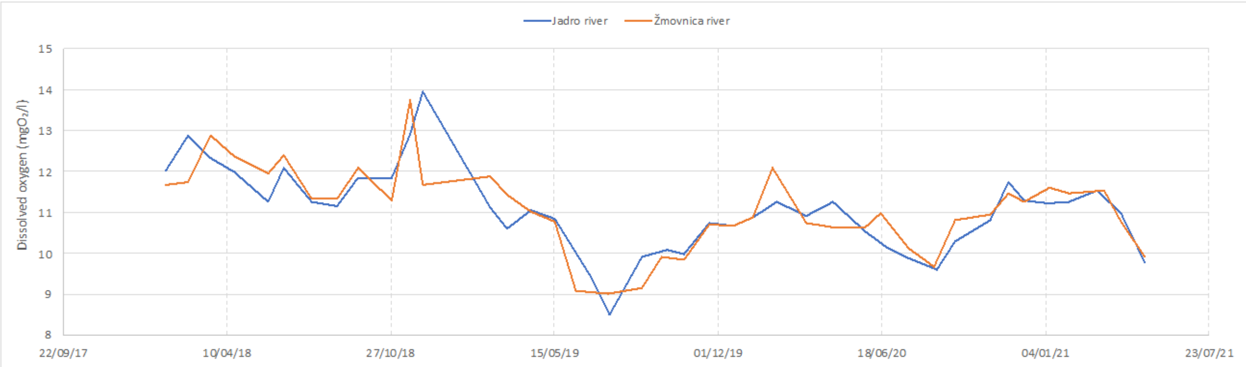

Figure 47 - Trend of dissolved oxygen values in the two monitoring stations for the period 2018-2021. In blue are the Jadro river values and in orange are the Žrnovnica values.

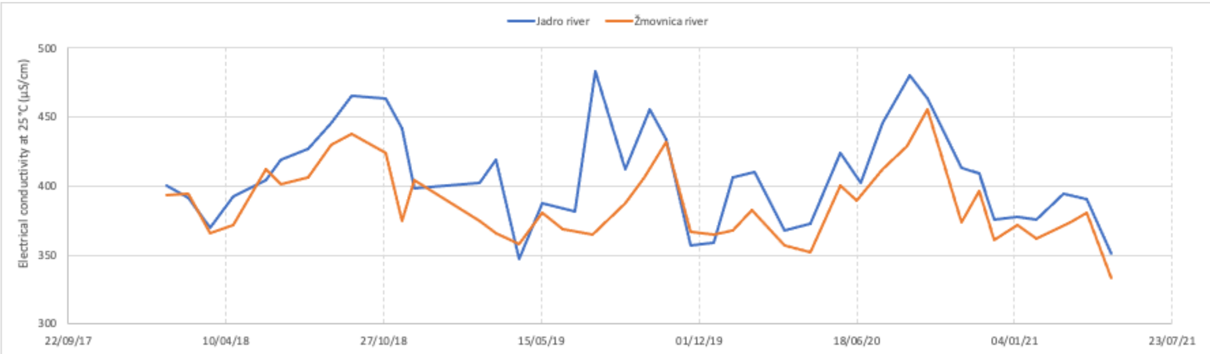

Figure 48 - Trend of electrical conductivity values in the two monitoring stations for the period 2018-2021. In blue are the Jadro river values and in orange are the Žrnovnica values.

To assess the effect of pollutants both related to society and agriculture/industry, the chemical and biochemical parameters were examined to investigate the temporal trend throughout the monitoring period.

The first two parameters analyzed specifically are:

- BOD_5 (Biochemical Oxygen Demand) indicates the oxygen requirement of water to oxidize the degradable organic substances present in it, by aerobic microorganisms. The greater the pollution to be removed, the more oxygen is needed.
- COD (Chemical Oxygen Demand) indicates the oxygen requirement necessary to chemically oxidize the oxidizable organic and inorganic substances present in a water sample. The quantity

of oxidant consumed is expressed in mg/l of oxygen and is proportional to the concentration of organic and inorganic substances oxidized under the conditions of the method.

The determination of COD is recommended as a complement to the determination of BOD_5, which is the only one capable of indirectly indicating the concentration of the biodegradable organic substance.

BOD_5 and COD are important because they are related to the amount of oxygen. If water is not very polluted, it has a good level of dissolved oxygen. Purification, aimed at condensing the natural self-purification processes typical of receiving water bodies in space and time, consists of the elimination of pollutants (which subtract oxygen), and the release of the oxygen itself used as fuel by aerobic microorganisms for the decomposition of pollutants suspended in stable elements (carbon dioxide, gaseous nitrogen).

In the absence of oxygen, anaerobic putrefactive phenomena are triggered with the transformation of pollutants into ammonia, phosphoric acid, and hydrogen sulphide: harmful and noxious substances that affect possible uses of water.

By analyzing in detail, the temporal trend of the values of BOD_5 and COD in Figure 50, it is noted that the waters of both rivers have very low values, far below the legal limits, defining a low type of pollution. biochemist. Furthermore, it is observed that both values from 2018 to 2021 show an important downward trend over time, this indicates a marked improvement in the waters of the Jadro and Žrnovnica rivers from a biochemical point of view.

Figure 49 - Trend of BOD_5 and COD values in the two monitoring stations for the period 2018-2021. In blue are the Jadro river values and in orange are the Žrnovica values.

Further parameters carefully analyzed are nitrogen and total phosphorus.
The main sources are identified in the agricultural and livestock sectors and, concerning phosphorus, the most significant contributions of nitrogen are derived from diffuse sources coming from the soils.
The nitrogenous nutrients, coming from point sources (cities, urban areas) and the washout of the land caused by atmospheric precipitations, reach the sea from rivers and port canals. Nitrogen is a nutrient microelement dissolved in water, whose nitrogenous components are represented by soluble mineral compounds. The nitrogenous components show high seasonal variability, with the lowest concentrations recorded in the summer period coinciding with the minimum flow rates of the rivers afferent to the coast; consequently, the trend of these parameters is generally well correlated with salinity.

Total nitrogen concentrations are closely related to the presence of organic particles suspended in the water column, of both phytoplankton and, above all, detrital origin and, therefore, directly related to river supplies.
Phosphorus is carried to the transition waters mainly by rivers. The main sources are identified in the civil and industrial sectors. Furthermore, as regards the agricultural sector, the phosphorus more than the fertilizer shares assimilated by plants, under certain environmental conditions, can be washed away from agricultural land and reach watercourses.
Phosphorus is a nutrient microelement dissolved in water, the main components of which are represented by phosphorus-orthophosphate (P-PO4) and total phosphorus (P-tot). The concentrations of total phosphorus are, in particular, closely related to the presence of organic particles in suspension in the water column, of both detrital origins, and therefore directly related to river and phytoplankton inputs.
In detail, the temporal trend of the values of nitrogen and total phosphorus in Figure 51 shows how the waters of both rivers have very low values, defining low chemical pollution. Furthermore, it is observed that both values from 2018 to 2021 always show very low values over time, this indicates a good qualitative state of the waters of the Jadro and Žrnovnica rivers from a chemical point of view.

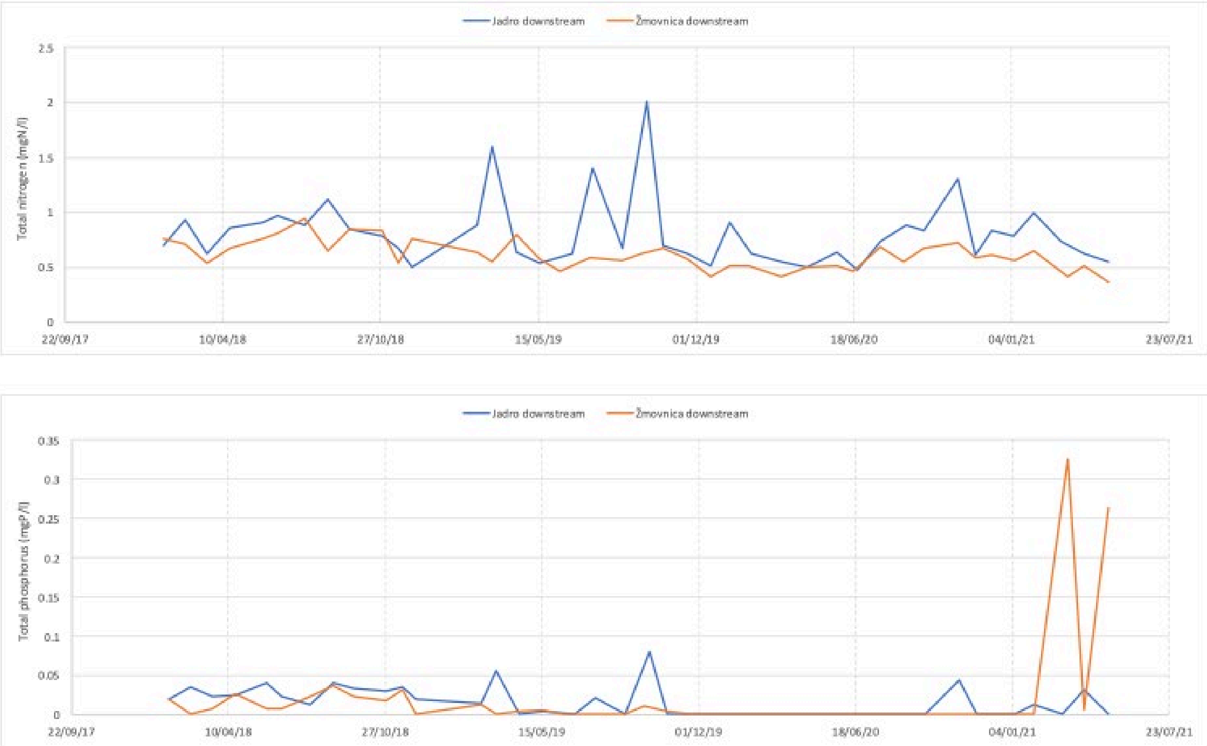

Figure 50 - Trend of nitrogen and total phosphorus values in the two monitoring stations for the period 2018-2021. In blue are the Jadro river values and in orange are the Žrnovnica values.

Discussion

It has been seen how the monitoring activities carried out in the last 3 years on the Jadro and Žrnovnica rivers have revealed good water quality throughout the year.

They are purely calcic bicarbonate waters due to their karst origin, presenting themselves with very low values of electrical conductivity and very oxygenated.

We have seen how the influence of anthropogenic activities operates in a very limited way in the two monitored rivers, having very low biochemical and chemical indices and far from the threshold values set by the legislation. In fact, BOD_5 and COD, together with total nitrogen and phosphorus, were found in very low values.

With pleasure, it is highlighted that, in addition to the very low values, there was a clear decrease in the values examined from the start of monitoring.

Karst Aquifers

Introduction

Karst terrains contain many natural resources, such as freshwater for human consumption, aquatic ecosystems and agricultural irrigation, great biodiversity both at the land surface and the underground, and soils that provide the basis for agricultural production, also acting as a natural sink for atmospheric carbon dioxide (Goldscheider, 2019).

In the Alpine orogenic belt and its branches Dinarides, Apennines, Carpathians, Balkans, Hellenides and the Pindus the karstified carbonate rocks are either dominant or widely distributed (Figure 52), and karst aquifers represent the main water resource for potable water supply (Stevanović, 2021).

Many cities and tourist centers along the Adriatic, Ionian and Aegean coasts are consumers of karstic groundwater (Stevanović & Filipović, 1994; Milanović, 2005; Radulović, 2000; Stevanović & Eftimi, 2010; Fiorillo & Guadagno, 2012; Kallioras & Marinos, 2015). In Croatia, the Zvir group of springs (0.6–3.0 m^3/s) supplies water to Rijeka; Jadro Spring (3–50 m^3/s) is the main source for the water supply of Split; Ombla Spring is the largest permanent karstic spring in the Southern Adriatic (Q_{min}= 2.3 m^3/s), supplying water to the city of Dubrovnik (Stevanović, 2021).

Karst systems are characterized by an unstable groundwater regime because of irregular rainfall distribution over the year. Many consumers fight every year to ensure a water supply during low water periods. This problem is growing in large urban areas: migration of the population towards the cities, their fast urbanization, and the growth of the industry in the 20th century have caused an increase in the number of tapped springs. In addition, during the summer seasons, the number of consumers and demands significantly increase along the coastal area (Stevanović & Eftimi, 2010).

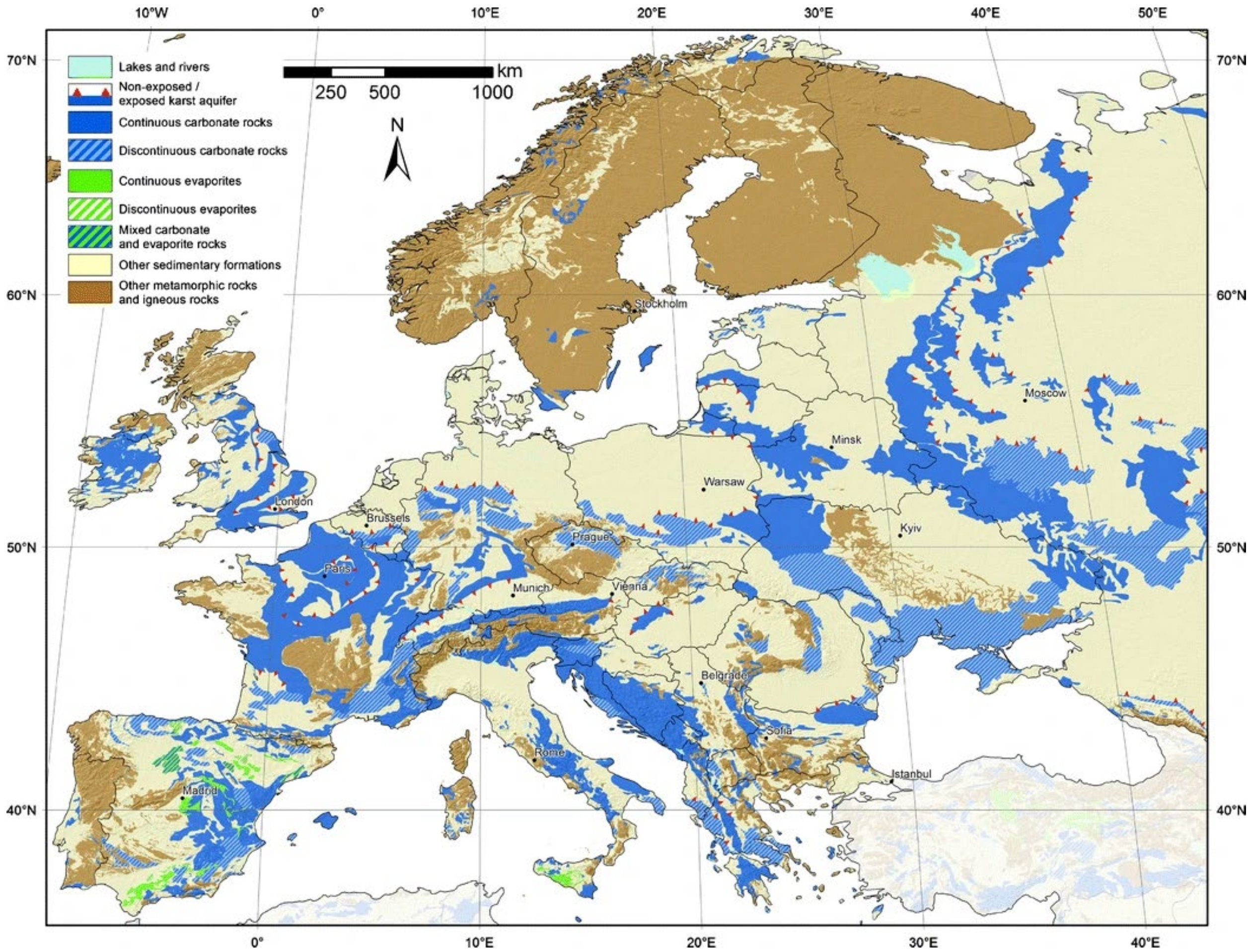

Figure 51: Draft karst aquifer map of Europe, as an example of the World Karst Aquifer Map. Source: The World Karst Aquifer Mapping project: concept, mapping procedure and map of Europe (Chen et al., 2017).

Karst process

Karst aquifers form in soluble rocks by flowing groundwater (Figure 53) and they are characterized by solutionally enlarged fractures, bedding planes and conduits, which form a hydraulically connected drainage network (Goldscheider and Drew, 2007).

Karst systems are the result of intense water–rock interactions, most often with strong involvement of the biosphere. They typically form by chemical dissolution of rocks by water containing carbon dioxide (Dreybrodt, 2000): $CaCO_3 + H_2O + CO_2 = Ca^{2+} + 2HCO_3^-$.

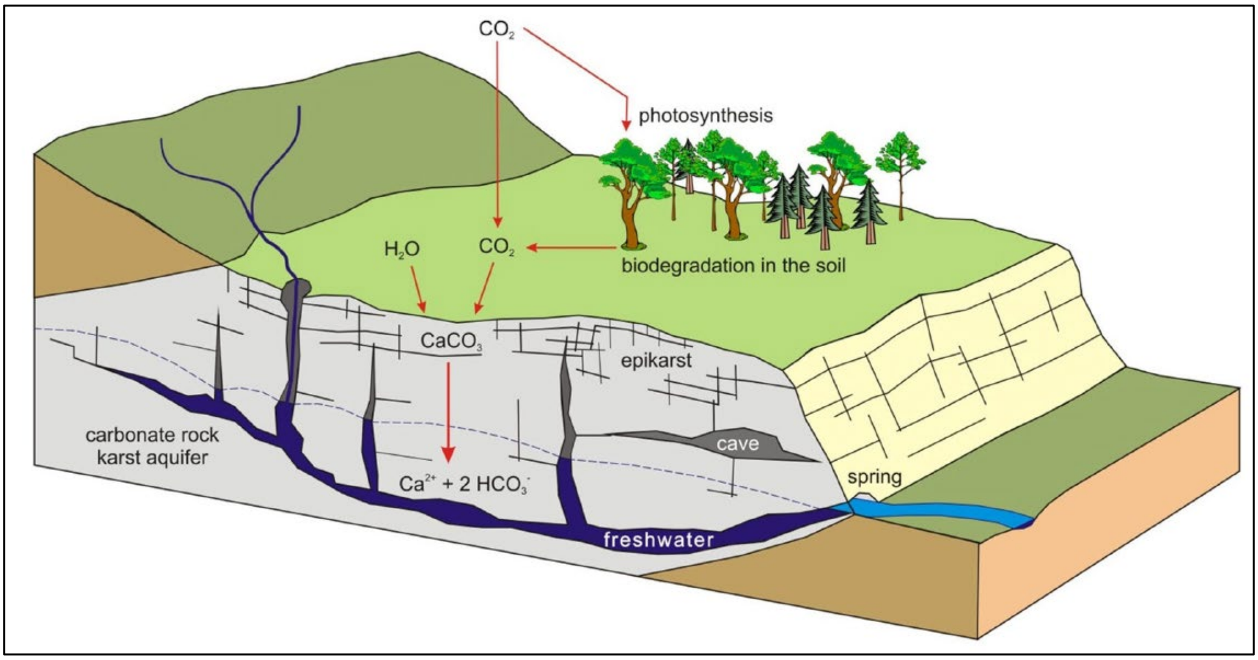

Figure 52: Schematic illustration of a karst system, its natural resources, and relevant processes (Goldshneider, 2019).

Carbonate sedimentary formations including more than 75% of carbonate minerals such as limestone and dolomite are the most important karstifiable rocks (Ford & Williams, 2007).

Because of their unique hydrogeological characteristics, karst aquifers are particularly vulnerable to human impacts (Drew & Hötzl, 1999) and are difficult to manage (Stevanović, 2015). In exposed karst systems, contaminants can easily enter the subsurface, often via thin soils and open fractures, and rapidly spread in the conduit network. Nonexposed karst aquifers (i.e., concealed, confined or artesian aquifers) are better protected against direct contamination from the land surface (Chen et al., 2017).

Karst aquifers in the Split/Podstrana area

The area of the cities of Split and Podstrana falls within what is called the "Dinaric Karst". It covers about 60,000 km^2 stretching the length of the eastern coast of the Adriatic Sea, from the Bay of Trieste in the north, to the Drim River basin in the south, and the Western Morava River valley in the east (Bonacci, 2015). The hydrogeological and hydrological regime of all water phenomena in the Dinaric karst depends mostly upon the interaction between groundwater and surface water. The dominant flow of the groundwater contained in the Dinaric karst is towards the Adriatic Sea through rivers and many permanent and intermittent coastal and submarine springs (Bonacci, 2015).

As a consequence of karst rocks' solubility, the Dinaric karst rocks develop high permeability along with fractures and faults. A wide range of closed surface depressions, a well-developed underground drainage system, and strong interaction between the circulation of surface water and groundwater typify Dinaric Karst (Bonacci, 2015).

Based on lithological differences, major geomorphological features and hydrological characteristics, Croatian karst can be divided into three parallel zones (Herak et al. 1969; Šarin 1984): low coastal and insular Adriatic karst, mountainous hinterland karst and low inland karst. This area belongs to the low coastal and insular zone, which is formed mainly by Cretaceous limestones, where karst is the dominant relief type, but in many cases, the homogeneity of karst is interrupted with belts of Eocene flysch rocks trending in a typical Dinaric northwest-south-easterly direction, and stimulating superficial drainage, even sometimes containing small ponds, often low lying and brackish. One of the main characteristics of the low coastal and insular zone is the contact of freshwater with seawater (Čanjevac & Orešić, 2020).

This area is characterized by sediments of high permeability (foraminiferal limestones), sediments with some vertical and lateral changes (calcitic silty clay and coarse gravel, cobbles and boulders) in permeability in the form of the presence of partly impermeable sediments (clayey glauconitic limestones.), sediments and impermeable sediments (Flysch) (Šestanović et al., 2012).

Analysis of structural-geologic and lithological characteristics of flysch showed that groundwater appears in those areas consisting of calcirudites and/ or calcarenites of flysch and highly tectonized marls. The depth of groundwater flow varies, and it depends upon the layer's

thickness, the frequency of joints, their orientation, and its surface conditions. The general direction of the groundwater flow is from the east toward the west (Šestanović et al., 2012).
The second general direction is from the west to the east. Water also flows along the faults and joints in the southwest, i.e. northeast direction west (Šestanović et al., 2012).
Several submarine springs are recorded in Kastela Bay, near the northern slopes of the Marjan Peninsula (Alfirevic, 1966, 1969; Fritz and Bahun, 1997). Similar phenomena were recorded along the whole southern coast of this area (Šestanović et al., 2012).
The result obtained by Kapelj et al., 2013 on the assessment of the intrinsic vulnerability of the aquifer system in karst areas is presented here, using the example of the Jadro and Žrnovnica catchment area. The evaluation was made with the application of the SINTACS method, which is based on the evaluation of seven parameters that describe the geological, hydrogeological, and hydrological conditions that directly affect the sensitivity of the aquifer to the influence of human activity leading to contamination. of groundwater. Furthermore, this study also considered the density of sinkholes.
The vulnerability map is shown in Figure 53.

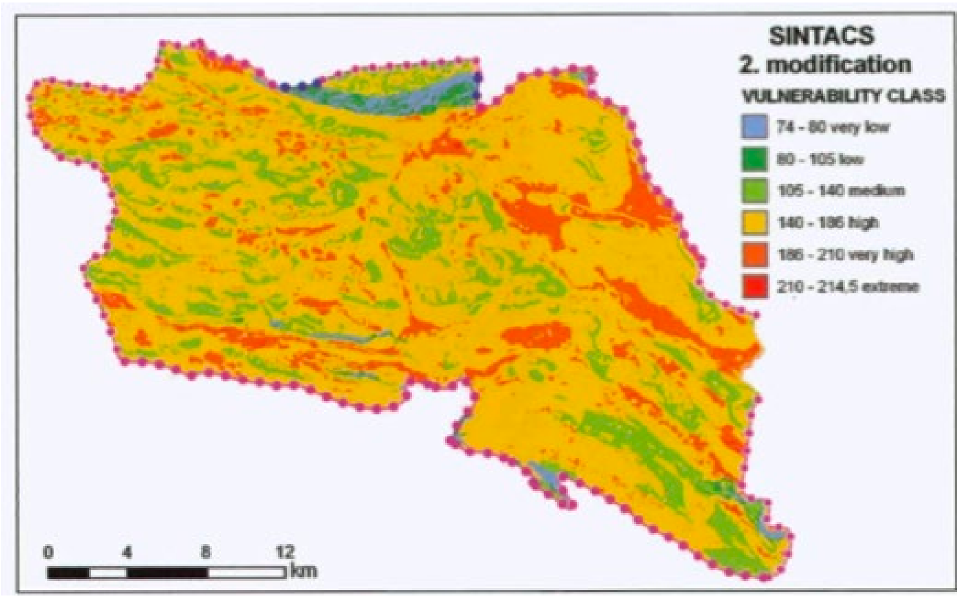

Figure 53: Map of intrinsic aquifer vulnerability according to the modified SINTACS method (including sinkhole density) and weighted factors for karst (from Kapelj et al., 2013).

The study highlighted how sinkhole density affects the assessment of the intrinsic vulnerability of the aquifer in the karst area. Areas with a higher density of sinkholes are known to indicate a higher degree of karstification. These areas represent the potential areas for the fastest infiltration of underground water thus indicating a greater vulnerability of the aquifer.

Consequently, the isolated areas that show a higher density of sinkholes (a very sensitive indicator of karstification, or permeability of the rocks), indicate the most vulnerable areas that need a high level of protection. However, this also raises the possibility of expanding the exploitation areas in the karst which may be suitable for different uses in those areas with medium, low and very low vulnerability indexes.

Karst aquifers in the Ancona area

The Ancona area belongs to the external domain of the central Apennines, where Mio-Plio-Pleistocene terrigenous deposits are widespread. From a lithological point of view, these terrains are of a pelitic, arenaceous-pelitic and marly nature (Cello & Tondi, 2008). These lithologies do not allow the establishment of karst conditions and therefore around the municipality of Ancona, no aquifers connected to the karst environment are found. To identify an aquifer that is connected to the karst environment, it is necessary to move to the nearby Mt Conero, which is a pronounced coastal cliff that breaks the continuity of the coastal shore along the Italian part of the Adriatic Sea; it is located between Ancona and Sirolo and is 572 m a.s.l.

Figure 54: Satellite image of the Ancona area. Source: Google Earth.

This cliff is constituted of Limestone rocks. In this area, the main aquifer represented by the Scaglia Fm. (Figure 55), is already exploited for water supply with two deep wells, at a depth of 280 m and it is confined by two marly formations (Mussi et al., 2017).

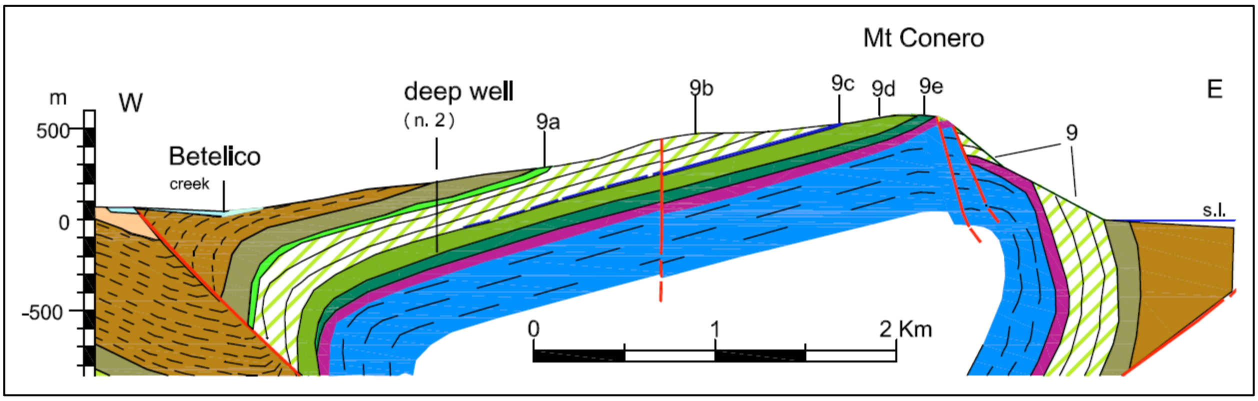

Figure 55: Fig. 2 – Cross section of Mount Conero (Mussi et al., 2017) Legend: 9- Scaglia Fm. (9a-Scaglia variegata member, 9b upper member, 9c, 9d middle members, 9e basal member).

The Scaglia aquifer is laterally sealed by the marly aquicludes owing to tectonics and is therefore hydraulically separated from the shallow aquifers (debris deposits and alluvial deposits), which stand on the Eocene-Miocene aquiclude (Mussi et al., 2017). In the Scaglia aquifer, the infiltration is through fissure and microkarst, although the breccia zones, which characterise this rock at many points, are connected to the occurrence of faults (Díaz General et al., 2015) and likely represent preferential pathways for infiltration and recharge. Karst phenomena have been identified in the peak zone of Mt Conero (Coltorti et al., 1987, 1989), where there is the occurrence of a wide doline (thus proving a permeability likely by karst) with residual soils that frequently turn into marshlands during the rainy periods was observed.

Karst aquifer in the Bibione area

The territory of Bibione constitutes the western distal portion of the megafan of the Tagliamento river. In this area, the ancient alluvial plain was buried or remodelled following the formation of the Caorle lagoon and delta systems. In these lands there are no conditions for the establishment of karst phenomena, therefore there is no presence of karst aquifers in this area.

Aquifers Salinization

Introduction

Groundwater is a subject of rising social concern, especially in coastal zones where most big cities are located. Due to growing demographic pressure in coastal areas, groundwater is increasingly mobilized to satisfy water demands (essentially for agriculture and urban uses). Overexploitation of coastal aquifers may lead to permanent water quality degradation because of seawater intrusion (Oude Essink 2001a).

The mixing of saline water and freshwater is a frequent cause of aquifer salinization in many coastal regions (Werner et al. 2013a). Because of high population densities and predicted sea-level rise, coastal aquifers are very vulnerable to groundwater extraction.

Coastal aquifers are more vulnerable to groundwater extraction because of high population densities and predicted sea-level rise (Ferguson and Gleeson, 2012).

In most cases, coastal aquifers are hydraulically connected to seawater. Usually, in natural conditions, the net water flow moves from the freshwater aquifer toward the sea. However, any excessive pumping of groundwater can alter the hydraulic balance and allow seawater to enter the aquifer and replace the fresh water pumped out (Werner et al. 2013a). Furthermore, a low natural recharge rate of groundwater in combination with projected sea-level rise can introduce and accelerate the movement of saltwater into freshwater aquifers, although Ferguson and Gleeson (2012) have found that the impact of groundwater abstraction from coastal aquifers is more significant than the impact of sea-level increase or change in groundwater recharge.

Because of its significant salt content, a small fraction of seawater would dominate the chemical composition of the groundwater mixture. The contribution of 1% of seawater would almost triple the salinity of typical groundwater (with an initial chloride content of 100 mg/l). The contribution of 5% of seawater would result in water with salinity above 1000 mgCI/L (Jones et al., 1999).

Salinization can be caused by several salinity sources related to natural phenomena and anthropogenic activities. In decreasing order of affected land area globally, the origins of the groundwater salinity can be considered terrestrial (67.3% of the global land area), marine

(22.0%), anthropogenic (8.3%), and mixed (a combination of the previous three types, 2.4%) (IGRAC, 2009).

Aquifers salinization in the Croatian sites

Littoral karst aquifers subject to seawater intrusion can be divided into two groups (Mijatovic, 1985):

- Aquifers opened to the sea, where exploitation of the freshwater zone always causes the intrusion of brackish water into the freshwater zone. In general, the intensity of disturbance is less for greater distances between the captage and the sea;
- Aquifers with incomplete barriers to the seawater, where the intrusion is localized to that part of the aquifer between sea level and the contact surface of the aquifer with the impermeable barrier.

Karst aquifers are of exceptional importance for drinking water supply and cover about half of the country’s needs. In fact, the drinking water supply along the Croatian coastal belt depends almost entirely on abstraction from the abundant karst springs (Ravbar & Kovacic, 2015).

In the coastal belt, the increase in population, the growth of tourism and the concentration of agriculture, traffic and industry pose threats to groundwater quality and seasonally determine very high exploitation of groundwater resources (Ravbar & Kovacic, 2015).

Regarding the Split and Podstrana area, the Jadro spring is the main source of drinking water, that has been in use since pre-Roman times. Furthermore, the Jadro spring represents the most important karst spring in the whole Croatian coastal belt, since it supplies water to the whole area of Split, other areas around it, and the island of Trogir (Antolašić 2011; Bonacci 2012; Kapelj et al. 2013).

Salinisation of karst drinking water resources is not a major issue in Croatia and the ECOMAP sites, because most springs used for drinking purposes are situated at elevations above possible seawater influence (Ravbar & Kovacic, 2015).

Aquifers salinization in the Italian sites

As early as the 1970s it was evidenced that the saline intrusion affected a large part of the Venetian coastal plain (Benvenuti et al., 1973). However, the study of this phenomenon took a back seat compared to that of other processes considered to be a priority at the time for the protection of Venice and its lagoon. As part of the "studies to safeguard" the lagoon area, the problem of saline intrusion in the central-northern area was reconsidered at the end of the 1990s, about the multi-aquifer artesian system that develops between 55 and 340 m of depth and whose exploitation was the primary cause of the Venetian subsidence (Carbognin et al., 2005a).

In the Venetian area, due to how the process is carried out, it would be appropriate to replace the term "saline intrusion" with that "saline contamination", as the former refers to a component of the overall process; the terms "saline intrusion" and "saline wedge" should therefore be used to indicate only the ingress of seawater into coastal aquifers (Carbognin et al, 2005b). In fact, the natural process of saltwater intrusion due to the proximity of the sea and the lagoon is aggravated by a series of factors, among which is the critical altitude of the territory (up to -4 m a.s.l.) is of particular importance. Therefore, subsidence and eustatism (Carbognin et al., 2004) are closely linked to saline contamination. The dispersion of sea and lagoon water from rivers and canals, which in lean situations can go up the mouth for 20 km, and drought events that prevent adequate recharge of the aquifers are factors that, when they act jointly, can induce an increase in the threshold risk of land desertification.

In the area of San Michele al Tagliamento, at the moment there would not seem to be any problems related to the intrusion/contamination of the aquifers by seawater (ARPAV, 2020).

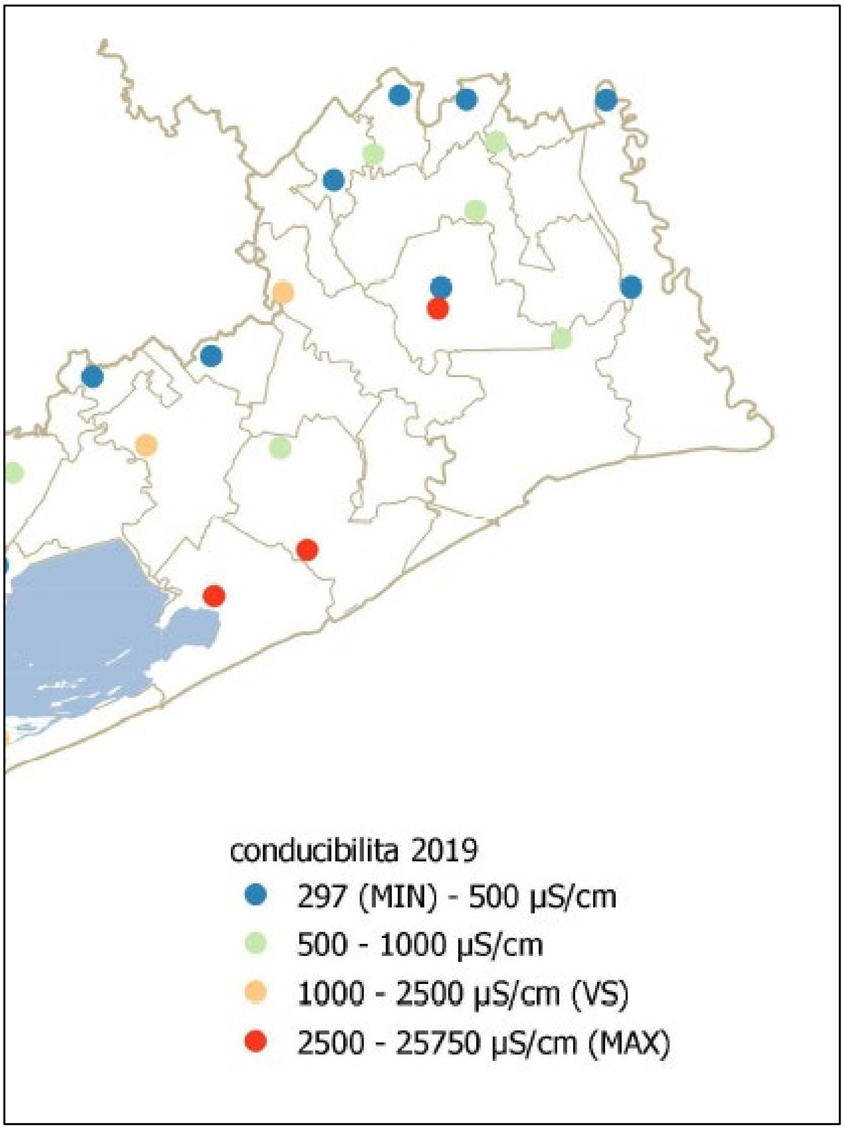

Figure 56: Spatial distribution of the average annual concentrations of the electrical conductivity parameter at 20 °C.

It should be emphasized, however, that the area in question is affected by a strong phenomenon of subsidence (Figure 57) ranging from minimum values of 2 mm / y up to maximum values of 7 mm / y (Provincia di Venezia, 2008).

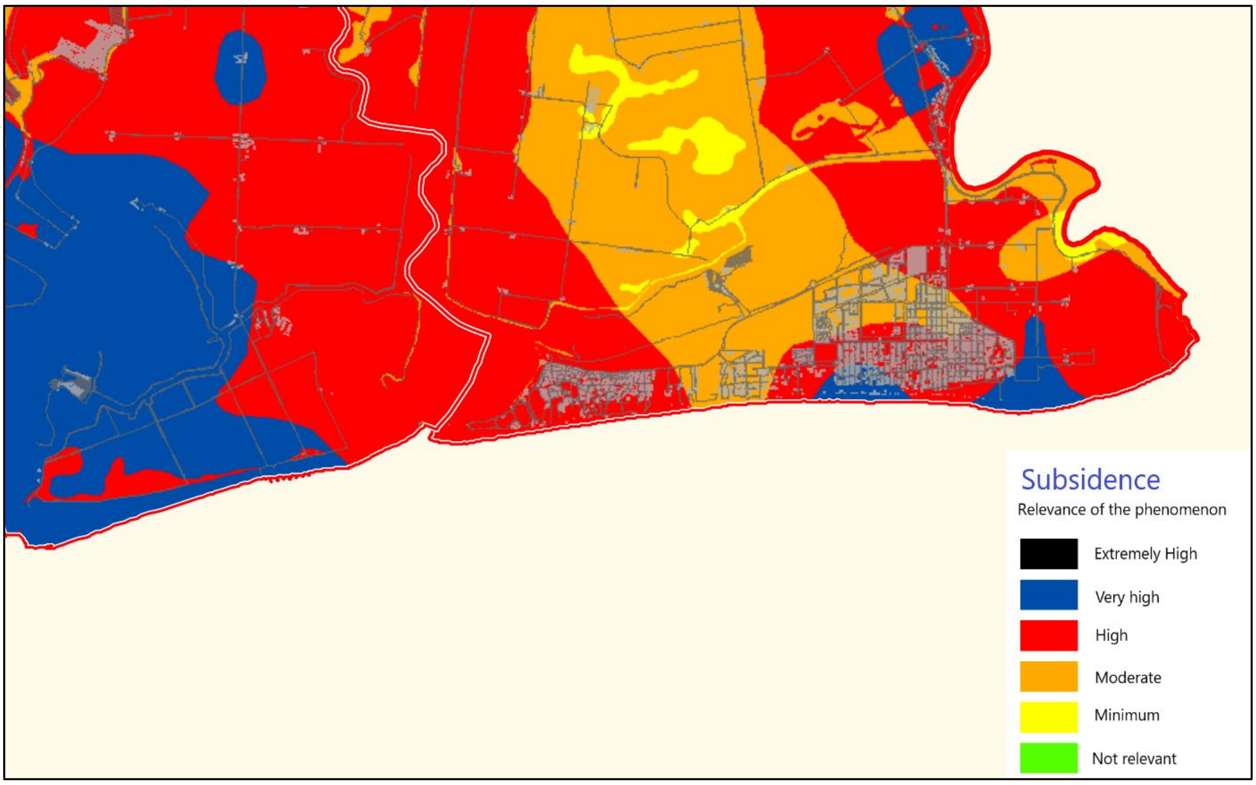

Figure 57: Map of the subsidence of the Bibione area (Provincia di Venezia, 2008).

The subsidence already underway in this area, together with the accelerated sea-level rise due to climate change could have major impacts on this area. These impacts can include salinisation of aquifers, damage to infrastructure, increased vulnerability to floods and storm surges, and permanent flooding of low land. River deltas, with their compressible substrates, low gradients, and large populations, are particularly vulnerable (Higgins, 2016).

As regards the salinization processes of the aquifers, linked to the phenomenon of marine intrusion in the Ancona area, it is more or less accentuated in the coastal area. Concerning the Esino river, Coltorti & Nanni (1983) and Nanni (1985) concluded that the high conductivity values found near the coastal strip are closely related to the phenomenon of marine intrusion. Furthermore, areas with low conductivity waters were generally found between the high conductivity areas and the coastline. This could depend on the fact that the marine intrusion is not direct but linked to the rising cone of the salty waters due to the strong pumping to which the aquifers are subjected near the coastal area (Nanni & Vivalda, 1986).

More recent studies, carried out in the petroleum refinery located at the mouth of the Esino river (Alberti et al., 2009) have shown, through a stationary model dependent on the density of groundwater and a large field database, that in the area there it is a slight intrusion of saline water. Furthermore, they identified two "secondary" sources of saline water which have been shown to have a major influence on the presence of brackish water in the unconfined aquifer: leakage from the fire extinguishing system (containing seawater) and small flooding events due to maritime events.

Alberti et al. (2009) conclude that in the area, seawater represents, the main saline source for the aquifer system only in the areas adjacent to the mouth. In the Adriatic Sea, the tidal fluctuations are too small to cause a high mix of seawater with the waters of the Esino river within the river channel. However, surface water bodies cannot always be considered natural barriers against seawater intrusion. Although the river creates a dilution of seawater in the mouth area, it can lead to saltwater wedge movement inland due to its level changes and strong seasonal drainage effects on groundwater flow.

Submarine springs in the Mediterranean area

Groundwater discharge into surface water bodies is, in many cases, below the level of surface and non-surface water immediately visible. This discharge can be diffuse or concentrated in the form of submerged (underwater) sources. Karst rocks make up 60% of the Mediterranean coast and it is estimated that they contribute 75% to its freshwater supply, mainly through direct discharge into the sea (UNESCO, 2004). The groundwater runoff to the coast and its subsea runoff is determined by the hydraulic gradient between the internal recharge areas and the sea level. Suppose the aquifer is confined and well protected by a thick aquifer. In that case, the flow of groundwater can continue well beyond the coast with the final discharge taking place along a distant outcrop in the underwater aquifer (Kresic, 2010) (Figure 58).

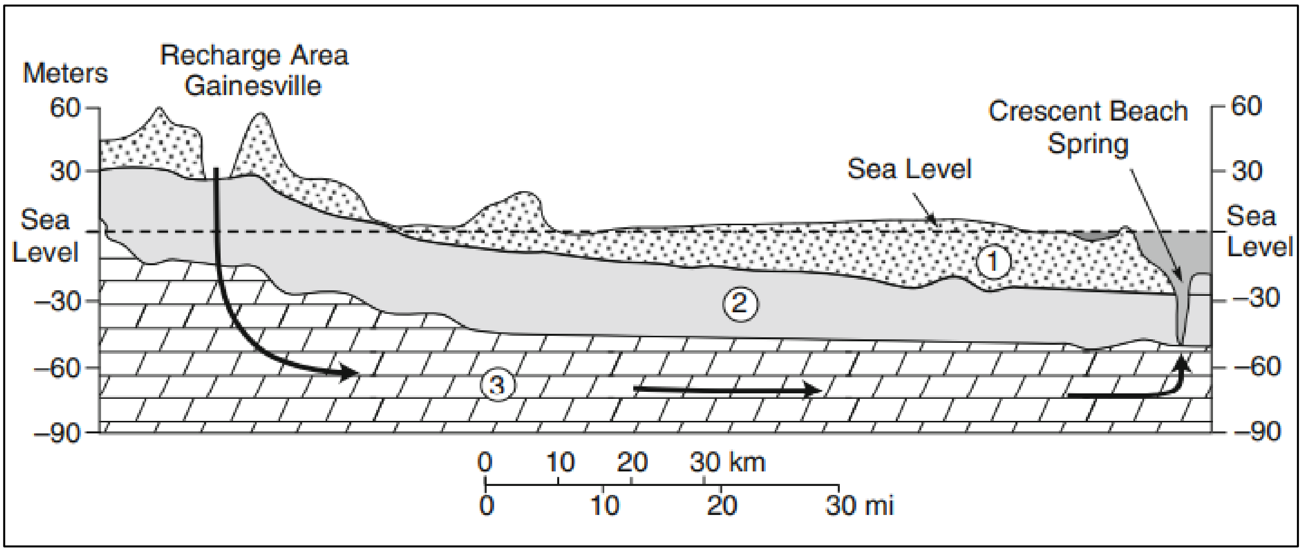

Figure 58: Idealized cross-section of groundwater flow to Crescent Beach Spring, Florida: (1) post-Miocene deposits (green clay, sand, and shell); (2) confining unit (Hawthorn Formation); (3) Upper Floridan aquifer (Eocene Ocala Limestone). Barlow, 2003. Modified by Kresic, 2010.

Submarine springs have been known to exist for a very long time. The Phoenicians already used their water, 1000 years before our era. Most of these springs have been discovered over the centuries but studies focusing on them are nevertheless rare and sketchy (Fleury et al., 2007)
Much of the karst territory of the Croatian Dinarides is currently submerged following the last Late Pleistocene-Holocene transgression. About 18.000 years ago, in the maximum phase of the Würm glaciation, the sea level (Figure 59) was about 125 meters below the current one (Fairbanks, 1989).

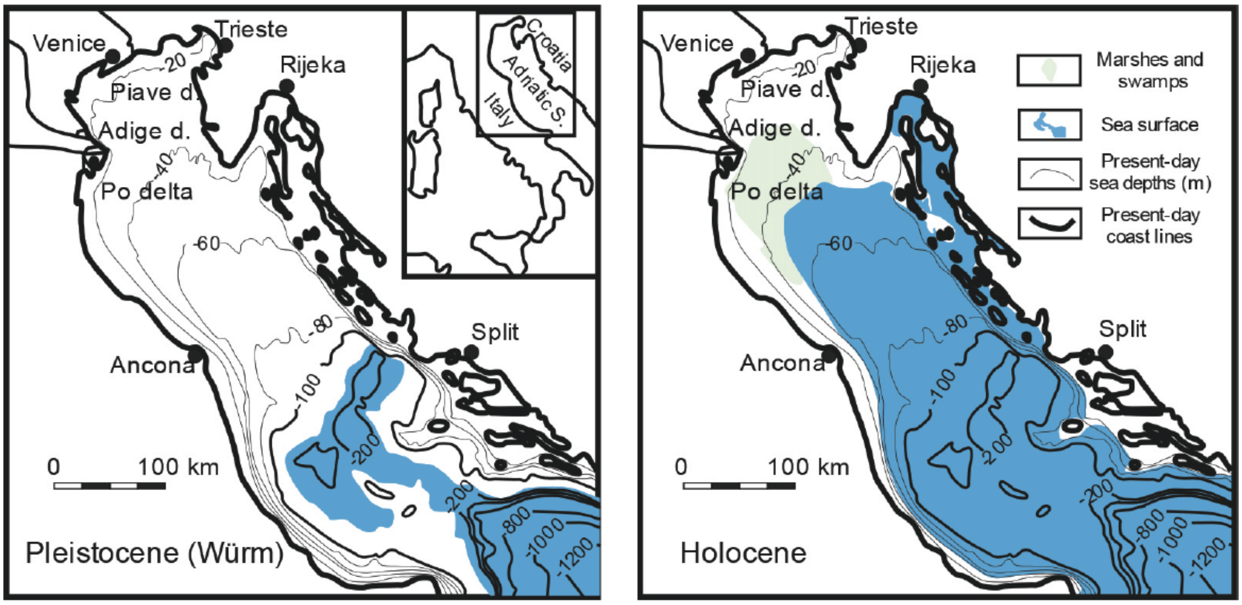

Figure 59: Borders of Adriatic Sea during Würm (111,000–11,700 y. ago) and Early Holocene (about 11,700 y.a.). From: Malvic, 2016.

Because of this, the karstification processes have affected the carbonate bedrock down to the absolute erosive base, i.e., sea level. Today, despite the thousands of years in the sedimentary environment, all kinds of karst features (karrens, dolines, poljes, caves, wells, river valleys and canyons, etc.) are still recognizable on these bottoms, due to the speed of sedimentation very slow thanks to the prevalence of easily soluble carbonate rocks in the drainage area of most of the rivers of the eastern Adriatic (Suric, 2001). This means that only about 20% of the river material is suspended while the remainder undergoes processes of dissolution. For this reason, the seabed is only partially covered by recent sediments. On the contrary, the western Adriatic, towards the Italian coasts, is intensively filled with suspended material transported by the Po River and other Apennine rivers, rapidly covering existing stretches (Correggiari et al. 1996).
In this context, Along the Adriatic coast in Croatia, there are over 300 perennial or periodic coastal and submarine springs (Ford and Williams, 1989).

Submarine springs in the Croatian sites

As part of the scientific studies concerning submarine springs in the Croatian area, the first to study these phenomena were Alfirevic (1966) and Jeveremovic (1966).

Alfirevic (1966), studying two submarine springs located in the western part of Kastela Bay, noted that the flow rate of these underwater springs increased during periods of heavy rain, while at other times the flow of water stopped allowing seawater to infiltrate down into the limestone aquifer.
In Kastela Bay the depth of water to the seafloor at the orifice of the springs resulted in about 15 m, and the bottom of the vertical channel through which the springs flow resulted at a depth of about 35 m according to profiles based on echo sounding.
The echographic profiles indicated that the vertical channels were funnel-shaped sinkholes which, represented a type of sinkhole present in the karst of that region. (Alfirevic, 1966)
Alfirevic (1966) stated that during a submarine survey, frogmen noticed specimens of submarine vegetation being torn up and sucked into the mouth of the funnel-shaped sinkholes. The downward water pressure, which prevented frogmen from moving away from the bottom of the sinkhole despite their attempts to swim upward, represented additional evidence of the flow of seawater into the underground channels. He added that this type of karst spring, known as an "estavelle," acts as a spring during high stages of the ground-water level and acts as an intake hole for the flow of seawater into the orifice of the spring when the fresh-water head is low, although the flow of seawater into the sinkhole is not so conspicuous on the surface.
Jeveremovic (1966) investigations showed that in the winter, spring, and autumn when the submarine estavelles in Kastela Bay were discharging water, the temperature of the water showed little difference from the surface to the bottom of the estavelle. During that time, especially in April and May, the salinity of the water from the springs was less than that of the Adriatic, and the salinity gradually increased from surface to bottom. During the winter season the water of the submarine springs, being lighter (warmer and less saline) than the surrounding seawater, spread out on the surface of the heavier seawater. During summer, discharge of the spring decreased, and at times the seawater flowed into the sinkhole.
In September 1971, Alfirevic succeeded in confirming the water sink in the Arbanija submarine spring. 20 kg of sodium fluorescein was used on that occasion, and it gradually disappeared into the submarine spring. It was proof that this submarine spring is also a swallow hole (Fritz and Bahun 1998).
A large volume of freshwater flows out from the submarine springs which, is karst groundwater derived from the hinterland. Since the whole coast and a part of the offshore oh the Kastela Bay is composed of impermeable Eocene flysch deposits, overlain by a permeable Cretaceous-Palaeogene carbonate complex, the flysch deposits provide a hydrogeological barrier for mainland karst groundwater (Fritz and Bahun, 1998). So, the groundwater moving to the submarine springs must pass beneath those impermeable rocks. The barrier in one part does not extend deeply enough underground and forms a "hanging" barrier. From this point laterally, the

flysch deposits have the function of a barrier. Under these conditions, a large volume of karst groundwater, partly retarded by flysch deposits in the western part of the Kastela Bay, is drained towards the hanging hydrogeological barrier (Fritz and Bahun, 1998).
Regarding the origin of these springs, they formed in the period between the last glacial stage until the present conditions in the areas where karst groundwater had hydro geologically open pass towards the erosional base - towards the sea.
Considering the data presented by Segota (1962, 1968) and Segota & Filipcic (1991) on sea-level fluctuation from the Wurm till recent times, it's possible to state that all the old coastal springs would have been submerged, becoming submarine springs due to a global sea-level rise between the Wurm and approximately 1000 years ago, resulting in a gradual migration of the submarine springs toward the direction of the present coastline (Fritz and Bahun, 1991).
As a result of the hydrogeological conditions in karst terrains, the sea level change (coastal movement, or rather the movement of the erosional base) is always accompanied by the appearance of new coastal springs. From a primordial spring, several hydraulically connected submarine springs could have been formed, as well as the coastal spring occurring at the present coast. Therefore, the most distant submarine springs gradually become inactive or are intermittently active, during the maximal rates of mainland water flow. This is the reason why most present submarine springs are situated relatively near the present coastline, also why a small number of them are permanently active and why the largest portion of karst groundwater flowing from the mainland hinterland during dry seasons does not emerge from submarine springs but along the coastline, from brackish coastal springs (Fritz and Bahun,1991).
Regarding the influence of these submarine springs from a biological point of view, Novosel et al. (2004) studied in depth the colonies of *Pentapora fascialis* in connection with the underwater freshwater springs: the surveys in this study were carried out between 1995 and 2004 in the northern area of the Croatian Adriatic coast, inside the Velebit Channel.
P. fascialis (Pallas, 1766) is the largest and most conspicuous calcified bryozoan in the Adriatic Sea (Figure 60). The colonies are attached to the substratum through an encrusting base. From this, they grow upwards in bilaminar sheets that from time to time fuse. Adult colonies may be a dominant and important part of the sessile benthos and colony size may be substantial (Hayward & Ryland, 1999).

Figure 60: Specimen of Pentapora fascialis. Source: www.biologiamarina.org. URL: https://www.biologiamarina.org/pentapora/

Novosel et al. (2004) identified large colonies of the *P. fascialis* bryozoan in four locations along the coast of the Velebit Channel in the north Adriatic, growing only near the outflow from underwater freshwater springs. Two surveyed underwater springs were active all year except for 132.9 hours in February and March 2003. The period of inactivity was never constant for the entire 24-hour period, which means that the colonies of *P. fascialis* are permanently adapted to grow in conditions of fluctuating medium-low salinity. The temperature of the outflow of underwater springs in the area was low and constant. The outflow was expressed as a strong and constant current throughout the year. The amount of total CO_2 dissolved CO_2 and bicarbonate was significantly higher in the source runoff than that of seawater. The amount of nitrate in the stream was 10 to 50 times that of seawater. Based on the study carried out, the authors concluded that both the high concentration of CO_2 and bicarbonate, which stimulate a higher concentration of phytoplankton in the area, together with the strong and constant currents, are the reason why *P. fascialis* colonies grow only within the outflow of the underwater spring.

References

Antolašić P. (2011). Analiza ugroženosti kakvoće podzemne vode izvora Jadra i Žrnovnice. Diploma thesis. University of Zagreb, Varaždin.

Alberti L., Francani V. & La Licata I. (2009). Characterization of salt-water intrusion in the lower Esino Valley, Italy using a three-dimensional numerical model. Hydrogeol J 17, 1791–1804.

Alfirevic S. (1966) Hydrogeological investigations of submarine springs in the Adriatic. Internat. Assoc. Hydrogeologists Mémoires, Tome VI, Réunion de Belgrade of 1963 (1966) 255-264. (Published by the Comité National Yougoslave pour la Géologie de Génie, Civil et l'Hydrogéologie, Belgrade.)

ARPAM (2021). Relazione triennale (2018-2020) sulla qualità dei corpi idrici fluviali della Regione Marche. Report su bacino Esino.

ARPAV (2009). Integrazione della tipizzazione delle acque marine e di transizione della regione del Veneto e individuazione dei corpi idrici. Report.

ARPAV (2020). La qualità delle acque interne in provincia di Venezia. Report anno 2019.

Autorità di Bacino Distrettuale delle Alpi Orientali (2010). Piano di gestione dei bacini idrografici delle Alpi Orientali - Bacino del fiume Tagliamento. Report.

Barlow, P.M., 2003. Ground Water in Freshwater-Saltwater Environments of the Atlantic Coast. U.S. Geological Survey Circular 1262, Reston, VA.

Benvenuti G., Norinelli A., Zambrano R., (1973). Contributo alla conoscenza del sottosuolo dell'area circumlagunare veneta mediante sondaggi elettrici verticali. Boll. di Geofisica Teorica e Applicata, XV, 57, 23-38.

Bonacci O. (1978): Hidrogeoloska studija Zmovnice.- [Hydrogeological study of Zrnovnica - in Croatian].- Unpubl. Report. Arhiva Gradevinskog instituta. Split.

Bonacci O. (1987). Karst Hydrology. Springer Verlag, Berlin. 184 pp.

Bonacci O., Kerovec M., Bonacci T.R., Mrakovicic M. and Plenkovic-Moraj A. (1998). Ecologically acceptable flows definition for the Zrnovnica river (Croatia). Regulated Rivers: Research & Management Regul. RiTers: Res. Mgmt. 14: 245–256 (1998).

Bonacci O (2012) Hidrološka analiza odvođenja vode iz krškog izvora rijeke Jadro. Hrvatske vode 79(80):23–28.

Bortolan Pirona A. (2008). Le risorgive del Friuli orientale: idrogeologia e idrochimica. Tesi di Laurea specialistica in Scienze Ambientali, Università Cà Foscari, a.a. 2007-08, 359 pp.

Carbognin L., Teatini P., Tosi L., (2005a). Land subsidence in the Venetian area: known and recent aspects. Giornale di Geologia Applicata (Italian Journal of Applied Geology), 1, 5-11.
Carbognin L., Rizzetto F., Tosi L., Teatini P., Gaparetto-Stori G., (2005b). L'intrusione salina nel comprensorio lagunare veneziano. Il bacino meridionale. Giornale di Geologia Applicata, 2, pp. 119–124.
Chen Z., Auler A. S., Bakalowicz M., Drew D., Griger F., Hartmann J., ... & Goldscheider N. (2017). The World Karst Aquifer Mapping project: concept, mapping procedure and map of Europe. Hydrogeology Journal, 25(3), 771-785.
Coltorti M. & Nanni T. (1983). Hydrogeology and neotectonics of the lower Esino basin. Paper of the Int. Conf. Groundwater and Man, 5-9 December - Sydney.
Coltorti M., Nanni T. & Rainone M.L. (1987) - Il contributo delle scienze della terra nell'elaborazione di un piano paesistico: l'esempio del monte Conero (Marche). Mem. Soc. Geol.It., 37, 629-647, 6 ff.,1 tav. Roma.
Coltorti M., Dramis F., Gentili B. & Pambianchi G. (1989) – Rilevamento geomorfologico. In "Cartografia Geologico -Tecnica del territorio del Comune di Ancona". Regione Marche, Università degli Studi di Ancona. Technical relation.
Correggiari A., Roveri M. & Trincardi F. (1996). Late Pleistocene and Holocene Evolution of the North Adriatic Sea, Il Quaternario, 9 (2), 697-704.
Díaz General E., Mollema P. & Antonellini M. (2015) - Fracture patterns and fault development in the pelagic limestones of the Monte Conero Anticline (Italy). Italian Journal of Geosciences. 134(3), 495-512. DOI: 10.3301/IJG.2014.3.
Drew D. and Hötzl H. (1999). Karst hydrogeology and human activities: impacts, consequences, and implications. IAH International Contributions to Hydrogeology 20, Taylor and Francis, London.
Dreybrodt W. (2000). Equilibrium chemistry of karst waters in limestone terranes. In: Klimchouk A., Ford D.C., Palmer A.N., Dreybrodt W. (eds) Speleogenesis, evolution of karst aquifers. National Speleological Society Inc, Huntsville, pp 126–135.
Fairbanks R. G. (1989). A 17000-year glacio-eustatic sea-level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation, Nature, 342, 637-642.
Ferguson G. and Gleeson T. (2012). Vulnerability of coastal aquifers to groundwater use and climate change. Nat Clim Chang 2(5):342–345.
Fiorillo F., Guadagno F. M. (2012). Long karst spring discharge time series and drought occurrences in southern Italy. Environ. Earth Sci., 65(8): 2273–2283.
Fleury P., Bakalowicz M., & de Marsily G. (2007). Submarine springs and coastal karst aquifers: a review. Journal of hydrology, 339(1-2), 79-92.
Ford, D. C., & Williams, P. W. (1989). Karst geomorphology and hydrology (Vol. 601). London: Unwin Hyman

Ford D. and Williams P. (2007). Karst hydrogeology and geomorphology. Wiley, Chichester, UK.

Fritz E. & Kapelj J. (1998): Osnovna hidrogeoloska karta Republika Hrvatske 1:100 000, listovi Split i Primosten [BasicHydrogeo- logical Map of the Republic of Croatia 1:100 000, sheets Split and Primosten - in Croatian].- Institut za geoloska istrazivanja, Zagreb.

Fritz F., Pavlicic A. Renic A. & Kapelj J. (1988). Izvori Jadro i Zmovnica. Dio hidrogeoloskih istraznih radova potrebnih za prijedlog zona sanitame zastite [Jadro and Zrnovnica springs. Part of the hydrogeological investigation works required for the proposal of sanitary protection zones - in Croatian]. Unpubl. Report. Arhiva HGI140/88, Zagreb.

Grassi S. (1994). Alcune osservazioni sulle caratteristiche geochimiche delle acque sotterranee della bassa pianura friulana. Atti Soc. Tosc. Sci. Nat., Mem., Serie A, 101 (1994). pagg. 1-15, fig. 9, tab. 2.

Goldscheider N. and Drew D. (2007). Methods in karst hydrogeology. Taylor and Francis, London.

Goldscheider N. (2019). A holistic approach to groundwater protection and ecosystem services in karst terrains. Carbonates and Evaporites, 34(4), 1241-1249.

Hayward P.J. & Ryland J.S. (1999). Cheilostomatous Bryozoa. Part 2. Hippothooidea – Celleporidea. Shrewsbury: Field Studies Council.

Herak M., Bahun S., Magdalenic A. (1969). Pozitivni i negativni utjecaji na razvoj krša u Hrvatskoj. In: Petrik M, Herak M (eds) Krš Jugoslavije/Carsus Iugoslaviae, vol. 6, JAZU, Zagreb, Croatia, pp 45–71.

Higgins S.A. (2016). Advances in delta-subsidence research using satellite methods. Hydrogeology Journal, 24(3), 587-600.

IGRAC (International Groundwater Resources Assessment Centre). 2009. Global overview of saline groundwater occurrence and genesis. Rep. No. GP 2009-1. Utrecht, Netherlands: IGRAC.

Jeveremovic M. (1966). Hydraulic characteristics and classification of brackish springs in the Adriatic Zone of the Dinaric Karst. internat. Assoc. Hydrogeologists Mémoires, Tome VI, Réunion de Belgrade of 1963 (1966) 293-298. (Published by the Comité National Yougoslave pour la Géologie de Génie, Civil et l'Hydrogéologie, Belgrade.).

Jones B.F., Vengosh A., Rosenthal E. & Yechieli Y., (1999). Geochemical Investigation. In Bear, J., Cheng, A. H. D., Sorek, S., Ouazar, D., & Herrera, I. (Eds.). (1999). Seawater intrusion in coastal aquifers: concepts, methods, and practices (Vol. 14). Springer Science & Business Media.

Kallioras A., Marinos P., 2015: Water resources assessment and management of karst aquifer systems in Greece. Environ. Earth Sci., Them. issue – Fiorillo F. & Stevanović Z. (eds.): Mediterranean Karst Hydrogeology, 74: 83–100.

Kapelj S., Loborec J. and Kapelj J. (2013). Assessment of aquifer intrinsic vulnerability by SINTACS methods. Geologia Croatica 66/2. 119-128.

Kapelj S., Kapelj J., Marjanac T., Prelogovic E., Cvetko-Tesovic B., Biondic B., Ivankovic T, Jukic D. & Denic-Jukic V. (2008): Studija upravljanja vodama sliva Jadra i Zmovnice - Druga faza studijsko istrazivackih radova [Water management study of the Jadro and Zrnovnica springs recharge area, secondphase - in Croatian]. EVV:9/2007. Hrvatske vode. Split, 122 p.

Kapelj S., Kapelj J., Biondic R., Biondic B., Kovac, 1., Tusar B., Prelogovic E., Marjanac T, Andric M., Kovacic D., Strelec S. & Gazdek M. (2006). Studija upravljanja vodama sliva Jadra i Zmovnice-Prva faza studijsko istrazivackih radova. EW: 1/2005.Hrvatskevode. Split, 147 p.

Kresic N. (2010). Types and classifications of springs. In Groundwater hydrology of springs (pp. 31-85). Butterworth-Heinemann.

Ljubenkov I., (2015). Hydrodynamic modelling of the stratified estuary: a case study of the Jadro River (Croatia). J. Hydrol. Hydromech., 63, 2015, 1, 29–37 DOI: 10.1515/john-2015-0001.

Malvic T. (2016). Regional turbidites and turbiditic environments developed during Neogene and Quaternary in Croatia. RMZ–M&G, 63, 39-054.

Martelli G. and Granati C. (2010). Hydrochemical general characteristics of the Friuli plain's deep aquifers (Northern Italy). Italian Journal of Engineering Geology and Environment, 1 (2010). DOI: 10.4408/IJEGE.2010-01. O-06.

Mijatović B. F. (1984). Problems of seawater intrusion into aquifers of the coastal Dinaric Karst. In: Hydrogeology of the inaric Karst (ed. by G. Castany, E. Groba Castany, E. Groba & E. Romijn), 115–142. International Contributions to Hydrogeology, AIH 4, Hannover, Germany.

Milanović P. (2005). Water potential in southeastern Dinarides. In: Stevanović, Z. & Milanović, P. (eds.): Water resources and environmental problems in karst, Proceedings of IAH International conference KARST 2005, Belgrade–Kotor, Fac. Min. & Geol., Belgrade, pp. 249–257.

Mussi M., Nanni T., Tazioli A., & Vivalda P.M. (2017). The Mt Conero limestone ridge: The contribution of stable isotopes to the identification of the recharge area of aquifers. Italian Journal of Geosciences, 136(2), 186-197.

Nanni T. (1985). Le falde di subalveo delle Marche: inquadramento idrogeologico, qualità delle acque ed elementi di neotettonica. Ed. Regione Marche, Materiali per la programmazione, 2.

Nanni T. & Vivalda P.M. (1986). Inquadramento idrogeologico ed influenza della tettonica sugli acquiferi di subalveo delle pianure marchigiane. Studi Geologici Camerti, volume speciale "La Geologia delle Marche" (1986), 105-133.

Novosel M., Olujic G., Cocito S. & Pozar-Domac A. (2004). Submarine freshwater springs in the Adriatic Sea: a unique habitat for bryozoan Pentapora fascialis. Bryozoan Studies 2004 – Moyano, Cancino & Wyse Jackson (eds). Taylor & Francis Group, London.

Orešić D. & Čanjevac I. (2020). Groundwater resources in Croatia. In Water Resources Management in Balkan Countries (pp. 109-132). Springer, Cham.

Oude Essink GHP 2001a. Improving fresh groundwater supply problems and solutions. Ocean Coast Manag 44 (5-6): 429-449.
Radulović M. (2000). Hidrogeologija karsta Crne Gore. Pos. izd. Rep. Zavoda za geol. istraž. CG, vol. XVIII, Podgorica, p. 271.
Ravbar N. and Kovačič G. (2006). Karst water management in Slovenia in the frame of vulnerability mapping. Acta Carsologica 35(2):73–82.
Regione Marche (2008). P.F. Tutela delle risorse ambientali ed attività estrattive. Servizio Ambiente e Paesaggio. Report sezione-A.
Saccon P., Leis A., Marca A., Kaiser J., Campisi L., Böttcher, M.E., Savarino J., Escher P., Eisenhauer A. and Erbland J. (2013). Multi-isotope approach for the identification and characterisation of nitrate pollution sources in the Marano lagoon (Italy) and parts of its catchment area. Applied Geochemistry 34 (2013) 75–89.
Šarin A. (1984). Hydrogeologic regional classification of the karst in Yugoslavia. In: Mijatović B.F. (ed) Hydrogeology of the Dinaric Karst, vol. 4, Verlag Heinz Heise, Hannover, Germany, pp 42–54.
Šestanović S., Toševski A., Mihalić S., Dečman A. & Ferić P. (2012). Preliminary data for the development of the engineering geological map of the city of Split (Croatia). Environmental Earth Sciences, 66(5), 1547-1556.
Stevanovic Z. (2015). Karst aquifers: characterization and engineering. Professional Practice in Earth Sciences, Springer, Heidelberg, Germany, 692 pp.
Stevanovic Z. (2021). Karst aquifers of southeast Europe – essential and rich resource of potable water. Board for Karst and Speleology, Serbian Academy of Sciences and Arts.
Stevanović Z., Filipović B. (eds), 1994: Groundwaters in carbonate rocks of the Carpathian-Balkan Mountain range. Spec. ed. of CBGA, Allston, Jersey, p. 237.
Stevanović Z., Eftimi R., 2010: Karstic sources of water supply for large consumers in Southeastern Europe – sustainability, disputes, and advantages, Geologica Croatica, 63/2: 179–186.
Suric M. (2002). Submarine karst of Croatia - evidence of former lower sea levels. Acta Carsologica, 31/3, 5, 89-98.
Valker A. (1989). 'Deltas and coastal areas, in Falkenmark M. and Chapman T. (Eds), Comparative Hydrology. UNESCO, Paris. pp. 405–428.
Werner A.D., Bakker M., Post V.E.A., Vandenbohede A., Lu C., Ataie-Ashtiani B., Simmons C.T., Barry D.A. (2013a). Seawater intrusion processes, investigation, and management: recent advances and future challenges. AdvWater Resour 51(0):3–26.

Annex 1: data of the Tagliamento river

Station	Date	Electric Conducibility 20°C (uS cm)
0606AS5F1	23/01/19	450
0606AS5F1	18/07/19	530
0606AS5F1	21/11/19	375
0606AS5F2	21/02/19	481
0606AS5F2	23/09/19	386
0606AS5F2	20/11/19	343

Station	Date	Dissolved Oxygen (%)
0606AS5F1	21/02/18	97
0606AS5F1	01/04/18	91.6
0606AS5F1	03/05/18	87.1
0606AS5F1	30/05/18	102
0606AS5F1	08/09/18	91
0606AS5F1	15/11/18	97
0606AS5F1	23/01/19	86
0606AS5F1	18/07/19	80
0606AS5F1	21/11/19	105
0606AS5F2	21/02/18	96.6
0606AS5F2	01/04/18	88.1
0606AS5F2	03/05/18	88.8
0606AS5F2	23/05/18	96.9
0606AS5F2	22/08/18	117.7
0606AS5F2	20/11/18	94.7
0606AS5F2	21/11/18	94.7
0606AS5F2	24/01/19	84
0606AS5F2	20/02/19	91.9
0606AS5F2	21/02/19	94
0606AS5F2	20/03/19	89.3
0606AS5F2	17/04/19	96.3
0606AS5F2	28/05/19	88
0606AS5F2	25/06/19	105.6
0606AS5F2	25/07/19	106
0606AS5F2	28/08/19	112.7
0606AS5F2	23/09/19	98
0606AS5F2	30/10/19	86.4
0606AS5F2	20/11/19	88
0606AS5F2	17/12/19	95.5

Station	Date	Total Phosphorus (mg/l)
0606AS5F1	08/01/18	<0.016
0606AS5F1	21/02/18	<0.016
0606AS5F1	01/04/18	<0.016
0606AS5F1	03/05/18	<0.016
0606AS5F1	30/05/18	<0.016
0606AS5F1	08/09/18	0.02
0606AS5F1	26/09/18	0.39
0606AS5F1	15/11/18	<0.016
0606AS5F1	23/01/19	<0.016
0606AS5F1	04/02/19	<0.016
0606AS5F1	18/07/19	<0.016
0606AS5F1	28/08/19	<0.016
0606AS5F1	28/10/19	0.02
0606AS5F1	21/11/19	0.18
0606AS5F1	06/12/19	<0.016
0606AS5F2	08/01/18	0.02
0606AS5F2	21/02/18	<0.016
0606AS5F2	01/04/18	<0.016
0606AS5F2	03/05/18	<0.016
0606AS5F2	23/05/18	<0.016
0606AS5F2	30/05/18	<0.016
0606AS5F2	22/08/18	<0.016
0606AS5F2	26/09/18	<0.016
0606AS5F2	20/11/18	<0.016
0606AS5F2	04/02/19	<0.016
0606AS5F2	21/02/19	<0.016
0606AS5F2	28/08/19	<0.016
0606AS5F2	23/09/19	<0.016
0606AS5F2	28/10/19	0.02
0606AS5F2	20/11/19	0.18
0606AS5F2	06/12/19	<0.016

Station	Date	Nitrate (mg/l)
0606AS5F1	21/02/18	5.76
0606AS5F1	30/05/18	3.54
0606AS5F1	08/09/18	6.2
0606AS5F1	15/11/18	3.1
0606AS5F1	23/01/19	4.87
0606AS5F1	18/07/19	17.71
0606AS5F1	21/11/19	3.1
0606AS5F2	21/02/18	7.53
0606AS5F2	23/05/18	4.43
0606AS5F2	22/08/18	5.31
0606AS5F2	20/11/18	4.43
0606AS5F2	21/02/19	6.2
0606AS5F2	23/09/19	6.64
0606AS5F2	20/11/19	3.1

Station	Date	pH
0606AS5F1	08/01/18	8.1
0606AS5F1	21/02/18	8.1
0606AS5F1	01/04/18	8.1
0606AS5F1	03/05/18	8.2
0606AS5F1	30/05/18	8
0606AS5F1	26/09/18	8.1
0606AS5F1	15/11/18	8.2
0606AS5F1	23/01/19	8.2
0606AS5F1	04/02/19	8.1
0606AS5F1	18/07/19	7.8
0606AS5F1	28/08/19	8.1
0606AS5F1	28/10/19	8.1
0606AS5F1	21/11/19	8.2
0606AS5F1	06/12/19	7.9
0606AS5F2	08/01/18	8.1
0606AS5F2	01/04/18	8
0606AS5F2	03/05/18	8.1
0606AS5F2	30/05/18	7.8
0606AS5F2	26/09/18	8.1
0606AS5F2	24/01/19	8
0606AS5F2	04/02/19	8
0606AS5F2	20/02/19	7.9
0606AS5F2	21/02/19	8
0606AS5F2	20/03/19	8
0606AS5F2	17/04/19	8.1
0606AS5F2	28/05/19	8
0606AS5F2	25/06/19	8
0606AS5F2	25/07/19	8
0606AS5F2	28/08/19	7.6
0606AS5F2	23/09/19	7.9
0606AS5F2	28/10/19	8.1
0606AS5F2	30/10/19	8
0606AS5F2	20/11/19	8.1
0606AS5F2	06/12/19	7.9
0606AS5F2	17/12/19	8

Station	Date	Temperature (°C)
0606AS5F1	08/01/18	22.7
0606AS5F1	01/04/18	8
0606AS5F1	03/05/18	9.2
0606AS5F1	30/05/18	17.6
0606AS5F1	26/09/18	17.2
0606AS5F1	04/02/19	14.4
0606AS5F1	28/08/19	20.5
0606AS5F1	28/10/19	16.8
0606AS5F1	06/12/19	18.9
0606AS5F2	08/01/18	24.4
0606AS5F2	01/04/18	8.9
0606AS5F2	03/05/18	11
0606AS5F2	30/05/18	18.5
0606AS5F2	26/09/18	15.9
0606AS5F2	04/02/19	16.1
0606AS5F2	28/08/19	22.3
0606AS5F2	28/10/19	15.8
0606AS5F2	06/12/19	19.9

Annex 2: data of the Jadro river

Name of the sampling point	Sampling date	Alcality m-valuet ($mgCaCO_3/l$)	Colour (mg/l Pt/Co)	Electrical conductivity at 25°C (µS/cm)	pH value	Toptal suspended matter (mg/l)	Temperature of water (°C)	Tvrdoća ukupna ($mgCaCO_3/l$)	BOD_5 (mgO_2/l)	COD-Mn (mgO_2/l)	Dissolved oxygen (mgO_2/l)	Oxygen saturation (%)	Ammonium (mgN/l)	Anorganic nitrogen (mgN/l)	Unionized ammonia ($mgNH_3/l$)	Nitrates (mgN/l)
Jadro, downstream	25.01.2018	160	<5	400	8.08	1	12.6	171	<0,27	0.8	12.04	113.4	<0,003	0.55	0.00005	0.55
Jadro, downstream	22.02.2018	196	<5	391	8.03	3.1	13.1	206	1.46	1.62	12.9	122.9	<0,003	0.55	0.00004	0.55
Jadro, downstream	21.03.2018	170	<5	370	8.2	1.2	12	187	2.38	2.5	12.35	114.8	<0,003	0.5	0.00006	0.5
Jadro, downstream	19.04.2018	204	<5	392	8.11	0.9	13.1	215	0.77	0.99	12.01	114.4	<0,003	0.57	0.00005	0.57
Jadro, downstream	30.05.2018	198	<5	404	8.02	1.8	14.9	215		0.9	11.28	111.8	0.076	0.616	0.00254	0.54
Jadro, downstream	18.06.2018	200	<5	419	8.28	2.4	15.7	217		0.66	12.11	122.1	<0,003	0.43	0.00009	0.43
Jadro, downstream	23.07.2018	190	<5	427	8.23	2.6	14.6	208		0.98	11.27	111	0.068	0.788	0.00355	0.72
Jadro, downstream	22.08.2018	175	<5	446	8.41	1.5	17.5	194	1.87	1.9	11.15	116.8	<0,003	0.45	0.00014	0.45
Jadro, downstream	17.09.2018	202	<5	465	8.33	<0,53	15.7	225	0.61	1.98	11.86	119.6	0.037	0.528	0.0026	0.49
Jadro, downstream	29.10.2018	204	<5	463	8.12	2.9	14.2	216	2.32	2.52	11.85	115.7	0.009	0.439	0.00036	0.43
Jadro, downstream	19.11.2018	196	<5	442	8.22	0.7	12.8	214	2.38	2.42	12.92	122.2	<0,003	0.521	0.00007	0.521
Jadro, downstream	05.12.2018	152	<5	398	8.04	0.8	12.7	162	1.85	1.9	13.97	131.9	0.022	0.486	0.00065	0.46
Jadro, downstream	26.02.2019	180	<1	402	7.21	<2	12.8	225	0.57	1.62	11.13	105.3	0.06	0.63	0.00027	0.57
Jadro, downstream	18.03.2019	192	<1	419	7.39	<2	13.1	231	1.05	1.43	10.63	101.2	0.18	1.28	0.00126	1.1
Jadro, downstream	17.04.2019	186	6	347	7.63	<2	13.7	200	0.24	0.82	11.06	106.8	<0,01	0.5	0.00006	0.5
Jadro, downstream	16.05.2019	181	5	387.4	7.67	<2	14.7	195	0.15	0.91	10.87	107.3	0.06	0.48	0.0009	0.42
Jadro, downstream	27.06.2019	190	<1	382	7.77	<2	16	204	0.1	1.33	9.49	96.35	0.04	0.54	0.00083	0.5
Jadro, downstream	22.07.2019	211	5	483	8.12	<2	20	213	1.17	1.23	8.51	93.72	0.54	1.03	0.0325	0.49
Jadro, downstream	30.08.2019	189	<1	412	8.13	<2	18	216	<0,1	1.52	9.94	105.2	<0,01	0.42	0.00027	0.42
Jadro, downstream	30.09.2019	201	<1	456	7.66	<2	15.5	221	0.8	1.56	10.11	101.5	0.66	1.19	0.01025	0.53
Jadro, downstream	21.10.2019	153	<1	434	7.47	<2	17.4	164	0.41	0.82	9.98	104.3	0.04	0.66	0.00046	0.62
Jadro, downstream	21.11.2019	194	9	357	7.63	<2	13.1	196	0.47	0.63	10.74	102.3	0.04	0.54	0.00048	0.5
Jadro, downstream	19.12.2019	183	<1	359	7.59	<2	12.1	201	0.68	0.97	10.69	99.53	<0,01	0.47	0.00005	0.47
Jadro, downstream	13.01.2020	214	4	406	7.43	<2	11	239	0.67	1.21	10.9	98.91	0.15	0.75	0.00098	0.6
Jadro, downstream	10.02.2020	190	<1	410	7.91	<2	10.3	198	0.32	0.7	11.27	100.6	<0,01	0.61	0.00009	0.61
Jadro, downstream	18.03.2020	192	3	368	8.19	<2	15.7	202	0.62	1.55	10.93	110.2	<0,01	0.4	0.00026	0.4
Jadro, downstream	20.04.2020	178	3	373	7.35	<2	16.3	201	0.91	1.37	11.28	115.2	<0,01	0.42	0.00004	0.42
Jadro, downstream	28.05.2020	193	4	424	7.76	<2	16.2	209	0.37	0.64	10.55	107.5	<0,01	0.4	0.0001	0.4
Jadro, downstream	23.06.2020	152	3	402	7.35	<2	21.8	192	0.39	0.71	10.16	115.8	<0,01	0.36	0.00006	0.36
Jadro, downstream	21.07.2020	179	3	446	7.79	<2	23.1	187	0.41	0.62	9.88	115.4	<0,01	0.42	0.00018	0.42
Jadro, downstream	24.08.2020	177	3	480	7.71	<2	16.6	227	0.26	0.45	9.62	98.87	<0,01	0.86	0.00009	0.39
Jadro, downstream	15.09.2020	147	3	463	7.95	<2	18.9	242	0.37	0.69	10.31	111.1	0.02	0.44	0.00077	0.42
Jadro, downstream	28.10.2020	181	<1	413	7.75	<2	15.2	221	0.61	1.01	10.82	108	0.38	0.92	0.00708	0.54
Jadro, downstream	20.11.2020	201	4	409	7.96	<2	11	204	0.57	1.3	11.76	106.7	<0,01	0.49	0.00011	0.49
Jadro, downstream	09.12.2020	193	<1	376	7.6	<2	10	211	0.23	0.58	11.31	100.3	<0,01	0.57	0.00004	0.57
Jadro, downstream	07.01.2021	175	<1	378	7.52	<2	11.6	195	0.75	1.63	11.23	103.4	<0,01	0.54	0.00004	0.54
Jadro, downstream	01.02.2021	184	4	376	7.9	<2	13.1	212	0.59	1.33	11.26	107.2	0.12	0.63	0.00268	0.51
Jadro, downstream	08.03.2021	181	3	394	7.24	<2	9	233	0.17	0.31	11.55	99.91	<0,01	0.46	0.00002	0.46
Jadro, downstream	06.04.2021	214	<1	390	7.3	<2	11.1	223	0.21	0.46	11.01	100.2	<0,01	0.51	0.00002	0.51
Jadro, downstream	06.05.2021	168	<1	351	8.05	<2	17.7	192	0.19	0.43	9.8	103	<0,01	0.37	0.00022	0.37

Nitrites (mgN/l)	Organic nitrogen (mgN/l)	Dissolved orthophosphates (mgP/l)	Dissolved organic carbon (DOC) (mgC/l)	Total nitrogen (mgN/l)	Total phosphorus (mgP/l)	Total dissolved carbon (TOC) (mgC/l)	Fluorides (mg/l)	calciumj (mg/l)	Potassium (mg/l)	Chlorides (mg/l)	Magnesiumj (mg/l)	Sodium (mg/l)	Total residual chlorine ($mgCl_2/l$)	Total residual chlorine (mgHOCl/l)	Sulphates (mg/l)	Dissolved copper (µg/l)	Dissolved zinc (µg/l)	Total zinc (µg/l)
<0,001	0.144	0.008	0.647	0.694	0.021	1.691	0.063	63.65	0.421	9.225	3.62	3.39	<0,04	<0,0148	5.73	1.77	<10	
<0,001	0.382	0.003	0.393	0.932	0.036	0.411	0.07	76.16	0.6	8.23	3.92	4.18	<0,04	<0,0148	5.85	1.82	<10	
<0,001	0.131	0.005	0.454	0.631	0.024	0.704	0.05	68.19	0.28	4.67	4.01	3.098	<0,04	<0,0148	5.71	2.8	<10	
<0,001	0.289	0.007	0.451	0.859	0.026	0.726	0.05	76.28	0.74	8.09	6.02	4.19	<0,04	<0,0148	7.33	3.8	<10	
<0,001	0.288	0.004	0.632	0.904	0.041	0.628	0.05	72.38	0.57	9.8	8.52	5.59	<0,04	<0,0148	14.2	<1	<10	
<0,001	0.544	0.008	0.834	0.974	0.024	0.903	0.038	74.2	0.63	10.8	7.67	6.61	<0,04	<0,0148	15	<1	<10	
<0,001	0.099	0.003	0.711	0.887	0.013	0.755	0.04	71.93	0.87	12.71	6.69	7.83	<0,04	<0,0148	15.87	<1	<10	
<0,001	0.67	0.009	1.085	1.12	0.041	1.281	0.05	67.14	1.32	18.44	6.47	11.46	<0,04	<0,0148	18.41	<1	<10	
0.001	0.325	0.019	0.578	0.853	0.034	0.61	0.05	78.76	0.76	21.04	7.11	14.12	<0,04	<0,0148	21.28	<1	<10	
<0,001	0.342	0.009	1.057	0.781	0.031	1.131	0.04	75.27	0.75	20.31	6.66	15.78	<0,04	<0,0148	16.48	<1	<10	
<0,001	0.155	0.015	0.501	0.676	0.036	0.556	0.05	77.3	1.14	18.9	5.29	12.1	<0,04	<0,0148	16.2	2.15	<10	
0.004	0.018	0.006	0.711	0.504	0.021	0.761	0.031	61.5	0.757	7.66	2.08	2.91	<0,04	<0,0148	5.32	<1	<10	
<0,03	0.25	0.007	0.44	0.88	0.015	0.54		80			5.97		0.04	0.0296		<0,3		3.11
<0,03	0.32	0.012	0.98	1.6	0.057	1.06		78.2			8.68		0.09	0.0665		<0,3		<2
<0,03	0.14	<0,005	0.46	0.64	<0,002	0.5		73.5			4		0.07	0.0518		0.343		<2
<0,03	0.06	<0,005	0.4	0.54	0.004	0.61		71.9			3.59		0.06	0.0444		<0,3		2.33
<0,03	0.08	<0,005	0.38	0.62	<0,002	0.5		71.7			6.09		<0,02	<0,00739		<0,3		<2
<0,03	0.37	0.016	0.66	1.4	0.022	0.78		73.1			7.25		0.09	0.0665		<0,3		<2
<0,03	0.26	<0,005	0.87	0.68	<0,002	1.24		73.6			7.64		0.03	0.0222		<0,3		2.24
<0,03	0.81	0.062	0.8	2	0.081	1.1		74.2			8.63		<0,02	<0,00739		0.406		3.8
<0,03	0.04	<0,005	0.42	0.7	<0,002	0.61		54.2			6.78		0.09	0.0665		<0,3		<2
<0,03	0.09	<0,005	0.55	0.63	<0,002	0.59		73.3			3.13		0.03	0.0222		<0,3		<2
<0,03	0.05	<0,005	0.81	0.52	<0,002	0.9		76			2.73		0.06	0.0444		<0,3		<2
<0,03	0.16	<0,005	0.94	0.91	<0,002	1.1		85.9			5.86		<0,02	<0,00739		<0,3		2.91
<0,03	0.02	<0,005	0.56	0.63	<0,002	0.66		68.6			6.55		0.03	0.0222		<0,3		39.1
<0,03	0.15	<0,005	1.2	0.55	<0,002	1.51		72.7			4.76		0.02	0.0148		<0,3		<2
<0,03	0.08	<0,005	0.85	0.5	<0,002	1.13		69			7		<0,02	<0,00739		<0,3		<2
<0,03	0.24	<0,005	0.46	0.64	<0,002	0.49		69.9			8.14		0.03	0.0222		<0,3		<2
<0,03	0.12	<0,005	0.53	0.48	<0,002	0.56		63.5			7.92		<0,02	<0,00739		1.19		<2
<0,03	0.32	<0,005	<0,3	0.74	<0,002	0.46		61.2			8.27		<0,02	<0,00739		<0,3		<2
0.47	0.02	<0,005	0.37	0.88	<0,002	0.4		74.9			9.67		<0,02	<0,00739		<0,3		<2
<0,03	0.4	<0,005	0.35	0.84	<0,002	0.58		80.9			9.73		<0,02	<0,00739		<0,3		17.9
<0,03	0.38	0.031	0.66	1.3	0.044	0.95		80.2			4.97		<0,02	<0,00739		<0,3		<2
<0,03	0.12	<0,005	<0,3	0.61	<0,002	1.18		71.7			6.17		<0,02	<0,00739		<0,3		<2
<0,03	0.27	<0,005	0.38	0.84	<0,002	0.51		78.8			3.41		<0,02	<0,00739		<0,3		<2
<0,03	0.24	<0,005	0.56	0.78	<0,002	1.52		73.5			2.77		<0,02	<0,00739		<0,3		<2
<0,03	0.37	<0,005	0.95	1	0.014	1.27		79.8			3.22		<0,02	<0,00739		0.404		<2
<0,03	0.28	<0,005	<0,3	0.74	<0,002	<0,3		82			6.86		<0,02	<0,00739		<0,3		<2
<0,03	0.11	0.012	<0,3	0.62	0.033	<0,3		78.2			6.7		<0,02	<0,00739		<0,3		<2
<0,03	0.18	<0,005	<0,3	0.55	<0,002	<0,3		70.5			3.87		<0,02	<0,00739		0.512		<2

Annex 2: data of the Žrnovnica river

Name of the sampling point	Sampling date	Alcality m-valuet ($mgCaCO_3/l$)	Colour (mg/l Pt/Co)	Electrical conductivity at 25°C (µS/cm)	pH value	Toptal suspended matter (mg/l)	Temperature of water (°C)	Tvrdoća ukupna ($mgCaCO_3/l$)	BOD_5 (mgO_2/l)	COD-Mn (mgO_2/l)	Dissolved oxygen (mgO_2/l)	Oxygen saturation (%)	Ammonium (mgN/l)	Anorganic nitrogen (mgN/l)	Unionized ammonia ($mgNH_3/l$)	Nitrates (mgN/l)
rnovnica, downstrea	25.01.2018	159	<5	393	8.05	0.6	13	172	0.58	1.05	11.68	111	<0,003	0.57	0.00005	0.57
rnovnica, downstrea	22.02.2018	196	<5	394	8.03	10.1	12.8	208	1.31	1.96	11.75	111.2	<0,003	0.56	0.00004	0.56
rnovnica, downstrea	21.03.2018	181	<5	366	8.22	<0,53	12.1	190		1.6	12.89	120	<0,003	0.41	0.00006	0.41
rnovnica, downstrea	19.04.2018	187	<5	372	8.23	0.6	14.4	195	1.48	1.98	12.37	121.3	<0,003	0.4	0.00008	0.4
rnovnica, downstrea	30.05.2018	198	<5	412	8.19	1.2	14.4	209		1.8	11.95	117.2	0.044	0.544	0.00207	0.5
rnovnica, downstrea	18.06.2018	195	<5	401	8.22	2.6	15.6	210		2.09	12.4	124.7	<0,003	0.363	0.00008	0.363
rnovnica, downstrea	23.07.2018	182	<5	406	8.21	1.5	14.4	195	2.47	2.91	11.34	111.2	<0,003	0.81	0.00007	0.81
rnovnica, downstrea	22.08.2018	181	<5	430	8.29	0.9	15.8	197	1.04	1.08	11.34	114.7	<0,003	0.49	0.0001	0.49
rnovnica, downstrea	17.09.2018	202	<5	438	8.22	<0,53	12.7	217	1.22	2.08	12.09	114.2	0.014	0.574	0.00062	0.56
rnovnica, downstrea	29.10.2018	203	<5	424	8.08	3.7	14.3	216	2.78	2.78	11.3	110.6	0.01	0.68	0.00037	0.67
rnovnica, downstrea	19.11.2018	180	<5	375	8.09	<0,53	11.8	189		1.28	13.75	127.2	<0,003	0.416	0.00005	0.416
rnovnica, downstrea	05.12.2018	178	<5	404	7.89	0.7	13	188	0.97	1.23	11.68	111	0.03	0.608	0.00065	0.578
rnovnica, downstrea	26.02.2019	198	2	375	7.83	<2	12.2	208	0.81	1.34	11.9	111	<0,01	0.47	0.00009	0.47
rnovnica, downstrea	18.03.2019	184	4	366	7.67	<2	14	206	0.94	1.09	11.43	111.1	<0,01	0.45	0.00007	0.45
rnovnica, downstrea	17.04.2019	150	8	358	7.81	<2	13.3	169	0.42	0.73	11.02	105.5	<0,01	0.49	0.00009	0.49
rnovnica, downstrea	16.05.2019	199	<1	380.8	7.78	<2	14.3	182	<0,1	1.09	10.79	105.6	0.04	0.52	0.00075	0.48
rnovnica, downstrea	11.06.2019	200	<1	369	7.94	<2	16.1	213	0.36	0.42	9.1	92.57	<0,01	0.38	0.00015	0.38
rnovnica, downstrea	19.07.2019	110	<1	365	7.71	<2	18.2	164	0.21	1.2	9.03	95.96	<0,01	0.47	0.00011	0.47
rnovnica, downstrea	30.08.2019	192	<1	388	8.08	<2	18	210	<0,1	1.4	9.18	97.14	0.03	0.45	0.00144	0.42
rnovnica, downstrea	23.09.2019	187	<1	406	7.88	<2	14.9	203	0.43	0.76	9.91	98.22	0.1	0.59	0.00244	0.49
rnovnica, downstrea	21.10.2019	184	<1	432	7.22	<2	16.1	199	0.6	0.94	9.86	100.3	0.02	0.64	0.00012	0.62
rnovnica, downstrea	21.11.2019	193	11	367	7.82	<2	13.7	200	0.84	1.13	10.72	103.5	0.06	0.5	0.00117	0.44
rnovnica, downstrea	19.12.2019	195	<1	365	7.67	<2	11.9	212	0.7	1.48	10.68	98.98	0.04	0.31	0.00048	0.27
rnovnica, downstrea	13.01.2020	188	3	368	7.56	<2	12.7	211	0.7	1.33	10.9	102.9	<0,01	0.46	0.00005	0.46
rnovnica, downstrea	06.02.2020	198	2	383	8.09	<2	7.9	291	0.53	1.16	12.1	101.9	<0,01	0.5	0.00012	0.5
rnovnica, downstrea	18.03.2020	182	2	357	8.13	<2	15.9	199	0.28	0.63	10.74	108.8	<0,01	0.35	0.00023	0.35
rnovnica, downstrea	20.04.2020	193	2	352	8.04	<2	16	205	0.72	1.46	10.66	108.2	<0,01	0	0.00019	<0,23
rnovnica, downstrea	28.05.2020	190	5	400	8.04	<2	16	195	0.4	0.68	10.65	108.1	<0,01	0.45	0.00019	0.45
rnovnica, downstrea	17.06.2020	164	2	389	8.04	<2	18.3	173	0.31	0.68	11	117.1	<0,01	0.36	0.00022	0.36
rnovnica, downstrea	21.07.2020	186	3	412	7.7	<2	23.1	205	0.32	0.59	10.12	118.2	<0,01	0.46	0.00015	0.46
rnovnica, downstrea	20.08.2020	161	3	429	8.02	<2	18.3	206	0.21	0.45	9.7	103.3	<0,01	0.39	0.00021	0.39
rnovnica, downstrea	15.09.2020	167	2	456	8.06	<2	17.8	223	0.3	0.54	10.83	114.1	<0,01	0.39	0.00023	0.39
rnovnica, downstrea	28.10.2020	183	2	374	7.67	<2	15.4	203	0.92	1.66	10.96	109.8	<0,01	0.53	0.00008	0.53
rnovnica, downstrea	20.11.2020	191	2	396	7.75	<2	10	214	0.38	0.82	11.48	101.8	<0,01	0.53	0.00006	0.53
rnovnica, downstrea	09.12.2020	181	3	361	7.53	<2	10	187	0.49	0.89	11.28	100	<0,01	0.42	0.00004	0.42
rnovnica, downstrea	08.01.2021	175	<1	372	7.78	<2	9.8	199	0.3	0.56	11.61	102.4	<0,01	0.43	0.00007	0.43
rnovnica, downstrea	01.02.2021	169	4	362	7.93	<2	13	208	0.41	0.9	11.49	109.2	0.1	0.44	0.00237	0.34
rnovnica, downstrea	16.03.2021	185	2	374	7.19	<2	9.9	222	0.15	0.34	11.55	102.1	<0,01	0.38	0.00002	0.38
rnovnica, downstrea	06.04.2021	199	<1	381	7	<2	11.7	209	0.19	0.4	10.78	99.45	<0,01	0.44	0.00001	0.44
rnovnica, downstrea	06.05.2021	145	<1	333	7.99	<2	18	156	0.15	0.34	9.94	105.2	<0,01	0.28	0.0002	0.28

Nitrites (mgN/l)	Organic nitrogen (mgN/l)	Dissolved orthophosphates (mgP/l)	Dissolved organic carbon (DOC) (mgC/l)	Total nitrogen (mgN/l)	Total phosphorus (mgP/l)	Total dissolved carbon (TOC) (mgC/l)	Fluorides (mg/l)	calciumj (mg/l)	Potassium (mg/l)	Chlorides (mg/l)	Magnesiumj (mg/l)	Sodium (mg/l)	Total residual chlorine ($mgCl_2/l$)	Total residual chlorine (mgHOCl/l)	Sulphates (mg/l)	Dissolved copper (µg/l)	Dissolved zinc (µg/l)	Total zinc (µg/l)
<0,001	0.197	0.004	0.698	0.767	0.021	0.704	0.063	63.6	0.42	9.22	3.62	3.38	<0,04	<0,0148	5.7	2.31	<10	
<0,001	0.148	<0,001	0.65	0.708	<0,003	0.688	0.05	74.72	0.34	7.5	4.79	3.48	<0,04	<0,0148	6.32	<1	<10	
<0,001	0.133	0.007	0.902	0.543	0.009	1.169	0.07	69.05	<0,28	6.93	3.61	3.46	<0,04	<0,0148	5.55	2.49	<10	
<0,001	0.276	0.004	0.655	0.676	0.027	0.833	0.05	72.33	0.89	8.45	3.52	5.06	<0,04	<0,0148	6.57	4.16	<10	
<0,001	0.223	0.004	0.576	0.767	0.009	0.616	0.05	72.74	0.461	9.43	6.58	5.37	<0,04	<0,0148	8.65	1.89	<10	
<0,001	0.445	0.003	0.748	0.808	0.009	0.839	0.048	74.6	0.601	10.6	5.99	6.11	<0,04	<0,0148	12.6	3.81	<10	
<0,001	0.136	0.007	0.785	0.946	0.023	0.832	0.06	70.62	0.96	10.26	4.41	6.65	<0,04	<0,0148	12.25	<1	<10	
<0,001	0.165	0.004	0.699	0.655	0.037	0.744	0.06	69.93	0.76	13.91	5.23	8.46	<0,04	<0,0148	14.01	<1	<10	
<0,001	0.269	0.005	0.626	0.843	0.024	0.68	0.04	77.71	0.77	18.05	5.9	11.8	<0,04	<0,0148	14.75	<1	<10	
<0,001	0.151	0.008	1.821	0.831	0.019	1.925	0.04	77.43	0.84	17.67	5.34	11.91	<0,04	<0,0148	12.74	<1	<10	
<0,001	0.119	0.009	0.811	0.535	0.032	0.908	0.044	70.82	1.123	10.5	2.93	5.39	<0,04	<0,0148	5.72	<1	<10	
<0,001	0.152	<0,001	1.233	0.76	<0,003	1.314	0.059	70.8	0.713	8.1	2.55	4.03	<0,04	<0,0148	5.46	<1	<10	
<0,03	0.17	0.008	0.67	0.64	0.014	1.28		76.7			3.99		0.06	0.0444		0.31		3.15
<0,03	0.1	<0,005	0.74	0.55	<0,002	0.76		71.8			6.53		0.06	0.0444		<0,3		<2
<0,03	0.31	<0,005	0.57	0.8	0.004	0.64		62			3.38		0.06	0.0444		0.373		<2
<0,03	0.06	<0,005	0.64	0.58	0.007	0.78		68			2.97		0.09	0.0665		<0,3		3.56
<0,03	0.09	<0,005	<0,3	0.47	<0,002	0.41		77			4.92		0.03	0.0222		<0,3		2.08
<0,03	0.12	<0,005	0.42	0.59	<0,002	0.5		57.5			4.74		0.05	0.03697		<0,3		<2
<0,03	0.11	<0,005	0.63	0.56	<0,002	1.19		73.2			6.55		0.07	0.0518		<0,3		<2
<0,03	0.04	<0,005	0.63	0.63	0.011	0.69		69.5			6.96		<0,02	<0,00739		<0,3		<2
<0,03	0.04	<0,005	0.55	0.68	0.005	0.86		68.5			6.71		0.04	0.0296		<0,3		<2
<0,03	0.08	<0,005	0.87	0.58	<0,002	0.92		73.9			3.57		<0,02	<0,00739		0.3		<2
<0,03	0.11	<0,005	1.1	0.42	<0,002	1.2		80			2.94		0.09	0.0665		<0,3		<2
<0,03	0.05	<0,005	0.72	0.51	<0,002	1		78			3.8		<0,02	<0,00739		<0,3		<2
<0,03	0.02	<0,005	0.73	0.52	<0,002	0.73		107			5.72		0.03	0.0222		<0,3		<2
<0,03	0.07	<0,005	0.5	0.42	<0,002	0.59		72.4			4.27		<0,02	<0,00739		<0,3		<2
<0,03	0.5	<0,005	0.86	0.5	<0,002	1.22		73			5.55		<0,02	<0,00739		<0,3		<2
<0,03	0.06	<0,005	<0,3	0.51	<0,002	0.53		67.4			6.54		0.02	0.0148		<0,3		<2
<0,03	0.11	<0,005	0.61	0.47	<0,002	0.65		59.1			6.16		<0,02	<0,00739		<0,3		<2
<0,03	0.23	<0,005	<0,3	0.69	<0,002	0.43		71.7			6.21		<0,02	<0,00739		<0,3		<2
<0,03	0.16	<0,005	<0,3	0.55	<0,002	0.33		69.5			7.73		<0,02	<0,00739		<0,3		<2
<0,03	0.29	<0,005	<0,3	0.68	<0,002	0.37		76.5			7.82		<0,02	<0,00739		<0,3		<2
<0,03	0.19	<0,005	0.73	0.72	<0,002	1.04		73.8			4.56		<0,02	<0,00739		<0,3		<2
<0,03	0.06	<0,005	<0,3	0.59	<0,002	0.77		78.2			4.65		<0,02	<0,00739		<0,3		<2
<0,03	0.19	<0,005	0.76	0.61	<0,002	0.78		71.3			2.13		<0,02	<0,00739		<0,3		<2
<0,03	0.13	<0,005	0.3	0.56	<0,002	0.37		75.1			2.74		<0,02	<0,00739		<0,3		<2
<0,03	0.21	<0,005	0.7	0.65	<0,002	0.84		78.8			2.55		<0,02	<0,00739		<0,3		<2
<0,03	0.04	0.311	<0,3	0.42	0.325	<0,3		80.3			5.05		<0,02	<0,00739		<0,3		<2
<0,03	0.08	<0,005	<0,3	0.52	0.006	<0,3		75.1			5.16		<0,02	<0,00739		<0,3		<2
<0,03	0.09	0.144	<0,3	0.37	0.264	<0,3		58.2			2.67		<0,02	<0,00739		<0,3		<2