HyMoCARES Project

WPT3.
EFFECTS OF HYDROMORPHOLOGICAL MANAGEMENT AND RESTORATION MEASURES
D.T3.3.1 Technical note on the evaluation of physical and ecological effects of river restoration works

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1 Introduction

1.1 The study site: Adige River

The Adige River is the longest river in the South Tyrol region located in the North-Eastern part of Italy, and the second longest river in Italy. It has a total length of 410 km and flows from the Alps into the Adriatic See.

Within the HyMoCARES project, many restoration works took place along the Adige River. In this study, two reaches have been investigated since restorations characterized by different features were carried out (see Figure 1):

1. the Postal reach stretches from km 79 to km 81[1];
2. the Ponte Adige reach stretches from km 97 to km 99.

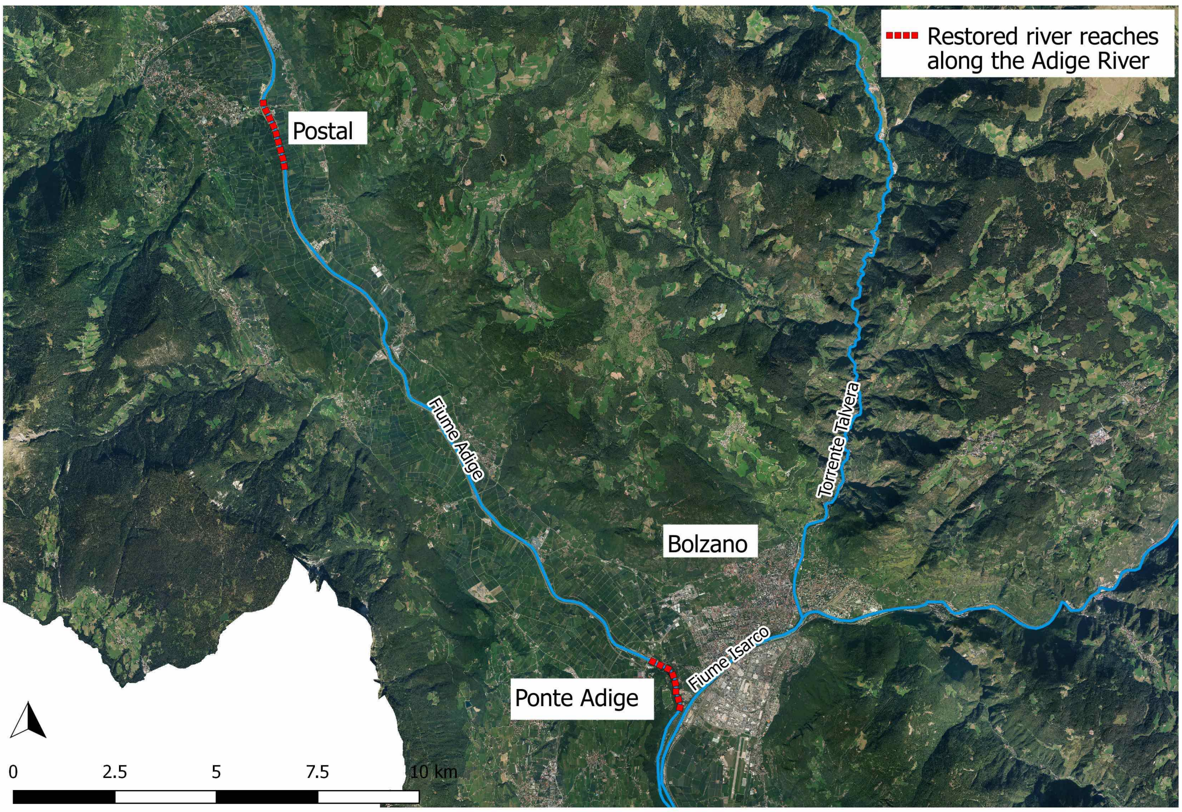

Figure 1: *Overview of the study reaches along the Adige River that have been studied within the HyMoCARES project. Restoration took place in several parts along the entire reach stretching from Postal to Ponte Adige*

[1]km refers to the Adige spring next to the Resia reservoir

Table 1 reports the main characteristics of the catchment closed at Ponte Adige (240 m a.s.l.). The drainage area is 2700 km^2, of which glaciers encompasses a 2.88%. The hydrological regime of the catchment is nivo-glacio-pluvial, which means that the average annual discharge is characterized by three peaks; one occurs in late spring-early summer, due to snow melt, the second occurs during late summer, due to glacier melt and the third one occurs during the fall, due to rainfall. The geological composition varies from slate to paragneiss and porphyry rocks.

Pilote Site	**Adige River**
Catchment area closed at Ponte Adige (km^2)	2705
Minimum elevation of the catchment (m a.s.l.)	240
Maximum elevation of the catchment (m a.s.l.)	3893
Start coordinates (East, North) - Postal river reach	666965.716, 5164266.872
End coordinates (East, North) - Postal river reach	667502.216, 5162580.728
Length of the Postal river reach (km)	2.0
Start coordinates (East, North) - Ponte Adige river reach	676482.209, 5150458.376
End coordinates (East, North) - Ponte Adige river reach	677242.251, 5149232.090
Length of the Ponte Adige river reach (km)	2.0
Active channel width (m)	40 - 60
Channel slope (%)	0.2 - 0.3
Planform morphology	Single-thread

Table 1: *Main physical features of the study reaches and catchment characteristics closed at Ponte Adige*

1.2 Human alterations

The major human alterations influencing the Adige River are due to hydropower production, river channelization and agriculture pressure. The recent development and spread of infrastructures, railway, electric lines and pipelines contributed to increase the anthropic pressure on this area. The mountainous topography of South Tyrol makes this region prone to water exploitation through hydropower plants. In the Venosta Valley, between the Resia reservoir and the village of Tel, many hydropower plants contribute to modify the natural flow regime of the Adige River. Water level fluctuations have a negative impact on aquatic and terrestrial species, especially when occurring in delicate seasons (e.g. winter for fish reproduction).

Since its channelization at the beginning of the XIX century, the Adige has been confined within a narrow and often straight channel. The average river width ranges between 40 to 60 m; due to its monotonous shape, the flow depth is generally homogeneous and insular areas are quite rare or restricted. The consequences, clearly visible when comparing the river morphology in 1800 to the current one (Figure 2), are a loss of morphological variability, loss of habitats and species, channel incision due to the limited sediment supply. In particular, the partly sinuous, partly braided structure is now completely lost, in favour of a monocursal mainly straight channel (Figure 2). The Adige Valley is also affected by intensive agriculture activities, being characterized mainly by apple tree crops. The use of pesticides and other chemical products negatively affects water quality and therefore influences the organisms living in the near watercourses.

1.3 The restoration project: goals and measures

The Civil Protection Agency of the Autonomous Province of Bolzano has been carrying on restoration works along the Adige River since 2002, with the main aim of improving its physical heterogeneity, diversifying habitats and thus enhancing the value of the aquatic communities. In particular, river restoration works started in 2011 at Postal and in 2013 at Ponte Adige. The main restoration objective for both the study reaches pursuits the improvement of fish habitat, through creating a variability in the river morphologies, since it leads to a higher number of microhabitats which in turn enhances the colonization by aquatic species. The restoration actions for the two study sites are:

1. Postal (restoration 2011-2014; pre-restoration $<$ 2011; post-restoration $>$ 2014)

   - **Channel widening and riverbanks renaturalization** along the right bank.
   - **Improving lateral connectivity** between the Adige River and its tributaries to enhance fish passage.
   - **Creation of macroforms** such as flow deflectors, island and inlets contribute to create sheltered areas where water flows slowly, alternated to areas of faster flow. In particular, flow deflectors were generally placed perpendicular to the flow, slightly leaning upstream. The flow is therefore mainly diverted toward the center of the riverbed and downstream each flow deflectors, areas

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Figure 2: *Adige at Postal at the beginning of 1800 (left) and in the 1998-1999 (right). The yellow lines on the left image indicate the river channelization proposal of the Austrian military engineer Ignaz von Nowack (FESR 4017 - Spatium Etsch-Adige, 2018)*

characterized by a slower current allow new habitat formation. Spawning gravel zones for trout reproduction will be re-established and the fish population is expected to grow.

- **Distribution of boulders and introduction of dead wood** into the river bed to create morphological structures and to slow the flow down, with the purpose of creating sheltered areas for fish spawning and ro foster the juveniles growth.
- **Promoting a recreational use** of the river embankments by smoothing the banks so that cyclists and pedestrians can access the reach; in addition recreational areas have been built along the river (picnic and fishing areas).

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2. Ponte Adige (restoration 2013; pre-restoration $<$ 2013; post-restoration $\geq$ 2014)

    - **Channel widening and riverbanks renaturalization** along the left bank.
    - **Creation of macroforms** such as flow deflectors, island and inlets contribute to create sheltered areas where water flows slowly, alternated to areas of faster flow. Spawning gravel zones for trout reproduction are expected to re-establish and, as a consequence, the fish population is expected to grow.
    - **Distribution of boulders** in the river bed to create morphological structures and to slow the flow down, with the purpose of creating sheltered areas for fish spawning and to foster the juvenile growth.
    - **Promoting a recreational use** of the river embankments by smoothing the banks so that cyclists and pedestrians can access the reach; in addition recreational areas have been built along the river (picnic and fishing areas).

Figure 3 shows some measures carried out at the two study sites. In particular, Figure 3-a displays the improved connectivity to a tributary on the orographic right, local turbulence created by the large boulder displaced along the river bed and gravel bow beaches on the left bank at Postal. Figure 3-b shows the restoration works at Ponte Adige; in particular the reshaping of the left bank, which provides morphological variability to the river.

The ambitious goal of the Autonomous Province of Bolzano to widen the river and act on a large scale is strongly limited by the surrounding context. In fact the pressure coming from infrastructures and agricultural lands makes this task hard to be achieved. So far, the number and the extension of these measures have been constrained to the available public land.

(a) *Location: Postal. Restored connectivity between the Adige and the lateral ditch*

(b) *Location: Ponte Adige. Restoration of the left riverbank through channel widening and riverbank reshaping*

Figure 3: *View of restoration works on the two study reaches*

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2 Monitoring approach

Restoration projects stem from a need for addressing critical morphological and ecological conditions of a water body. Monitoring and evaluation of restoration actions provide an important feedback on the restoration project effectiveness, including how physical habitat and biota respond to different restoration techniques. The monitoring activity is an ensemble of repeated observations and measurements followed by appropriate analyses, which provide useful information to evaluate changes in conditions and progress toward achieving a management objective. The objective describes the desired condition to be achieved (e.g. increase the number of deep pools in a river to favor fish refuge); management is designed to achieve the objective (e.g. creating or deepening the existent pools); and monitoring is designed to determine whether the objective is met (e.g. counting the number of fish before and after the intervention).

Funding and legal frameworks often require monitoring of at least a portion of projects. In the European Union, for example, both the Water Framework Directive (WFD) and the Habitats Directive require ecological monitoring and reporting on the status of all water bodies and evaluation of restoration measures. Monitoring should be part of the design of a restoration project and be planned in the early stage of the restoration planning process and well before actions are implemented on ground (Roni and Beechie, 2013).

Many authors (e.g. Elzinga et al., 2001) distinguish between monitoring as part of an observational study and of a proper research. Both are information gathering activities, and the field techniques used may be quite similar; however, the confidence on the conclusion one can obtain is very different. Because of this, confusion exists about the difference between an observational study (especially one that applies sampling design and statistical analysis) and research. Observational monitoring and research are ends of a continuum (Figure 5). The confidence of attributing a change to a particular cause increases along the continuum, and so does the cost for data acquisition. Monitoring data are usually of limited value in detecting true causes of change; care must be paid to not mistake causes for effect. For example, an increase of species richness observed after augmenting habitat heterogeneity in a river reach, would support the hypothesis that heterogeneity positively affect species, but it does not prove that heterogeneity is the cause of the increase. To proof the link between a cause and an effect, the increase has to be consistently found at several river reaches, and proved that the increase of species richness does not occur in other unmodified reaches. Only by comparing several times (replications) the situation between the site under restoration and sites were no interventions took place (control sites), changes can be confidently attributed to a treatment or cause. Therefore, monitoring design must incorporate control sites (to minimize the differences between the treatment and non-treatment areas except for the treatment itself) and replication (to measure the difference between treatment and non-treatment consistently over several-to-many independent units).

When designing a monitoring approach setting up a monitoring frame is crucial; it consists of the following elements:

- the **treated reach**, where the restoration action took place (pre- or/and post-restoration);
- a **control site** that is nearly identical to the treated location, with exception that no treatment occurs;
- a **reference site** which represents the desired or target condition following the restoration.

The restoration goals and monitoring objectives need to be clearly defined from the beginning. Restoration goals identify the target to be achieved and help the implementation of a sounded monitoring design. Some steps useful to design an efficient monitoring program are outlined in Figure 4.

Figure 5 illustrates a continuum of increasing confidence in determining likely causation from left to right in the diagram. In column B, there is no pre-treatment measurement and changes may be due to IHH (Increase of Habitat Heterogeneity) or they may be the result of some other factors. In column C, where data was gathered both before and after the intervention, still it is unknown whether changes were due to the IHH or some other factor that differed between the two time periods. In column D, there is a single treatment unit and a single control unit. In the last two columns, the treatment and control are replicated in space; thus there is a possibility of attributing differences to the treatment. The larger number of replicates in column F greatly increases the likelihood of detecting treatment differences due to the higher statistical power associated with 8 replicates as compared to 3 replicates.

Analyses should be able to identify unambiguously whether changes in a restored site were a response to the process of restoration (i.e. changes due to the restoration itself), occurred only in the site being restored and occurred in the direction and with the magnitude necessary to converge on the reference sites (Figure 6).

Different types of monitoring can be applied in habitat management or restoration: baseline, status, trend, implementation, effectiveness and validation. The first three types of monitoring are important in assessment, action identification and prioritization process. **Effectiveness monitoring** refers to assessing

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the primary response (i.e. whether the restoration action leads to the expected changes in physical habitat), while **validation monitoring** examines the secondary or tertiary responses (e.g. whether the change in habitat due to the restoration action leads to the expected change in biota or other conditions).

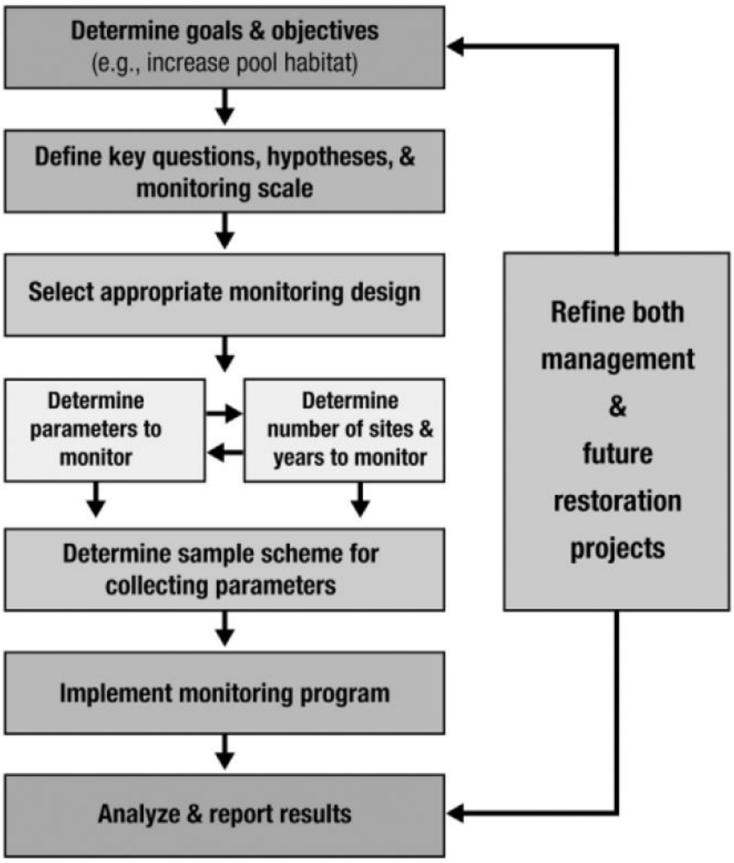

Figure 4: *Steps for designing a monitoring program (Roni and Beechie, 2013)*

The most common approach to evaluate restoration projects is the Before-After (BA) design, which simply involves monitoring the treated site before and after restoration. When also information regarding a control site is available the monitoring approach is the so-called BACI (Before-After Control-Impact). In other cases, data were not or cannot be collected before restoration occurs. The monitoring design therefore relies on a comparison of treatment and suitable control reaches or watersheds, with the assumption that the control was similar to the treatment before restoration (IPT, Intensive Post-Treatment and EPT, Extensive Post-Treatment). Once the monitoring design has been chosen, monitoring parameters have to be identified in order not to invest resources and time on unnecessarily monitoring programs. Ideally, the monitoring parameters should be tied to the objectives of the project and sensitive or responsive to the

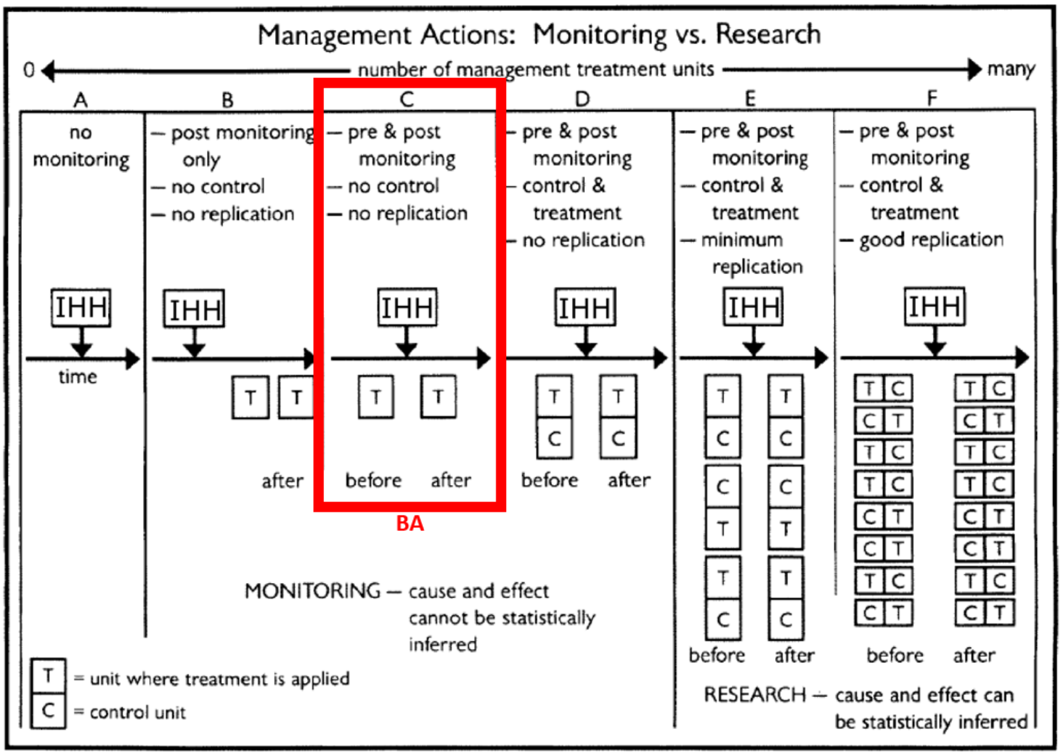

Figure 5: *A comparison of monitoring and research approaches for detecting a treatment effect (e.g. Increase of Habitat Heterogeneity, IHH, in rivers). In this case study the general design is based on the BA approach and only for the fish monitoring a BACI approach was implemented. From Elzinga et al. (2001)*

restoration action.

The last step of the monitoring design scheme involves the analysis and representation of the results. For BA or BACI designs, particularly those with little spatial replication, emphasis should be initially placed on the graphical interpretation of the data rather than statistical analysis.

In this case study the general monitoring design is based on the BA approach (see Figure 5, column C) with the exception of fish monitoring, for which data is available only after restoration for both reaches (Postal and Ponte Adige) so that a comparison is possible only for the current situation, between the restored and a control site. On the contrary, both for the physical and the ecological parameters, data are available pre- and post-restoration. The scheme displayed in Figure 7 shows the monitoring design used to assess the achievements of the main restoration measures performed along the Adige River. The available data and year in which the survey took place are summarized in Figure 8.

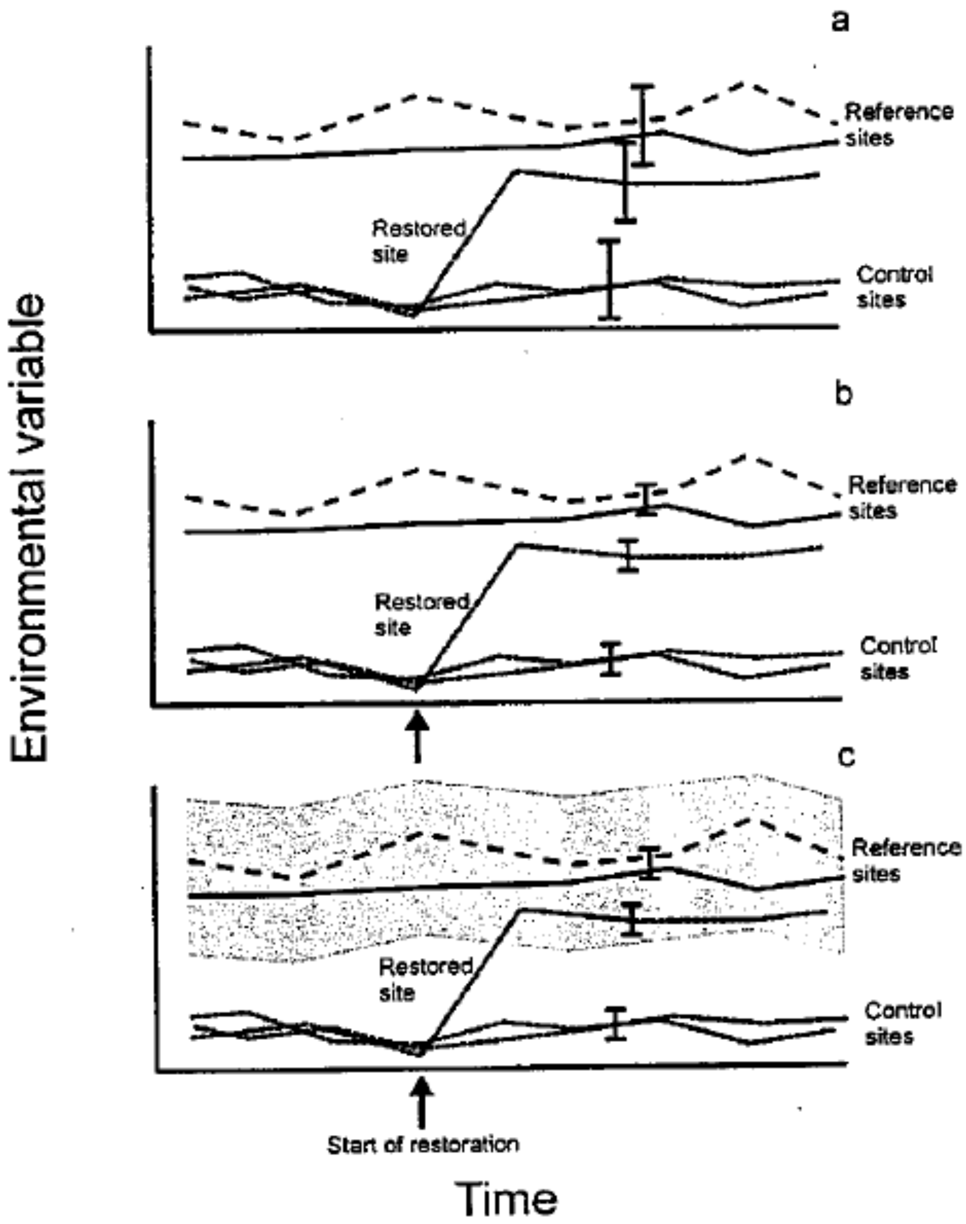

Figure 6: *Measurement of the restoration effect: (a) the large confidence intervals, due to imprecise sampling, cause the conclusion that the site being restored is not different from the reference sites; (b) more precise sampling, with smaller confidence interval, would reveal the failure of restoration; (c) the shaded area indicates a predetermined range below the mean of the reference sites that has been defined to indicate that restoration is adequate. From Underwood (1997)*

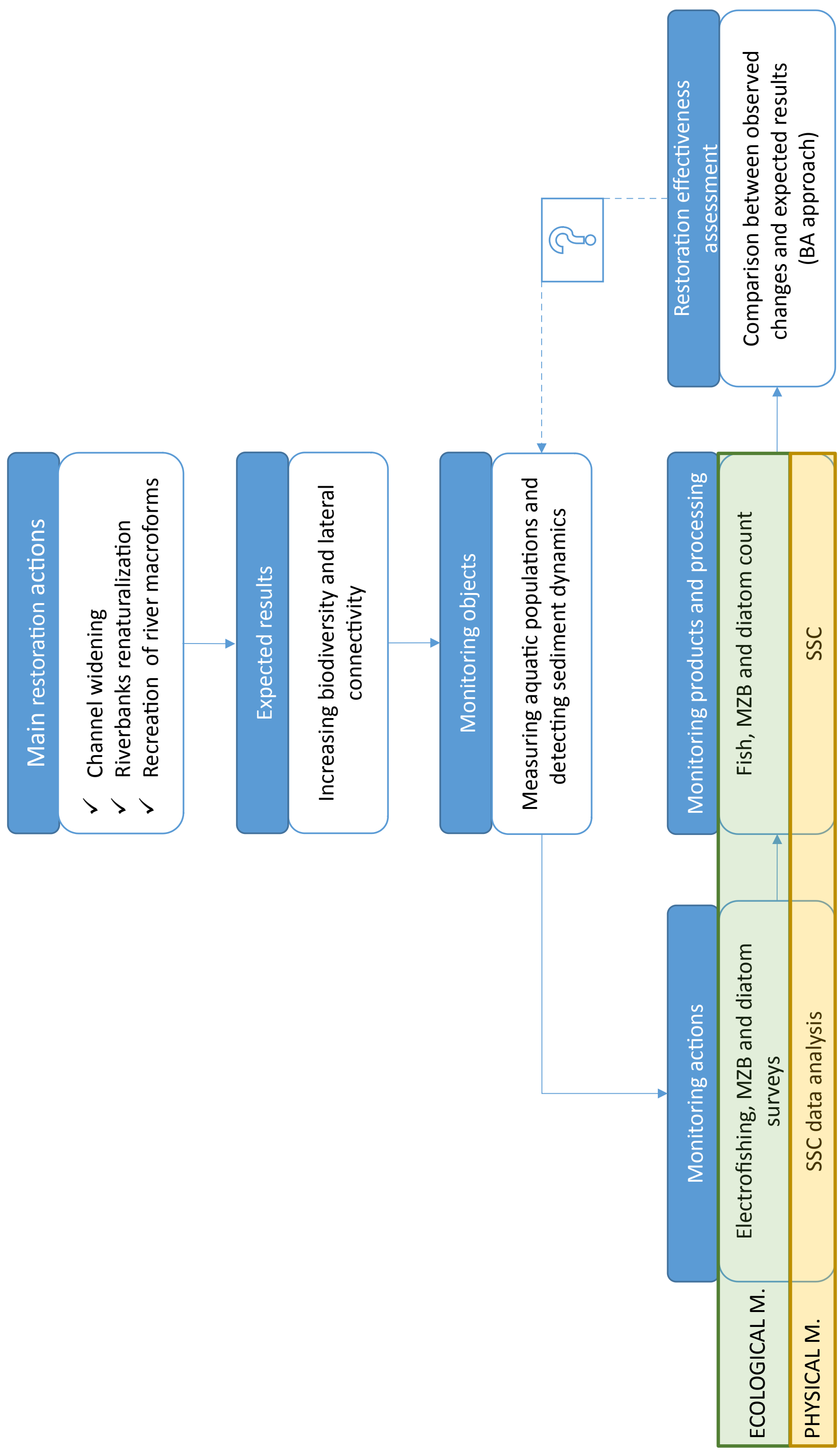

Figure 7: Main restoration measures, expected results and monitoring design for the Adige River case study

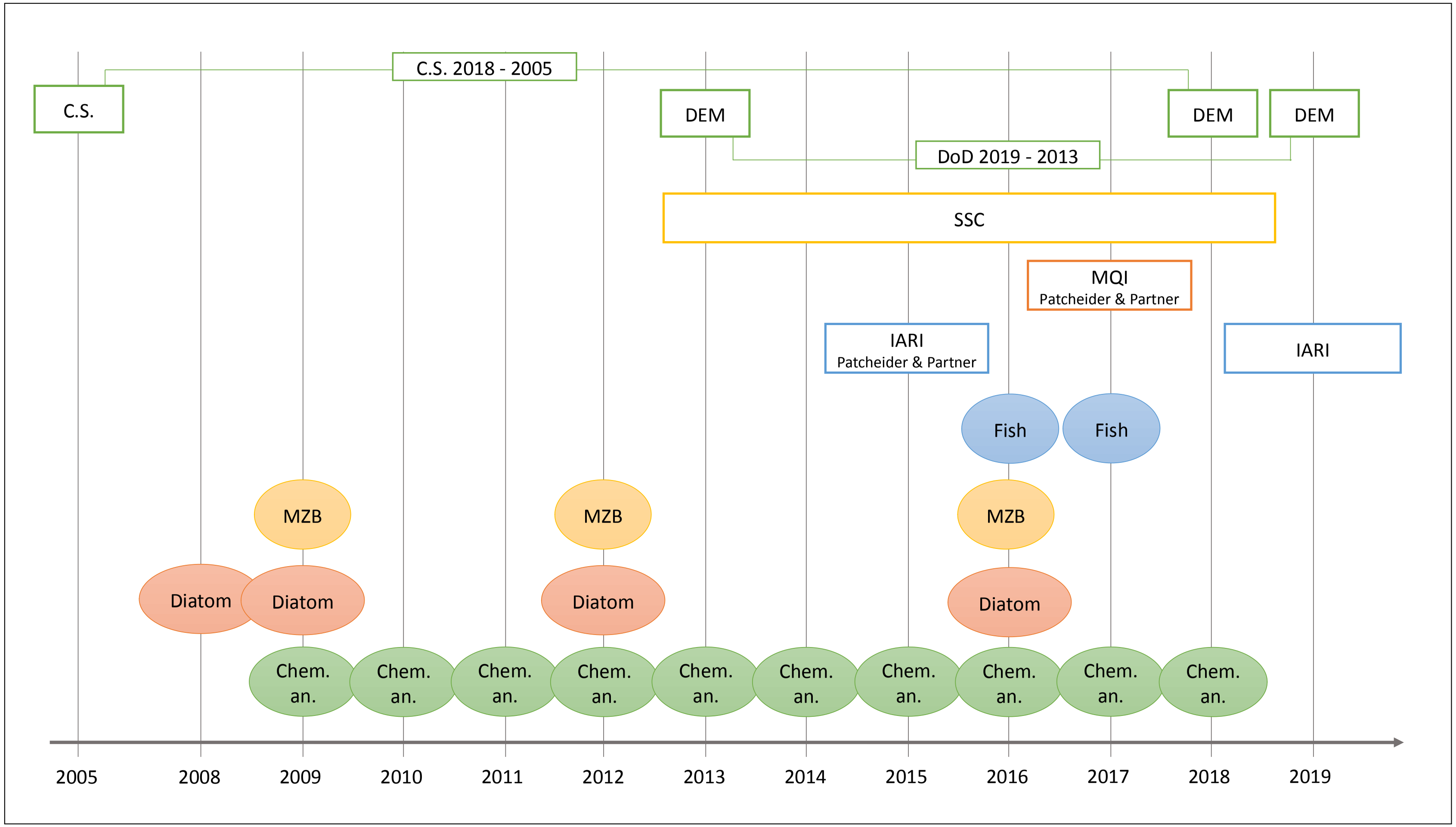

Figure 8: *Available data for the morphological and ecological monitoring and relative years. Restoration works within the HyMoCARES project started in 2011 and ended at the beginning of 2018. C.S. stands for "cross section", while "MZB" for the microinvertebrate population*

3 Physical monitoring

The physical monitoring on the Adige River encompasses different measures:

- **Topographic surveys and photo analysis**: at Postal the detection of variations on the riverbanks (i.e. erosion or deposition) is performed by comparing 2005-cross sections with 2018-topographic data. For the study site at Ponte Adige, more consistent topographic data are available and a DoD (DEM of Difference) analysis allows to assess riverbanks variations. The DoD obtained by comparing 2013-DEM with 2019-DEM provides an overview on the restoration works aimed at improving river accessibility and river width. The comparison between aerial images, taken before and after interventions, shows the impact on the landscape of the restoration works both in terms of channel widening and macroforms generation.
- **Discharge data** collection from the gauging station located at Ponte Adige. These discharge data were used to estimate the IARI (Hydrological Regime Alteration Index).
- Field surveys for visual inspection were fundamental to asses the **MQI (Morphological Quality Index)** and the **MQIm (Morphological Quality Index for monitoring)**, which quantitatively analyse the river hydro-morphological status and trend.
- Trend analysis of **Suspended Sediment Concentration (SSC)** to understand if an increase in sediment transport occurred after the restoration works. Suspended sediment data, collected by a tubidimeter located in the gauging station at Ponte Adige, are available since 2013.
- Analysis of historical **groundwater data** to evaluate whether restoration works affected groundwater table.

3.1 Topographic surveys

The available data to assess the morphological changes along the study reach are the following:

- 2005 cross sections: a topographic survey was performed in 2005 by the company geo-line S.r.l. (Bolzano). Cross sections were evenly spaced by 250 m between Merano and Salorno.
- 2013-DEM (Digital Elevation Model): a LiDAR flight was commissioned by the Autonomous Province of Bolzano in 2013 to survey the valley bottoms of the province. This survey did not include the

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bathymetric analysis of the riverbed, therefore the information regarding the riverbed elevation is missing. The 2013-DEM resolution for the floodplain is 0.5 m x 0.5 m.

- 2018 topographic survey data: carried out by the Civil Protection Agency of the Autonomous Province of Bolzano in 2018, which surveyed terrain elevations along the riverbanks within the study reaches by using a GPS. A DEM with a 0.5 m x 0.5 m resolution was created from these data.

- 2019 bathymetric and topographic survey financed by the Civil Protection Agency of the Autonomous Province of Bolzano along the area of Ponte Adige (the survey did not cover the restored reach at Postal). The topography of the river banks was detected by using the TLS (terrestrial Laser Scanner) Riegl VZ2000i, while the river bed elevation was measured through an Echo boat on which was installed a Bathyswath-2 (Figure 9). This tool is a comprehensive bathymetric and seabed mapping survey system which allows to detect up to 280 m width for a water depth of 25 m. In addition, the Structure from Motion (SfM) photogrammetric technology allowed the implementation of a 5 cm resolution orthophoto. The 2019-DEM shows the topography of the latest restoration works with a resolution of 0.5 m x 0.5 m and provides an insight on the effects of the flood event of October 2018.

Figure 9: *Picture showing the bathymetric survey along the Isarco River*

Along the Ponte Adige study area, the use of the 2013 and 2019 data in a DEM of Difference (DoD) approach allows for an assessment of elevation changes in time by comparing pre- (2013) and post- (2019) restoration

DEMs. This analysis was carried out through the software Q-GIS by performing a raster difference on a cell basis. The challenge of this method is due to the large scale on which the analysis is performed. Erosion and deposition patterns detected through the DoD are of the orders of magnitude of tens of centimeters; the uncertainty related to the DoD was estimated to be around 10 to 15 cm. Noise might derive for example from inaccurate removal of vegetation data, therefore in this study scour and deposits smaller than 15 cm have not been considered.

At Postal restoration works along the river reach started before 2013. Therefore morphological variations are evaluated through a comparison between the 2005-cross sections (pre-restoration) and the 2018-DEM (post-restoration). The data post-processing was carried out using a CAD type software, which provides graphical representation of the two overlapped cross sections and also estimates the amount of scoured and filled volumes, after construction. Aerial photos were used together with the DoD analysis to map changes in morphology and validated the computations.

3.2 Discharge alteration - IARI

The reason for this analysis stems from the fact that the alteration of the hydrological regime is the main cause of the biological decay of a water body. The Italian institute for environmental protection and research (ISPRA) proposed a methodology to quantify the discharge alteration based on the IARI (Index of Alteration of the Hydrological Regime). The IARI provides a measure of the deviation of the observed hydrological regime, evaluated on a daily or monthly base, from the natural one, that would be present if anthropic pressures were not there.

The ISPRA methodology foresees three phases for the IARI computation: phase 0 - i.e. pressure analysis; phase 1 - IARI computation itself; and phase 2 - expert judgment (Figure 10).

Phase 0. The first step concerns the identification of all the human pressures on a catchment. If no or negligible pressures are associated to the hydrological regime, this can be identified as unaltered. On the other hand, when the presence of significant human pressures is assessed, an objective analysis must be performed by applying the IARI computation itself.

Phase 1. The IARI computation has to be carried out following 3 different approaches, according to the available dataset. The availability of data can be: null, scarce or sufficient (Table 2). Since the main objective

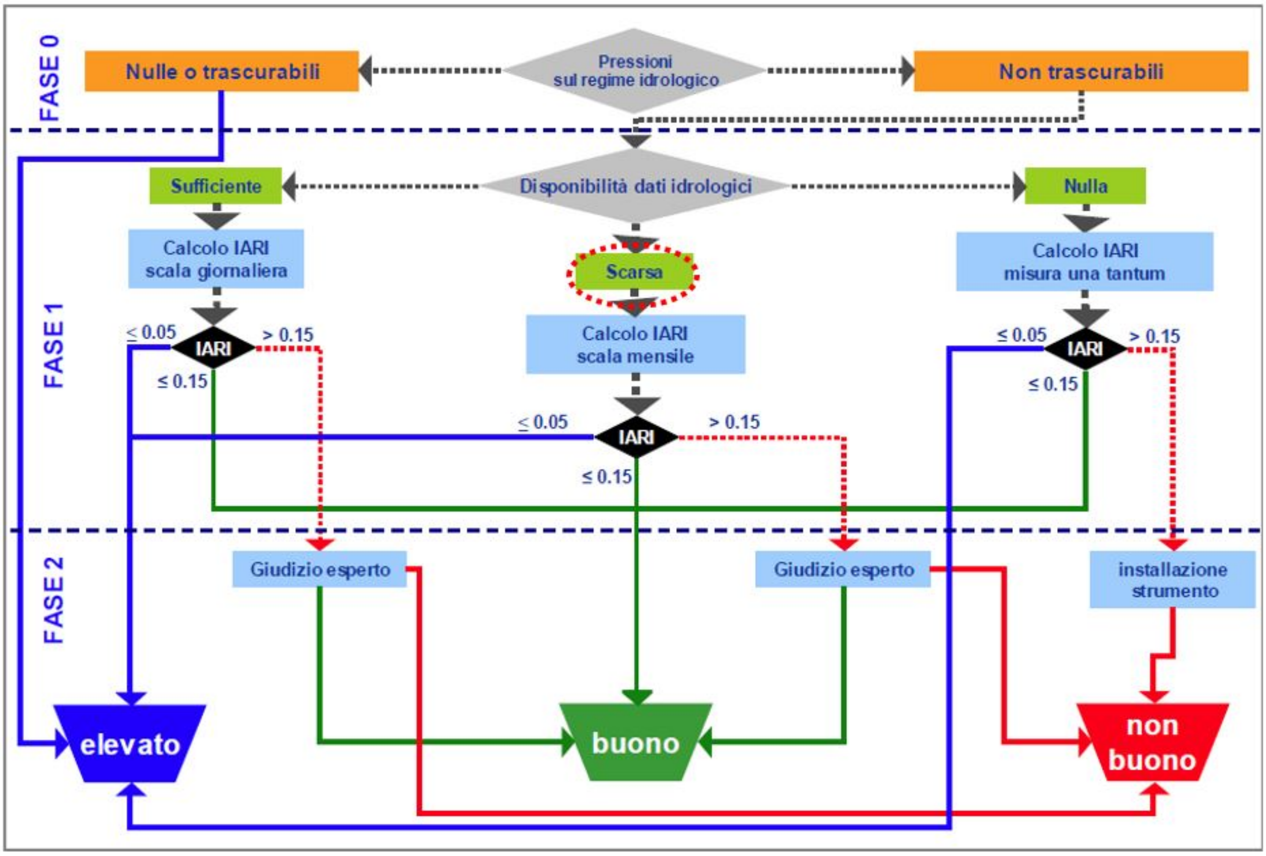

Figure 10: *Workflow diagram for the application of the ISPRA methodology for the IARI evaluation (from ISPRA, 2011)*

of the procedure is to detect any changes in the hydrological regime, a crucial aspect is represented by the definition of the reference/natural condition to which compare the actual regime. The hydrological regime is usually evaluated by analysing discharge data recorded by a gauging station. The actual regime is calculated from discharge data of the last 5 years. However describing the natural regime is not trivial, since data regarding the natural condition (e.g. before hydropower plans construction) are rarely available. In general, a *scarce availability* of data describes most of the case studies and the natural regime has to be calculated either through an ex-post reconstruction of discharges (accounting for withdrawal and inflow data, effect of man-operated structures, effect of reservoirs, etc.), or through hydrological modelling. Once the actual and the natural discharges and their differences have been calculated, the IARI value can be computed. The Italian Law 260/2010 establishes three hydrological status classes: High ($0 \leq$ IARI ≤ 0.05); Good ($0.05 <$ IARI ≤ 0.15); and Critical (IARI > 0.15) (Table 3). In general, if the IARI index reaches values higher than 0.15, the hydrological status is critical and a further analysis (Phase 2) is needed.

* N is the number of years in which discharge data are available		Hystorical Data		
		None N = 0	Not Significant N < 20	Significant N > 20
Recent Data	None N = 0	Null	Null	Null
	Not Significant N < 5	Scarce	Scarce	Scarce
	Significant N > 5	Scarce	Scarce	Sufficient

Table 2: *Data availability for the IARI calculation (from ISPRA, 2011)*

IARI	Hydrological Status
$0 \leq IARI \leq 0.05$	High
$0.05 \leq IARI \leq 0.15$	Good
$IARI \geq 0.15$	Critical

Table 3: *IARI ranges and relative river hydrological status*

Phase 2. This phase takes place when the IARI evaluated in Phase 1 reveals criticalities. Expert judgment is necessary to correctly evaluate the hydrological regime of a watercourse that presents either low/no data availability or high IARI index or hydropeaking (human pressure altering the hydrological regime but not always perceived in the IARI calculation). Indeed hydropeaking has an effect on a time scale much lower than the one investigated through the IARI (daily vs monthly).

In this case study, the gauging station is located at Ponte Adige. Flow depth and discharge data are collected at this station with a sampling rate of 10 minutes; the available time series is 41-year long. The recent data are therefore available to assess the actual hydrological regime, but historical/natural data are missing (*scarce data availability*) given that the hydrological regime has been altered before. The natural regime has to be estimated by considering the hydroelectic power plants activities of water withdrawal and release within the Adige catchment. Data regarding agricultural and other water uses were taken from the PGUAP[2] of the Autonomous Province of Bolzano (Provincia Autonoma di Bolzano APPA, 2017).

[2] Piano Generale Utilizzazione Acque Pubbliche

3.3 Morphological Quality Index - MQI

The IDRAIM methodology provides a standardized tool to assess the hydromorphological status of a water body. In compliance with Directives 2000/60/EC and 2007/60/EC, strategies are pursued to achieve environmental quality and mitigation of risks related to the processes of river dynamics (Rinaldi et al., 2014). The Morphological Quality Index (MQI) is part of this methodological framework as a specific system for the evaluation of current geomorphological processes. It is an instrument that expresses the deviation of the current conditions of the watercourse, in terms of riverbed morphology, compared to a reference state to which the definition of naturalness of the system is attributed.

The evaluation involves filling out fieldsheets through a guided procedure divided into three sections that cover fundamental aspects of: geomorphological functionality, artificiality and morphological variations. According to the type of river (confined or unconfined/semi-confined), the appropriate fieldsheet must be used. The method involves GIS and field analyses. The outcome of the procedure provides an index (MQI), whose values are classified into five classes, which describe the hydromorphological quality of the water body (Table 4).

Morphological Quality class	MQI score
High	$0.85 \leq MQI \leq 1$
Good	$0.7 \leq MQI < 0.85$
Moderate	$0.5 \leq MQI < 0.7$
Poor	$0.3 \leq MQI < 0.5$
Bad	$0 \leq MQI < 0.3$

Table 4: *Morphological Quality Index classes*

3.3.1 Morphological Quality Index for monitoring - MQIm

The Morphological Quality Index for monitoring (MQIm) is a specific tool for monitoring morphological changes in the short period (5-10 years). The MQIm assesses whether a restoration work has enhanced or deteriorated the morphological quality of the restored reach. As for the MQI, the evaluation involves filling out fieldsheets through a guided procedure divided into two sections that cover fundamental aspects of: geomorphological functionality and artificiality of the analyzed river reach. According to the type of river (confined or unconfined/semi-confined), the appropriate fieldsheet must be used. The method involves GIS and field analyses. The absolute value of the MQIm is meaningless if not associated to other MQIm values. The different MQIm values for a specific site have to be compared in time to define the morphological quality trend. In addition, the different components that contribute to express the MQIm can be considered separately to identify the most critical and the best aspects (i.e. the closer to 1 the value, the better the condition). The sub-indexes are:

- artificiality (MQIm_A);
- functionality (MQIm_F);
- continuity (MQIm_C);
- morphology (MQIm_M);
- vegetation (MQIm_VE).

The river reaches chosen for the analysis are almost the same as those for the MQI, despite that a shorter length has been taken for T1 (Postal) and T2 (Ponte Adige). T1 stretches for 2000 m, of which 500 m upstream the bridge at Postal and the other 1500 m run downstream the bridge. T2 starts at the Ponte Adige bridge and extends downstream for almost 2000 m. The identification of the sub-reaches used for the MQIm analysis is shown in Figure 11.

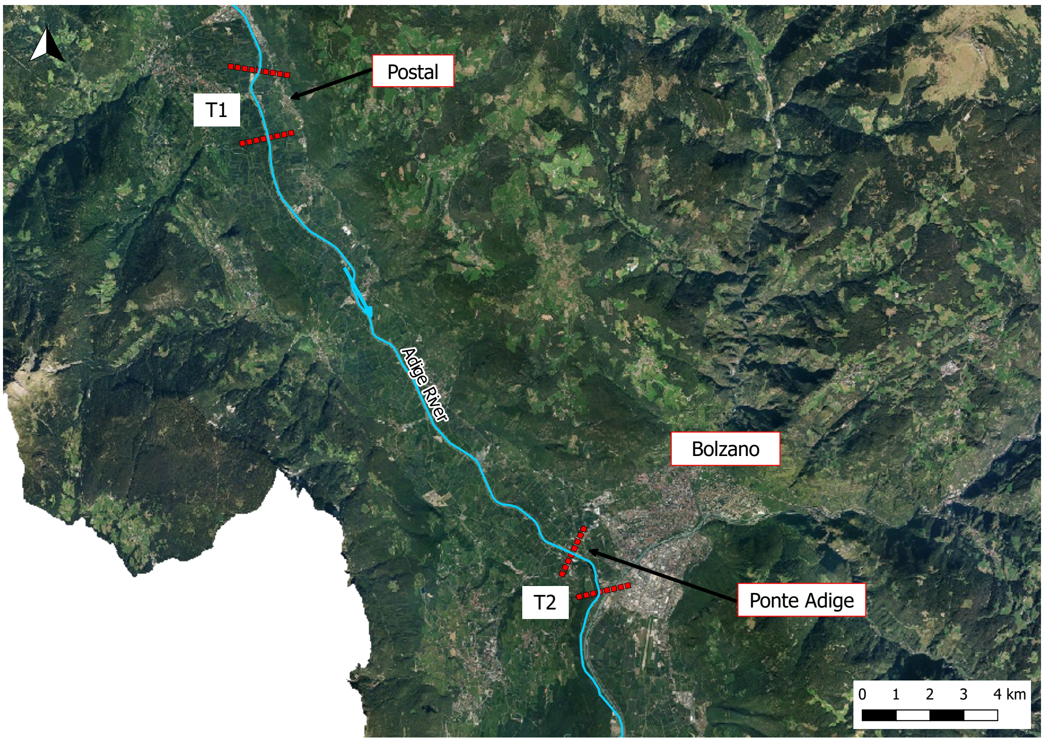

Figure 11: *MQIm reaches identification along the Adige River*

3.4 Suspended sediment analysis

Suspended Sediment Concentrations (SSC) have been recorded since 2013 by the turbidimeter located at Ponte Adige. Data is collected every 10 minutes and subsequently validated and calibrated by the Hydrographic Office of the Autonomous Province of Bolzano. This process requires two main steps: the first consists in the conversion of the data measured by the turbidimeter into sediment concentration values (expressed as mg/l). This operation involves the implementation of a relationship between the data recorded by the turbidimeter and the ones measured by an automatic pumping sampler and post-processed in a laboratory. The resulted concentration values refer to the turbidity recorded along the riverbed bank, where the turbidimeter is located. During the second step, water samples are collected along the entire cross section at different water depths, using a horizontal cableway, on which a water sampler is installed (Figure 12). Using these data an average cross-section conversion factor is computed. This factor is then used to associate the SSC values measured at the bank to the entire cross section (averaged value).
The SSC time series measured at Ponte Adige is still too scanty to detect a clear trend for suspended sediment dynamics and, in particular, to quantify whether, and to which extent, the restoration is having an effect on the SSC. In addition, the diffuse anthropization (hydropower reservoir and man-made structures across the river, slit dams, etc.) strongly modifies the natural sediment transport regime. Most of the coarse material is retained along the upstream tributaries by several check dams, built as flood mitigation measures across the entire Adige catchment.
In this context, the analysis focuses on the characterization of the average annual and seasonal trends of SSC; these can provide quantitative information useful to design future restorations by identifying reference seasonal SSC values, which can be used, for example, to define the suitable months for interventions, and thus avoiding mechanical sediment suspension when the natural turbidity in low (mainly during winter). Also SSC monitoring can be useful to assess the effectiveness of sediment-related measures.
Moreover, a detailed analysis of a flood event is carried out in order to quantify the magnitude of a single event with respect to the total average annual sediment yield. Seasons (S) are defined in this way:

- S1 Winter: January, February, March.
- S2 Spring: April, May, June.
- S3 Summer: July, August, September.

- S4 Autumn: October, November, December.

Bedload is not accounted due to lack of measures. However, this should be encompassed, as it plays an important role in the assessment of the restoration effects.

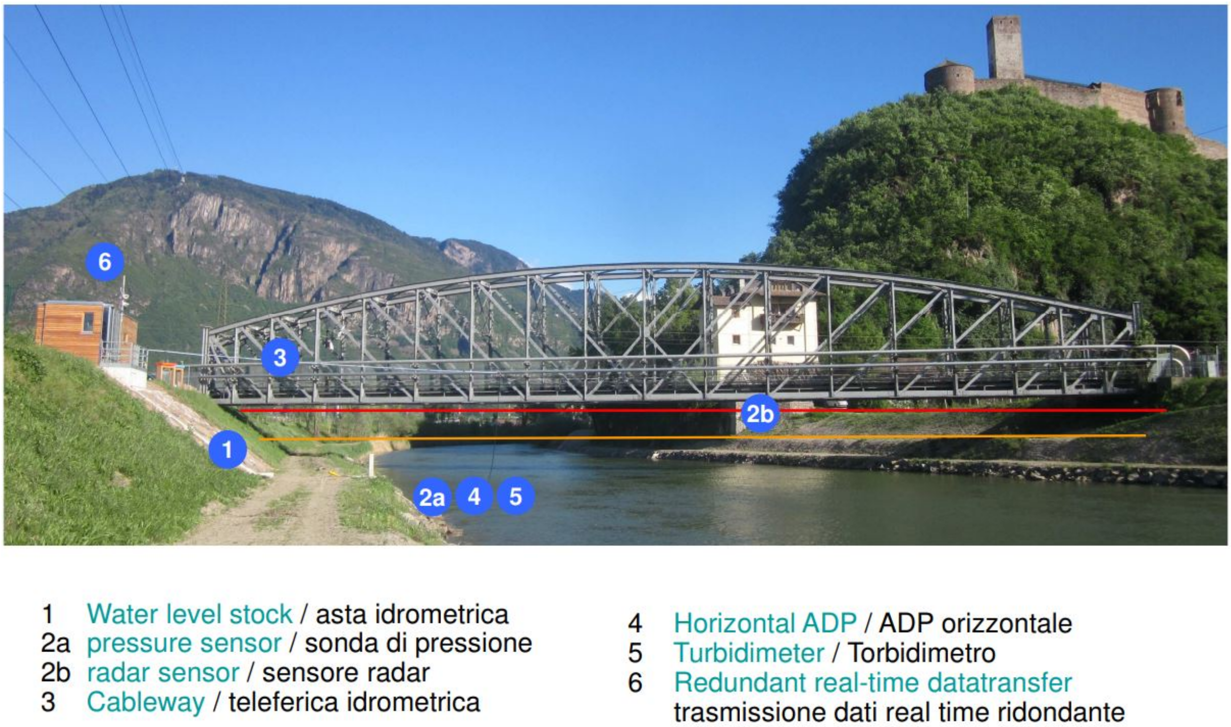

Figure 12: *Gauging station at Ponte Adige on the left riverbank. The turbidimeter is not visible, since it lays under water, but it is located on the left-hand side. The cableway is installed on the bridge and allows sample collection along the cross-section. Figure courtesy of the Hydrographic Office (Dinale, 2018)*

3.5 Groundwater analysis

The Province of Bolzano monitor the water table across the Adige valley through a wide pietzometer network (Figure 13 from Cainelli (2018)). The acquired data describe piezometric measurements and groundwater withdrawals and monitor the behaviour of the aquifer.

A study carried out by Cainelli (2018) aimed at analyzing the freatimetric regimes characterising the basin of Bolzano. The goal of this study is the assessment of the quality and completeness of the available information on the aquifer of the Bolzano valley, in order to create a numerical model to accurately reproduce its behaviour.

The results of this study were used to understand whether the aquifer could be influenced by the restoration works.

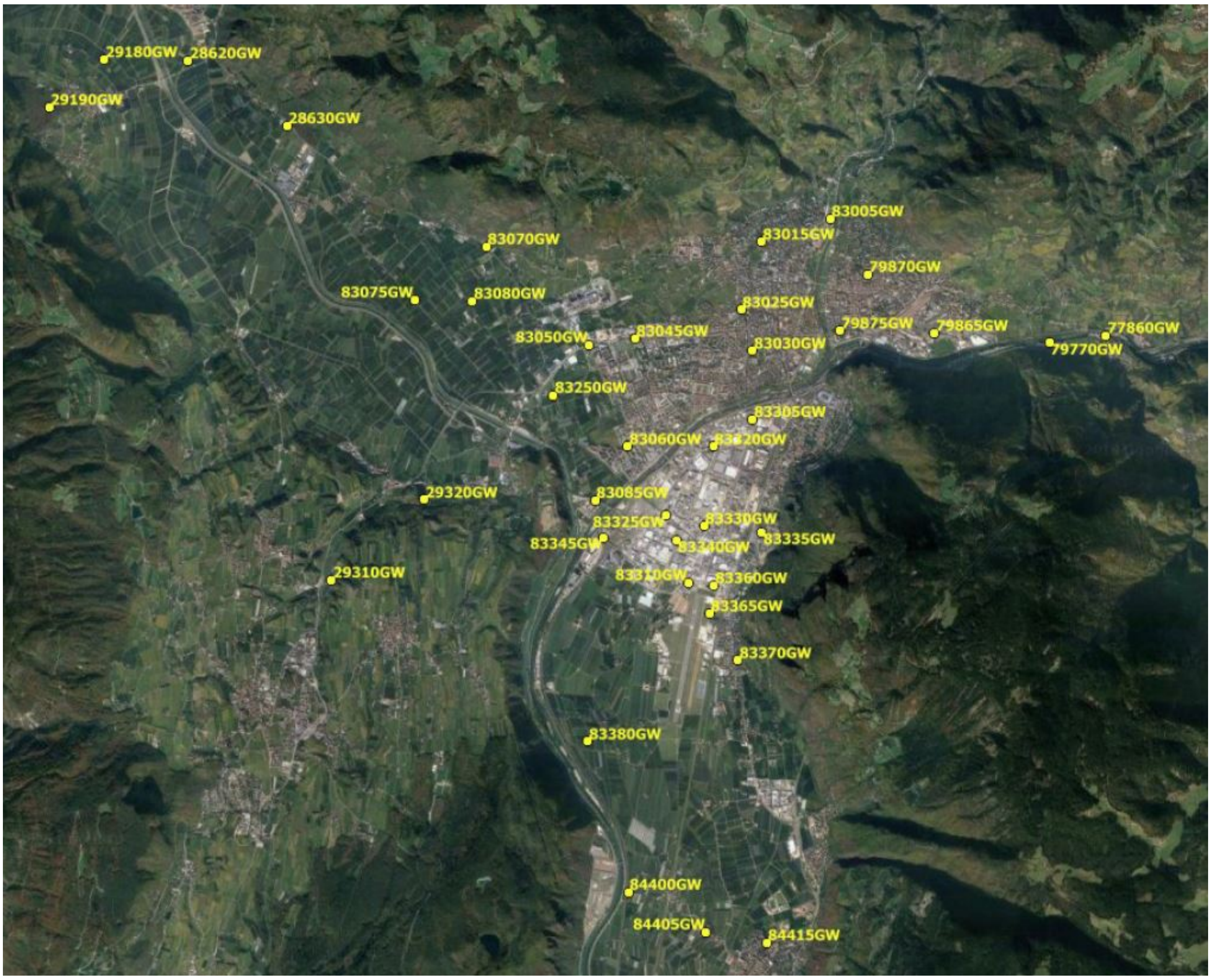

Figure 13: *Position of piezometers monitored by the Hydrographic Office of the Autonomous Province of Bolzano (Cainelli, 2018)*

4 Ecological monitoring

The ecological effects of the restoration works in the Adige River were evaluated by analysing chemical and biological data collected before and after the interventions (BA approach) as well as comparing control site data with the one collected in the restored reaches. In particular, hydrochemical, diatom and macroinvertebrate samples were collected by the monitoring station (Figure 14) placed by the Environmental Protection Agency (APPA Bolzano) for the assessment of the ecological status required by the Water Framework Directive (WFD). Fish data were also collected for the same purpose along a wider area, which includes both the restored and unrestored stretches, even though data are available only post-restoration.

The WFD requires member states to assess the ecological status of its rivers based on aspects characterizing the biota present at a given site. This biota (referred to as Biological Quality Elements, BQE, in the WFD) is represented by phytoplankton, macrophytes and phytobenthos, benthic invertebrate fauna and fish fauna (WFD, 2003). A water body assessment can be based on either a single BQE or a combination of BQEs. The choice of BQEs and the appropriate metrics within each BQE should depend upon their ability (statistical power and precision) and cost-effectiveness at quantifying the ecological quality of river sites, at detecting and quantifying changes in quality within monitoring programmes. The Environmental Protection Agency of Bolzano (APPA) uses chemical, phytobenthos (diatoms), macroinvertebrates and fish data to determine the ecological status of the water bodies, included the Adige.

4.1 Chemical data

The chemical and bacteriological analyses were performed by evaluating water samples collected by APPA from 2012 to 2016 at Postal and from 2009 to 2018 at Ponte Adige, at irregular intervals for a total of 10 and 120 samples respectively, both in the pre- and post-restoration periods. The chemical analyses were carried out to accomplish the WFD priority substances and other specific pollutants and the entire set of chemical parameters relevant in the assessment of the ecological or chemical status of a water body or in the assessment of programs of measures. Protocols of sampling and procedures for chemical analyses are explained with more details in the ISPRA Manuals (Belli et al., 2003; ISPRA, 2018).

The analysis results show that probably the ecological restoration carried out in the Adige River had not a direct effect on the water chemistry. Notwithstanding some chemical variations might have occurred during

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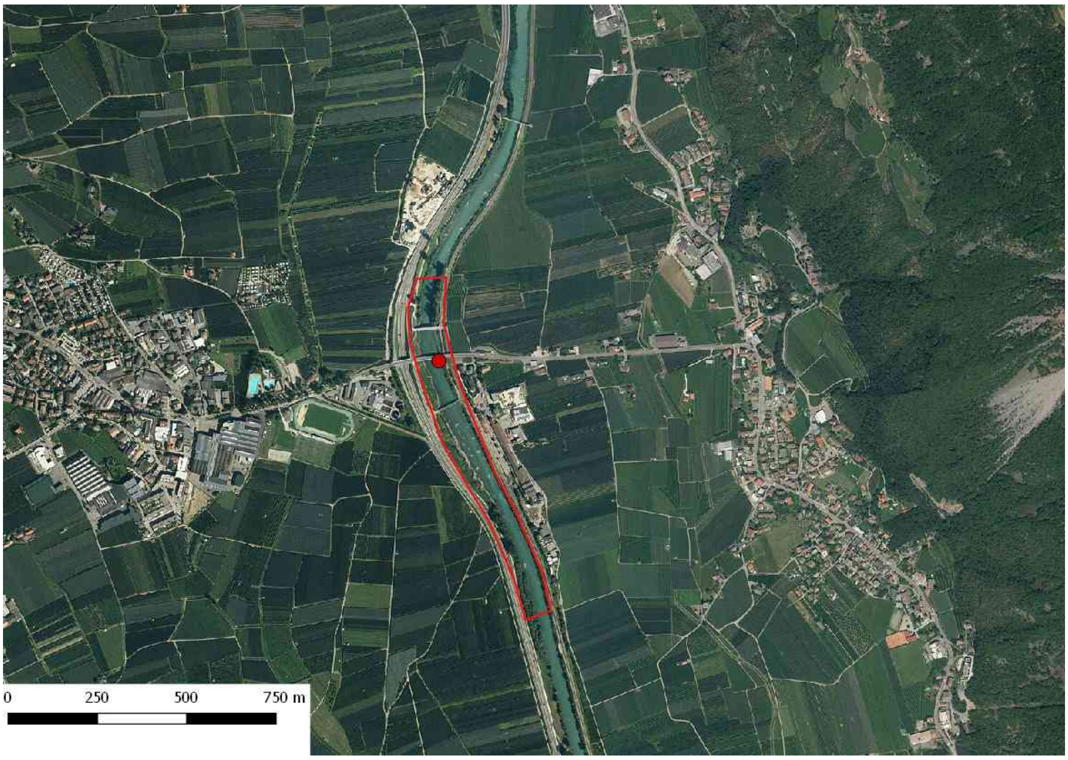

(a) *Location: Postal*

(b) *Location: Ponte Adige*

Figure 14: *Monitoring stations along the Adige River (red dot); the coloured contour is the restored area*

the monitoring period for other unknown reasons than restoration: these data may aid interpretation of possible biological effects of restoration.

4.2 Macroinvertebrates

Generally, the sampling method is based on a multi-habitat design, where major habitats are sampled according to their proportional distribution within a sampling reach. Macroinvertebrates are collected systematically from all available in-stream habitats. A total of 10 sub-samples is taken from all major habitat types in the reach (approx. 1 m^2 of habitat). Assuming that a given habitat is characterised by a certain substrate, if the substrate in the sampling reach consists of 60 % sand and 40 % gravel, then 6 sub-samples must be taken in sand and 4 sub-samples in gravel. The habitats are then categorised according to the site protocol. The sampling starts at the downstream end of the reach and proceeds upstream. Each of the 10 sub-samples is taken by positioning a net and distributing the substrate in an area that equals the square of the frame width upstream of the net (0.32 m x 0.32 m). Therefore, either a hand-net/shovel sampler or a Surber sampler with a frame of 0.25 m width and at least 0.25 m height can be used (Figure 15). The mesh size of the net is 0.5 mm. More details on the sampling protocol can be found on ISPRA (2014).

Figure 15: *Exemple of a Surber sampler used for collecting macroinvertebrates*

According to this methodology, macroinvertebrates were sampled at the sampling point displayed on Figure 14, with an irregular frequency as part of the routine monitoring carried out by the Environmental Protection Agency of Bolzano. At Postal a total of 6 samples (3 before and 3 after restoration) are available from 2012 to 2016, while 9 samples (6 before and 3 after restoration) are available from 2009 to 2016 at Ponte Adige. Numerical analyses were executed using the raw abundance data of taxa identified at family or genus level. The same analyses were carried out using the data lumped at low taxonomical level (orders).

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4.3 Diatoms

Diatoms surveys were performed by the Environmental Protection Agency of Bolzano at the monitoring point shown in the Figure 14-b (Ponte Adige only) with an irregular frequency before and after restoration. A total of 8 samples (6 before and 2 after restoration) collected between 2008 and 2016 are available, as part of the routine monitoring carried out by APPA. According to the ISPRA protocol (ISPRA, 2014) ten cobbles are collected from the middle of the stream and placed into a tray with a little stream water and the top surface of each cobble is brushed with a clean toothbrush in order to remove the biofilm. The resulting suspension is collected in a plastic bottle, fixed with alcohol and stored prior to analysis. Samples are either digested in a saturated solution of potassium permanganate or concentrated. Permanent slides are prepared using Naphrax (refractive index = 1.74) as a mountant. At least 400 undamaged valves of non-planktonic taxa are identified and counted using 1000x magnification (CEN,www.cen.eu, 2003). Taxa are identified at species level as requested by the national protocol.

The restoration effect on diatoms was assessed even though clear results were not expected, as the restoration measures did not affect the hydrochemistry. Diatoms as bio-monitoring tools are mostly used in rivers when the main stressor is related to pollution.

4.4 Fish

Electrofishing, as described in the European standard (CEN, www.cen.eu, 2003), is the most applied sampling method for fish status assessment in Europe. The process does not harm the fish. Electrofishing consists in catching fish by creating an electrical-field through water, around an anode and a cathode. Multiple pass-surveys are the most common approach to estimate density of fish in a river stretch. This electric-field develops a voltage through the fish exposed to it, such that galvanotaxis stimulates their nervous system, and they are forced to swim towards the anode (the source of the field). The larger the fish, the larger the electric effect through the fish body. Once the fish has been captured, its species is identified, it is weighted, measured and then released. The fish abundance or density is expressed as numbers or biomass per area or volume of habitat sampled. According to the WFD (European Commission 2000), the fish age structure is used in rivers and lakes as an indicator of failure in the reproduction or ontogenetic development of particular species, e.g. lack of old fish due to overfishing. More details on the sampling protocol can be found on ISPRA (2014).

In order to assess the effect of restoration, the Office for Hunting and Fishery of the Province compared each restored reach respectively with a control one (Figure 16). The control reach in the Postal area stretches for 500 m downstream the Postal restored site; instead the control reach in the Ponte Adige area runs upstream the Ponte Adige restored site. The surveys were carried out only along the shore to capture the juvenile fish. The sampling strip dimensions for each case are summarized in Table 5.

In both cases, it seems that fish density was not estimated using the *k-pass removal method* (Ogle, 2016), as requested by the standards protocols in order to estimate catchability on each strip.

The restoration effects on fish was not assessed using the ISECI (Index of the Ecological Status of the Fish Communities), as it was not developed for this aim. This index provides the ecological status of communities within 5 classes assessed by the calculation of the deviation between expected and founded fish community. The fish community and population structure were rather analyzed by applying statistical analyses commonly used in fish ecology.

	Date	Site	Width [m]	Length [m]	Depth [cm]
Postal	May 2016	Restored	1-2	217	5-60
		Control	1-2	217	60-100
Ponte Adige	May 2017	Restored	1-5	200	5-60
		Control	1-2	200	40-120

Table 5: *Characteristics for the sites where electrofishing took place*

(a) *Electro-boat used to estimate fish stocks*

(b) *Location: Postal. Technicians aimed at fish species identification*

Figure 16: *Different phases of the fish monitoring*

4.5 Data analyses

In order to assess the restoration effects, the raw ecological data were obtained from the Environmental Protection Agency and the Office for Hunting and Fishery of the Autonomous Province of Bolzano. These data were used to test if and to what extent biological and chemical data differ between pre- and post-restoration. Since this approach does not aimed at assessing the ecological status of the water body, rather to assess the ecological changes induced by the restoration, ecological indexes were not applied. Chemical parameters were scrutinized by means of *t-tests* to assess for possible differences in the periods before and after restoration. The *t-test* is one of the most common tests in statistics, which determines whether the means of two groups are equal to each other. A widely used variation of the *t-test*, known as *Welch's t-test* (t), adjusts the number of degrees of freedom (df) when the variances are thought not to be equal to each other, which was often the case in these datasets. In fact the two datasets (pre- and post-restoration) are not homogeneous. This statistical analysis aims at proofing whether the means of the two datasets (pre- and post-restoration) differ as to some specific reasons and not by chance. This can be understood by considering the values of *t, db* and *p* obtained from the analysis, where:

- *t*: is the *t-test* value;
- *df*: degree of freedom which provides information on the sample size. The higher *df*, the higher the number of available data and more robust the results are;
- *p*: is the probability or statistical significance that the null hypothesis is true. The null hypothesis states that the two mean values differ by chance and it is defined as the worst-case probability. For p-values lower than 5 % the test is meaningful. In this particular case, the null hypothesis states that pre- and post-restoration conditions remain unchanged. If the null hypothesis is rejected, i.e. $p \leq 5$ %, then the alternative hypothesis states that conditions pre- and post-restoration have changed.

Macroinvertebrate and diatom data were analysed with a community perspective, using a multivariate approach which synthesizes all the information regarding a community (e.g. species and their abundance) into a point. In particular, a ranking of samples was performed using the Principal Coordinate Analyses (PCoA) and the difference between before-after period was assessed using the **ANOSIM** test (Analysis of Similarities). PCoA statistic explores and visualizes similarities or dissimilarities of data (Bray and Curtis index of dissimilarity was used in this analysis). Interpretation of a PCoA plot is the following: points closer to one another represent more similar conditions than those represented by sparse points. Indeed, when looking at the points represented on a plane (x-axis and y-axis are respectively PCo1 and PCo2, e.g. Figure 34 on the left), the further the points representing the pre- and post-restoration status, the larger the differences (e.g. species and their abundance) between the two conditions. On the other hand, the closer the points, the less relevant the differences. The **ANOSIM** statistic compares the mean of ranked dissimilarities between groups to the mean of ranked dissimilarities within groups. An R-value[3] close to 1 suggests dissimilarity between groups, while an R-value close to 0 suggests an even distribution of high and low ranks within and between groups. Significance of the R statistic is determined by permuting group membership a large number of times to obtain the null distribution of the R statistic. Comparing the position of the observed R-value to the null distribution allows an assessment of statistical significance. The entire set of analyses were executed using the R statistical platform (R-Development-Core-Team, 2018).

[3] In the multivariate analysis R ranges from 0 to 1.

5 Assessment of the Physical Effects of the Restoration

5.1 Effects on Morphology - DoD

The results of the DoD analysis highlight the morphological changes due to the restoration works performed along the riverbanks.

Postal - The assessment of the changes of the morphology before and after restoration is based on a cross section analysis, which provides a qualitatively response. In particular, the 2005-cross sections are compared to the ones obtained from the 2018-DEM. The difference between 2005 and 2018 cross sections allows for scour and filled areas detection. One of the restoration targets was the smoothing of the slopes and the creation of an heterogeneous longitudinal profile to re-naturalize riverbanks and to promote river accessibility (as recreational areas). Cross section comparisons are shown in Figure 18 and Figure 19. Figure 18 represents the (man-made) morphological variation of the orographic left and right river banks along the cross section 2. Indeed, the right river bank has been excavated to widen the riverbed, while the left one underwent filling to strengthen the retaining wall underneath the cycle path. Along cross section 8 (Figure 19) the main works occurred along the orographic right and aimed at enhancing the connectivity between a small ditch and the Adige, to bring about benefits for the fish population. The terrain elevation along the ditch has been raised, while the surface in between the two water courses has been lowered. The ditch has been modelled with a sinuous shape in order to decrease the bed slope and to encourage the fish to move upstream. A better connection to the lateral watercourses is important to ensure specific habitat for spawning and for the juveniles fish.

Ponte Adige - Both qualitative and quantitative analyses were instead carried out at Ponte Adige. Restoration works began later than in Postal and the elaboration of a DoD was carried out by comparing the 2013-DEM to the 2019-DEM (Figure 20 and 21). The re-naturalization works were only performed along the orographic left, where scour is observed along the lower riverbanks; while filling or no major variations characterize the area along the cycle path (upper part of the riverbanks). Figure 20 displays the DoD of the upstream part of the study reach; the detail of the analysed cross section is displayed on the left of the figure. Scour corresponds to the smoothing of the cross section (as visible from the picture), which aims at river widening, enhancing riverbank variability (inlets) and promoting the aesthetic value of the river landscape. Inlets and coves provide higher morphological variability of the river banks which used to be uniform and geometrical before the restoration. In addition, low-water spots favour juveniles

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fish and spawning areas. Figure 21 displays the DoD of the study reach upstream the MeBo bridge. Also in this area, a riverbank smoothing can be observed as well as the filling or reinforcement of the upper part of the slope, which supports the cycle path.

From a morphological perspective, a general improvement can be observed in terms of recreational areas and riverbank re-naturalization. Spots of shallow water create habitats suitable for fish population, in particular for juveniles fish and spawning. The restoration works did not have a significant effect on sediment transport because the spatial constrains of the river do not allow for any further morphological improvements which might increase sediment dynamics or macroforms formation.

Figure 17: *Restored connectivity between a small ditch and the Adige to promote fish passibility*

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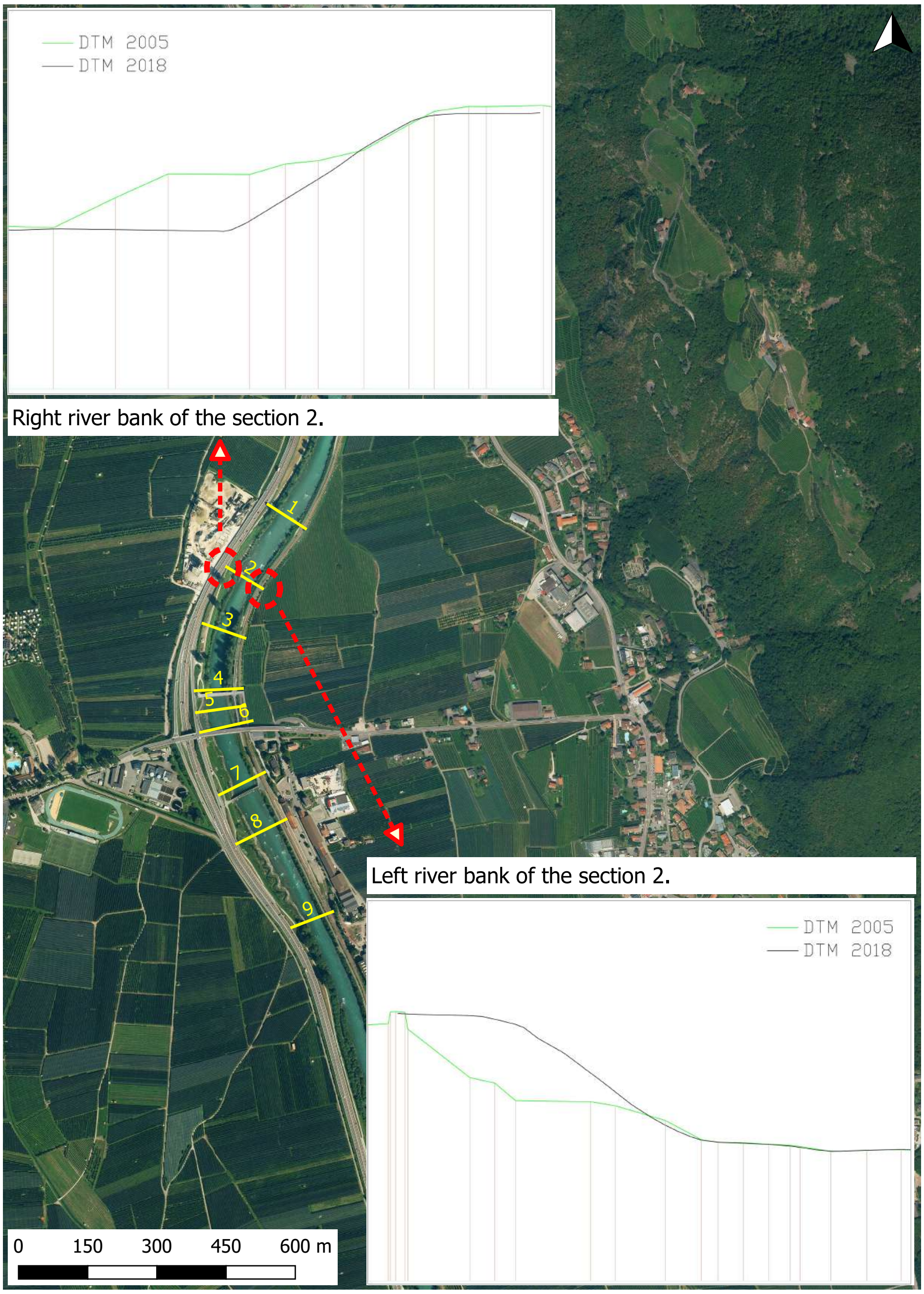

Figure 18: *Planimetric view of the cross-sections (1 to 9) at Postal (flow direction is from top to bottom of the picture). The red circles on Section 2 identify the section views of the right and left river banks (up- to down-stream view). In particular, the right river bank was scoured, while along the left one aggradation occurred*

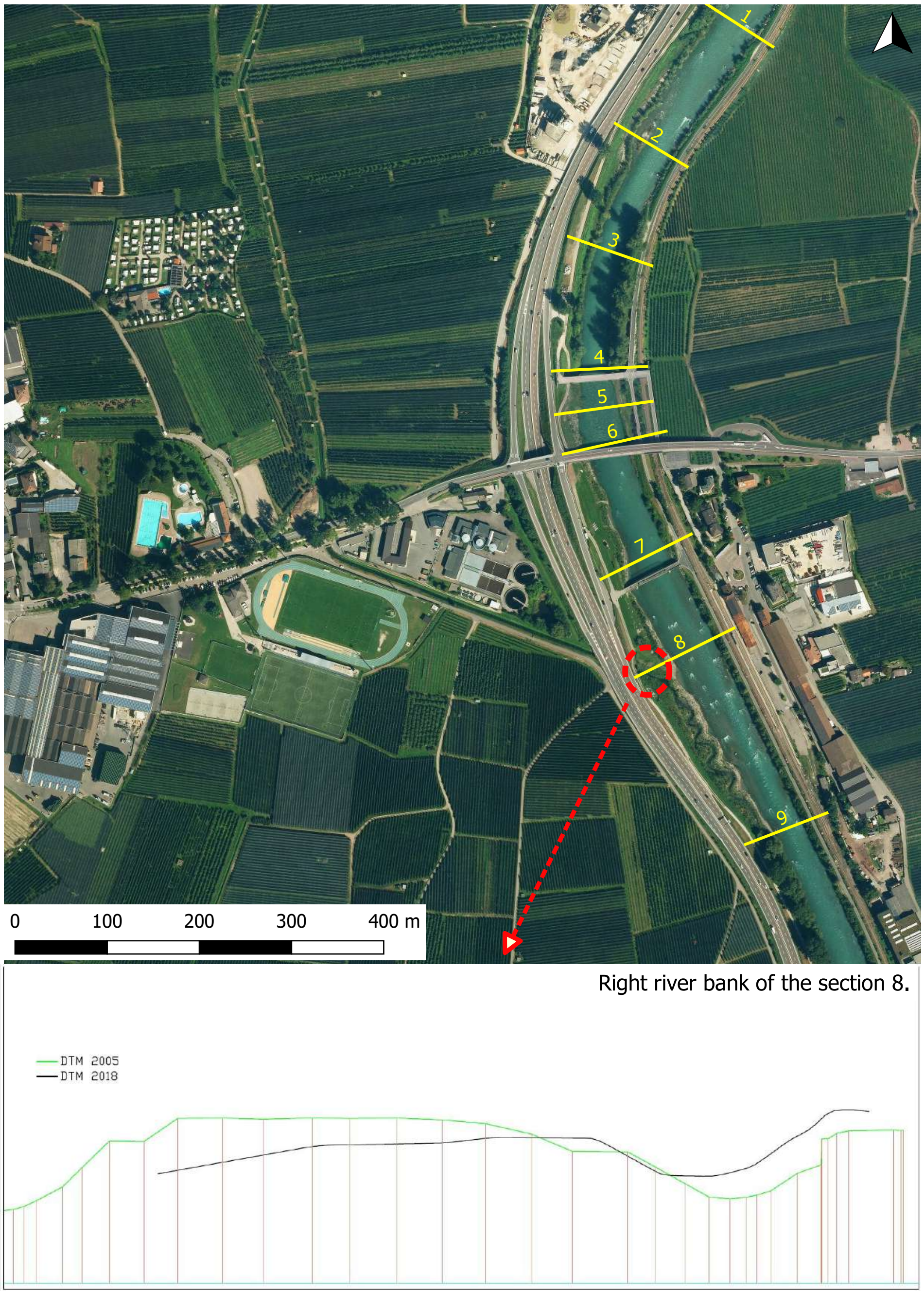

Figure 19: *Planimetric view of the cross-sections at Postal (flow direction is from top to bottom of the picture). The red circle on Section 8 identifies the section views of the right river banks and lateral ditch (up- to down-stream view). The depression corresponds to the ditch and sediment replenishment occurred. On the other hand, the terrain between the ditch and the Adige riverbed was lowered to provide a smoother profile to the riverbank*

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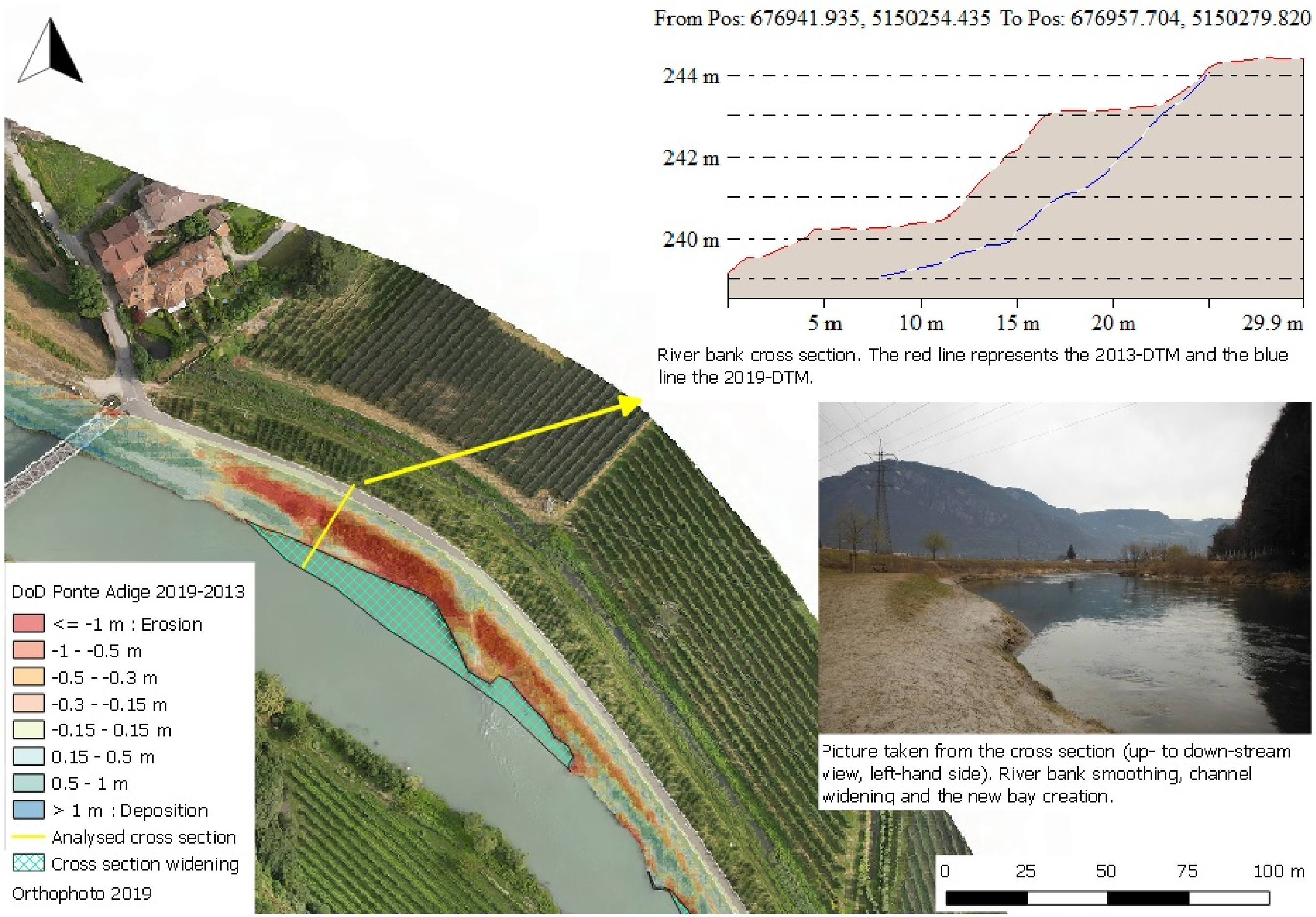


Figure 20: *DoD of the upstream study reach at Ponte Adige. Channel widening, riverbank smoothing and inlets formation*

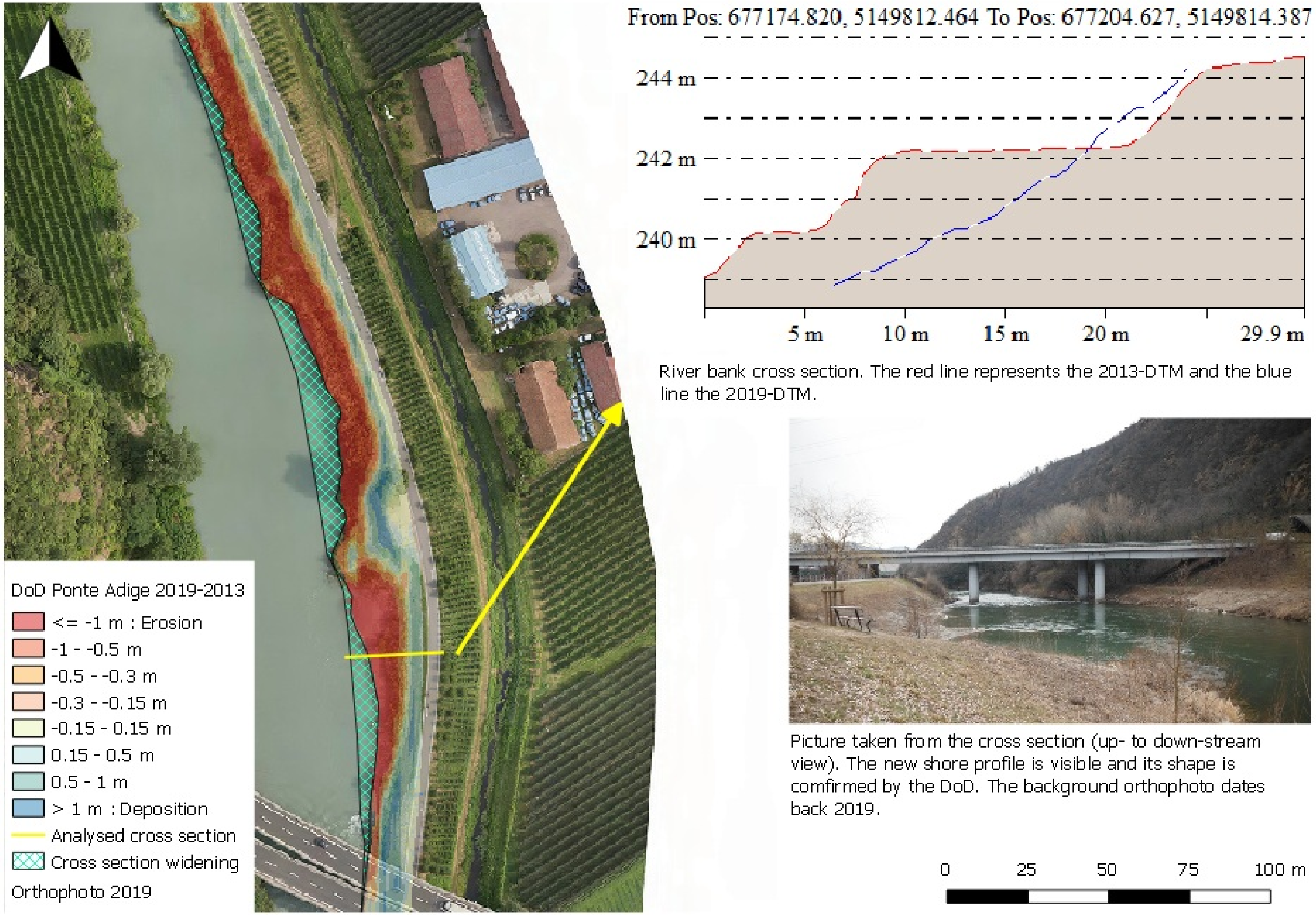


Figure 21: *DoD of the downstream study reach at Ponte Adige. Channel widening, riverbank smoothing and installation of benches to create a recreational areas*

5.2 Effects on Hydrological Regime Alteration - IARI

This analysis aims at assessing whether the restoration brought an effect on the hydrological regime of the restored reaches. The closest gauging station to the study sites is located at Ponte Adige; the time series is almost 100-year long (1926 - 2019). Despite the long time series, according to the ISPRA methodology and the included definitions, this gauging station has a *scarce* availability of data, since the human alteration of the hydrological regime dates back at the beginning of the last century (1900); the hydropower plan of Tel was built even before, in 1898. The time series of historical data (pre-impact) is therefore less than 20-year long, indeed there are no data at all; for recent data instead, the time series is longer than 5 years (post-alteration). In this case, the reconstruction of natural monthly average discharge data was performed through an ex-post reconstruction of discharge values, considering water withdrawal and inflow data.

Unfortunately a IARI assessment was never carried out before the restoration, and therefore there is no benchmark for a comparison. A recent study from Patscheider-Partner (2017) within the FESR Spatium Etsch-Adige project, computed the IARI evaluation (post-restoration) for a longer stretch of the Adige, which was subdivided into several sub-reaches. The one which encompasses the reaches subject to restoration is reported in Figure 22; it stretches from the confluence between Valsura and Adige to the confluence between Adige and Isarco. The quality of the hydrological status of the water course depends on how far the actual discharge regime is from its natural condition (IARI = 0). The IARI for this stretch resulted to be 0.13 in the first phase, indicating a *Good* state; then, during the second phase-*Expert Judgement*, it was changed to *Critical* due to the strong pressure from hydropower production, which is not captured by data averaged on a monthly basis (i.e. in the first phase).

In 2019, within this study, the IARI evaluation was performed considering the two different study sites of Postal and Ponte Adige. The IARI was calculated using both the mean and the median monthly values, resulting in 0.14 and 0.10 respectively at Postal and 0.10 and 0.07 at Ponte Adige (Table 3). Considering the first phase of this analysis, both river reaches present a *Good* hydrological status. Results are displayed in Figure 23, which shows how the natural condition would be (blue line) and the range (dotted blue lines) within which the actual discharge (red line) should lie.

However, these results require further investigations (Phase 2) to account for the human pressures characterized by a temporal scale shorter than the one captured by the IARI. The second phase confirms the *Critical* hydrological status (IARI $>$ 0.15) for both the study stretches (which proves the unchanged situation of the Adige hydrological regime when compared to the one in 2017). Table 6 summarises the results from Phase 1 and Phase 2.

Even if there is no benchmark for the IARI before restoration, since the restoration did not affect the hydrological regime, neither within the two reaches, nor upstream, it can be claimed that the restoration does not have an effect on the alteration of the hydrological regime.

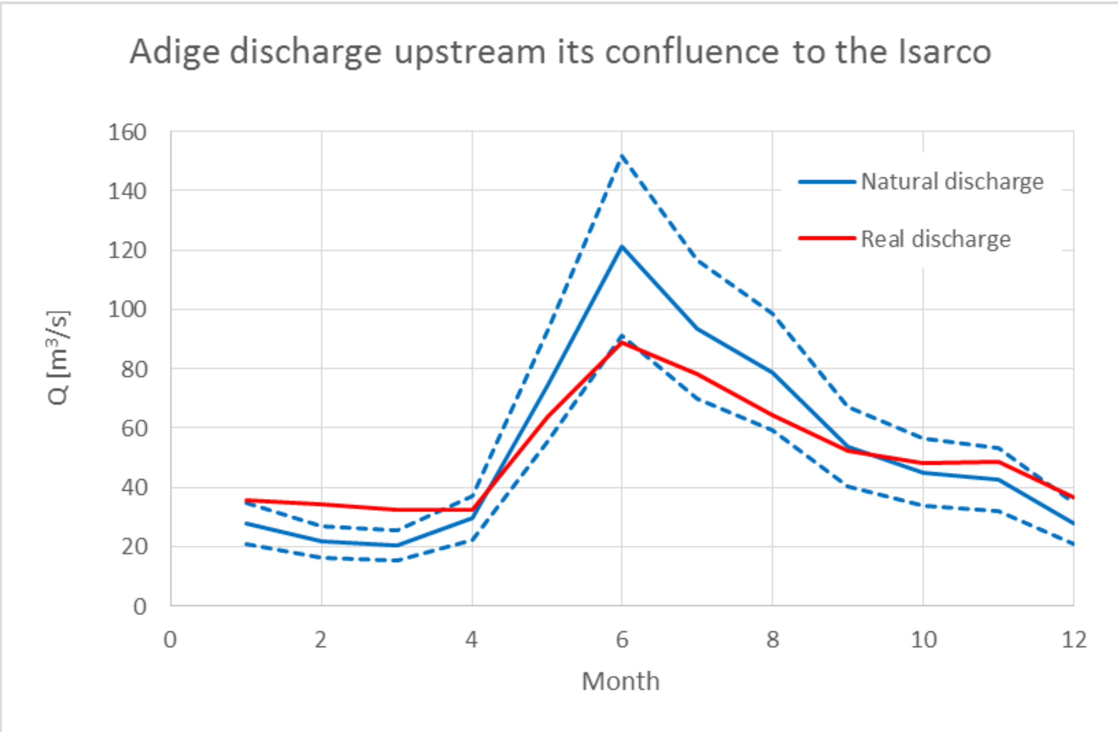
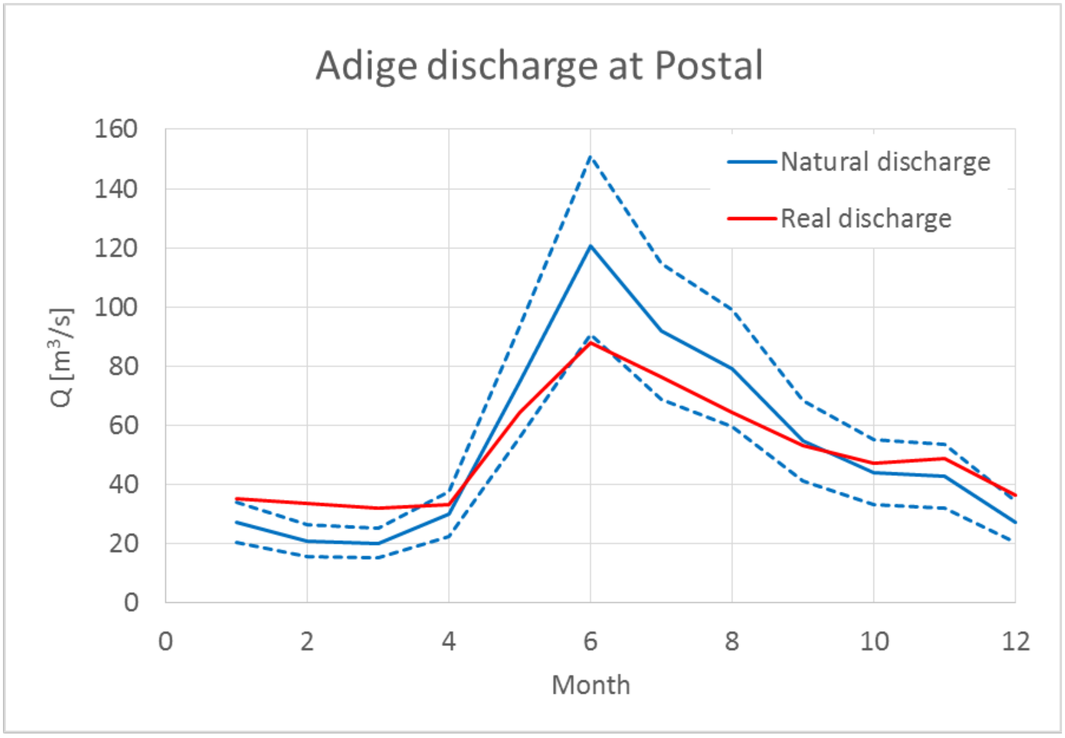


Figure 22: *Mean monthly discharge for the portion between the confluence Valsura - Adige and the confluence Adige - Isarco calculated using data from 1997 to 2016 (Patscheider-Partner, 2017). The blue lines show an estimation of the natural hydrological regime and its range (dotted lines) and the red stands for the measured discharge*

	PHASE 1		PHASE 2	
	IARI - mean	IARI - median	IARI	Hydrological status
Postal	0.14	0.10	> 0.15	Critical
Ponte Adige	0.10	0.07	> 0.15	Critical

Table 6: *IARI calcucated from the mean and median monthly values for the two study reaches. The green square indicates the IARI values coming from phase 1, while the red square shows the final IARI values which correspond to a Critical hydrological status for both river reaches (phase 2)*



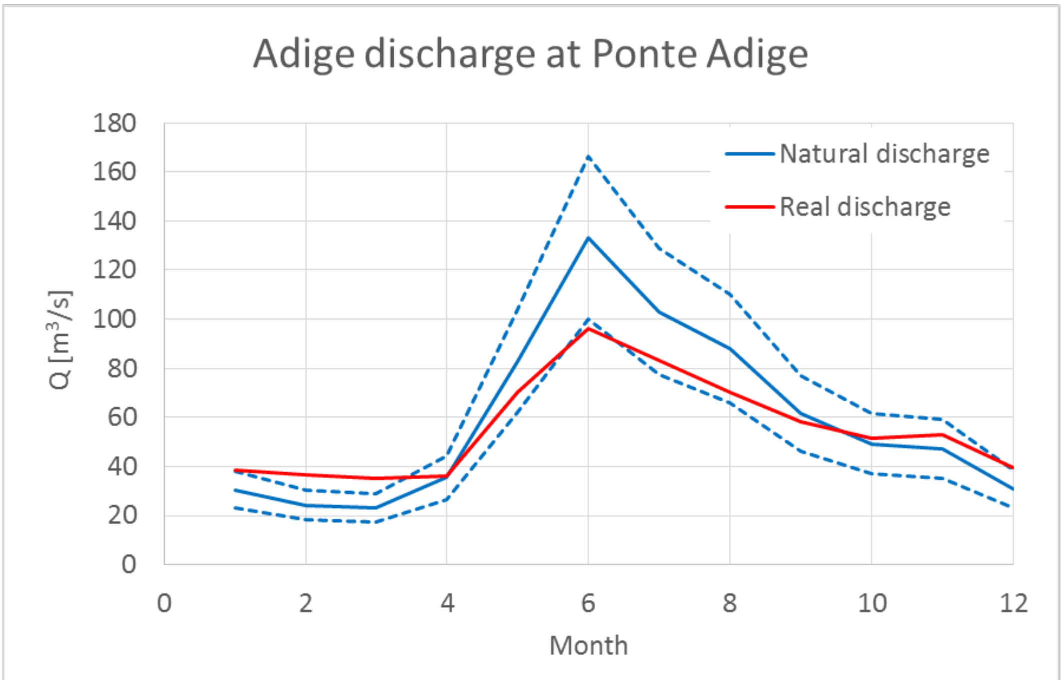


Figure 23: *Mean monthly discharge of the Adige at Postal (above) and Ponte Adige (below) calculated in the last 20 years (1997 - 2018). The blue lines show an estimation of the natural hydrological regime and its range 25^{th}-75^{th} percentile (dotted lines) and the red stands for the measured discharge*

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5.3 Effects on the Morphological Quality Index

The evaluation of the MQI in the restored reaches is taken from the recent analyses carried out by the Engineering Consultant Patscheider & Partner in 2017. This study is part of the Management Plan of the Adige River *Spatium Etsch-Adige*, which is an operational program within the FESR 2014-2020 frame (Patscheider-Partner, 2017). This study encompasses the Adige between Tel and Salorno, located at the southernmost border of the Province (30 km). Relevant information regarding the two restored reaches in Postal and Ponte Adige has been extracted from this work. Within the FESR Spatium Etsch-Adige project, the Adige reach extending from its confluence to the *Valsura* stream to its confluence to the Isarco is divided into five reaches, of which only two (Ah_003 and Ah_007) concern this analysis. In particular, Ah_003 refers to the restored site at Postal and Ah_007 refers to the restored site at Ponte Adige. According to the IDRAIM methodology (Rinaldi et al., 2014), the subdivision identifies river segments with homogeneous morphological characteristics, or elements that represent basic units functional to the subsequent analysis. The leading parameters for the sub-reach subdivision are: the type of confinement, the variations of morphological units within the study reach, the presence of hydrological and/or artificial discontinuities.

The first reach, Ah_003, extends for 3590 m and stretches between the Adige confluence to the Valsura stream and the Eschio stream. It has an unconfined configuration with a single straight channel with an average width of 42 m. The entire length is characterized by continuous bank protections, therefore bank erosion and bank variability are strongly altered. The functional formations have limited amplitude and intermediate longitudinal extension (Figure 24-a).

The second reach, Ah_007, is 5290 m long, it begins near the village of Frangarto and extends until its confluence with the Isarco. It has a semi-confined configuration with a single sinuous channel with an average width of 35 m. Its semi-confined configuration is due the rocky peak of Castel Firmiano, characterized by steep flanks, along which the Adige is currently flowing (Figure 24-b). The bank protections are present along the entire stretch, while the levees are limited to the orographic left. Therefore, erodibility and variability of the section are significantly altered. Both the amplitude and the linear extension of the functional formations are limited. Table 7 summarizes the main features of the two reaches just described.

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The application of the MQI for the described reaches results respectively 0.27 (poor) and 0.52 (moderate). This overall assessment of the application of the index is summarized on Figure 25.

Since the extension of the restoration works is minimal if compared to the length of each reach, the morphological changes due to restoration are considered negligible for the evaluation of the MQI, even though their effects locally improve the ecosystem (see Chapter 6). The effects of the restoration can rather be observed in the MQIm (Morphological Quality Index for monitoring) analysis.

Reach	Site	Conf.	L [m]	α [%]	EU [m a.s.l.]	ED [m a.s.l.]	MQI
Ah_003	Postal	NC	3590	0.2	263	255	0.27 poor
Ah_007	Ponte Adige	SC	5290	0.2	239	234	0.52 moderate

Table 7: *Macroscopic characteristics of the two sub-reaches. Conf. stands for confinement. The acronyms SC, NC indicate the type of confinement: semi-confined and non-confined. L is the length of the sub-reaches, α is the average riverbed slope, EU and ED are respectively the upstream elevation and the downstream elevation*

(a) *Location: Postal. Reach Ah_003*

(b) *Location: Ponte Adige. Reach Ah_007*

Figure 24: *Reach used for the MQI analysis*

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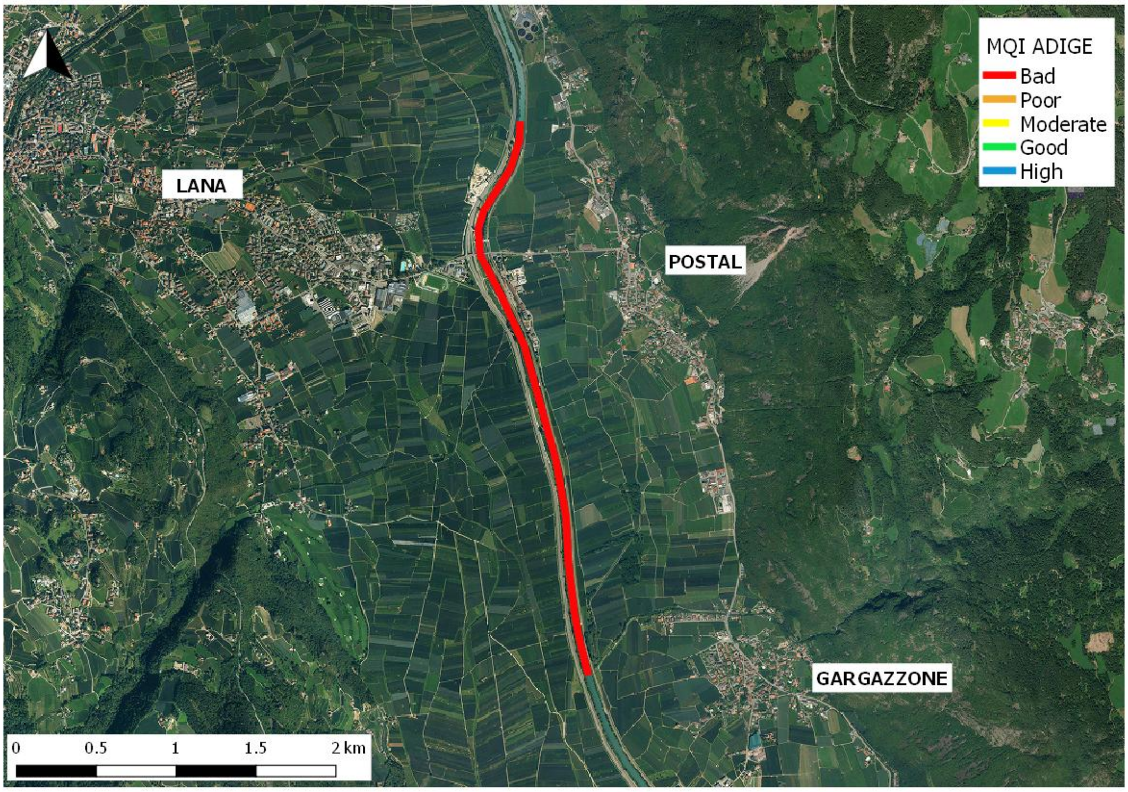
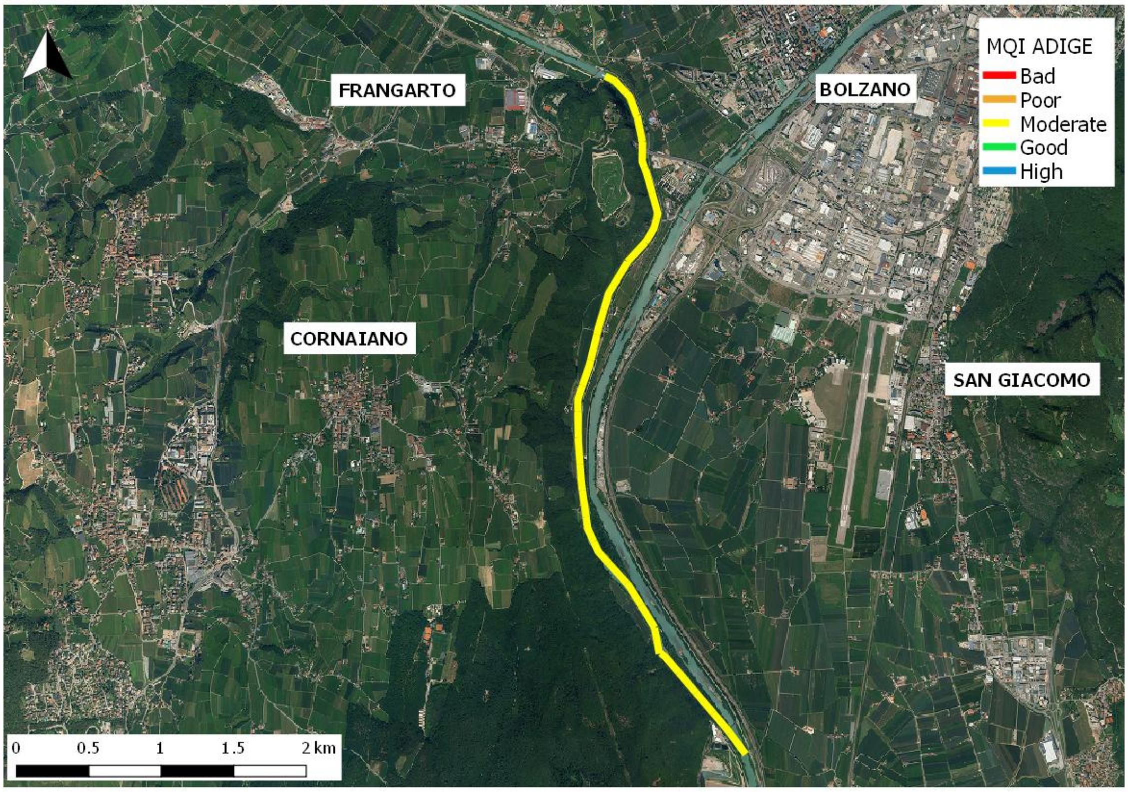


(a) *Location: Postal*



(b) *Location: Ponte Adige*

Figure 25: *MQI classes for the restored reaches*

5.3.1 Effects on the Morphological Quality Index for monitoring

As for the MQI analysis also the MQIm values are classified into five classes, which describe the morphological quality of the water body within a monitoring context, i.e. morphological changes are observed in a short time reference (few years). A MQIm value equals to 1 stands for *High* morphological quality while 0 indicates *Bad* quality. The MQIm values for the sub-reaches T1 and T2 are respectively 0.66 and 0.69 (moderate). These values are higher then the one obtained from the MQI analysis, indicating an improvement on the river morphology within the restored reach, or rather that the MQIm (compared to the MQI) better shows the effects of the restoration works. The MQIm sub-indexes for each river reach are reported in Table 8. The percentage (%) value corresponds to the ratio between the calculated value (”value”) and the maximum value (”max”). The higher the percentage, the better the morphological quality of the monitored reach. For example, both the sub-reaches present good longitudinal connectivity (MQIm_C): 71% and 75%, while shortcomings characterize the aspects related to functionality (MQIm_F) and presence of vegetation (MQIm_VE). In particular, T2 shows higher morphological quality (MQIm_M = 71%) compared to T1 (MQIm_M = 60%). However, these results cannot effectively capture the improvements due to the restoration works, since morphological changes need time to become evident and measurable.

	T1			T2		
	value	max	%	value	max	%
MQIm_F	0.05	0.20	25	0.05	0.21	24
MQIm_A	0.59	0.80	74	0.64	0.79	81
MQIm_C	0.36	0.51	71	0.40	0.53	75
MQIm_M	0.27	0.40	60	0.27	0.38	71
MQIm_VE	0.02	0.08	25	0.03	0.09	33

Table 8: *Sub-indexes of the MQIm analysis. F stands for Functionality, A for Artificiality, C for Connectivity, M for Morphology and VE for VEgetation*

This analysis is a reference point for future evaluations, since the MQIm is a tool to compare the river morphological quality variations over a short period of time, and therefore has a relative (not absolute) meaning. Therefore future monitoring is necessary to follow the morphological trend and the MQIm evaluation should be performed every 2 to 3 years.

5.4 Suspended Sediment Concentration analysis

The analysis of the Suspended Sediment Concentration (SSC) for the Adige has been carried out using the turbidity data measured at the gauging station at Ponte Adige. Figure 26 displays the available SSC data over time (from October 2013 to December 2018) and reports the mean seasonal values of SSC. Figure 27 shows the SSC seasonal analysis through a bean-plot[4]; in particular it displays average SSC values (blue dot) and the maximum SSC values (red dots) for each season; the frequency of occurrence of values is expressed through the width of the bean-plot. For example, when considering S1, many SSC values correspond to ca. 10 mg/l, while SSC of 715 mg/l were recorded just once or few times. This representation highlights the different values of SSC on a seasonal basis; ranging from 12 mg/l in winter to 180 mg/l in summer. Maximum natural SSC attain values higher than 33 g/l.

The Adige catchment has a nivo-glacio-pluvial hydrological regime, which means that discharge peaks are expected either on late spring or summer because of snow- and glacier-melt or during fall, due to autumn-rains. Higher discharges are related to higher sediment transport rates. Indeed, Figure 26 shows that an increase of SSC generally happens during the summers. During the fall local peaks can also be identified, however the duration of the events is shorter.

The maximum value recorded within the available dataset was in 2018 and corresponded to 33563 mg/l (5 August 2018). In 2018 the autumn peak happened during a flood event, the ”Vaia storm”, which affected the Italian North-East between October 27th and October 30th 2018. The data were analysed separately by comparing discharge (Q) and SSC patterns (Figure 28). A first discharge and SSC peak occurred almost simultaneously during October 28th, while a second peak was recorded during the night between October 29th and October 30th. Concerning the second peak, maximum values of Q and SSC were respectively 313 m^3/s and SSC 4576 mg/l. The delay between the two peaks was around 30 hours, indicating a supply-limited condition.

The mass transported during the event was computed by integrating concentration and discharge data over time. In particular, around 3.9$\cdot 10^4$ tons of suspended sediment have been transported between October 28th and November 3rd. This value corresponds to 14% of the total annual load in 2018 and conveys the idea of the impulsive nature of the sediment transport process. A small percentage of the total solid discharge is carried with the flow daily, however the largest amount is transported during few events. As an example,

[4] Bean plots represent the frequency distribution of the data; this type of plot allows for asymmetric or multimodal distributions to be represented; blue dots indicate the average and red ones the maximum value

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the ratio between the mass transported by the October flood event and the entire mass of suspended solids transported during the previous year (2017) is 15%.

Table 9 summarizes the mass values calculated on the available dataset.

	2014	2015	2016	2017	2018
Total Annual Mass [ton]	$3.2 \cdot 10^5$	$2.3 \cdot 10^5$	$2.6 \cdot 10^5$	$2.6 \cdot 10^5$	$2.9 \cdot 10^5$
Aug 13^{th} 2014 [%]	41	58	50	50	46
Oct 27^{th} 2018 [%]	12	18	15	15	14

Table 9: *Total mass calculated for each year. Percentage ratio of the two events (Aug 13^{th} 2014 and Oct 27^{th} 2018) to the available dataset years*

	Q_{max} [m^3/s]	SSC_{max} [mg/l]	Δt [h]	Mass [ton]	Duration [h]	Hysteresis
Aug 13^{th} 2014	425	9484	3.8	$13 \cdot 10^4$	45	counterclockwise
Oct 27^{th} 2018	313	4576	3.5	$3.9 \cdot 10^4$	192	counterclockwise

Table 10: *Main features of the two flood events: maximum discharge, maximum solid concentration, delay of the solid peak with respect to the hydrograph peak, total mass transported, duration of the event, direction of hysteresis*

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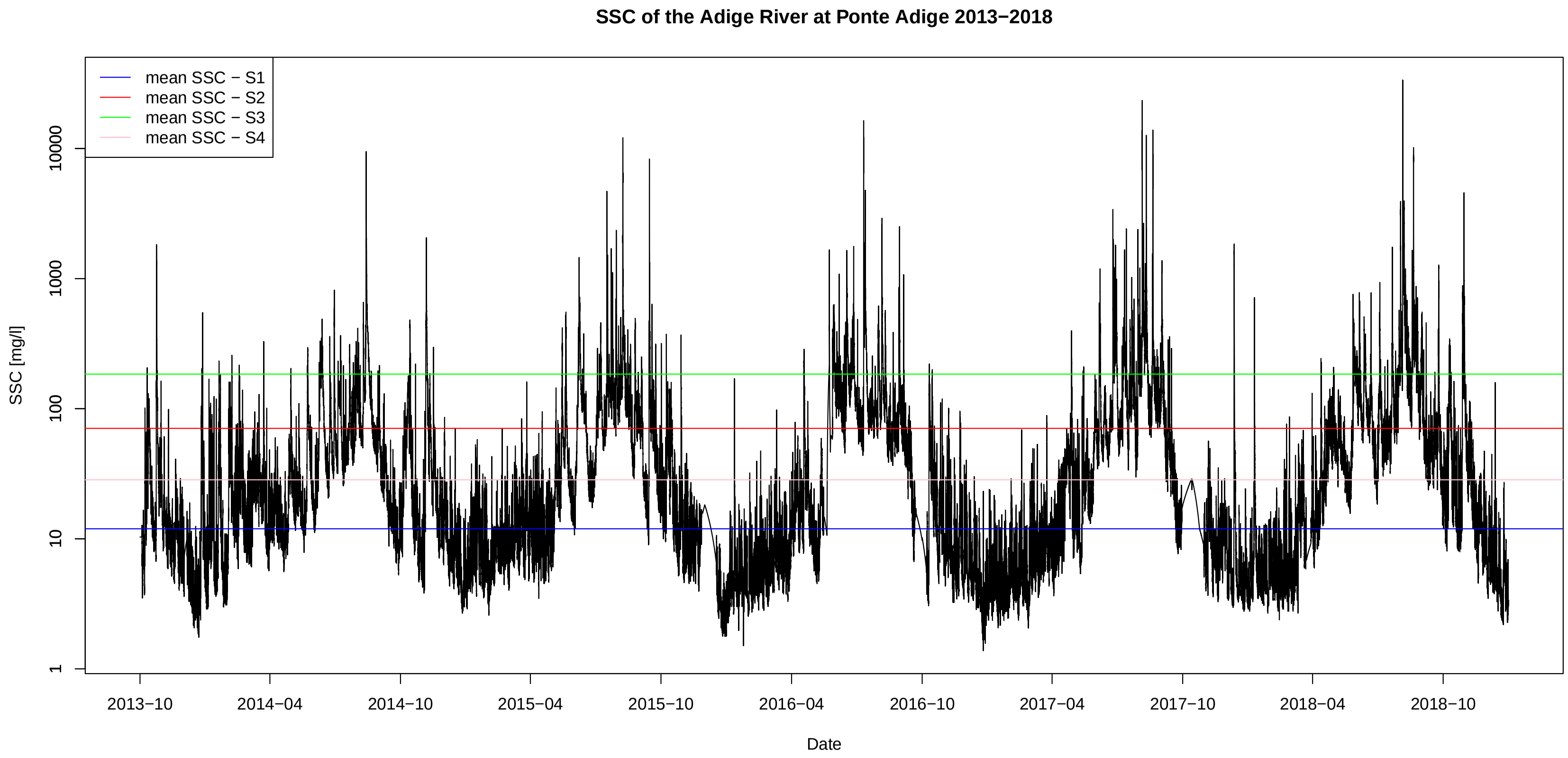


Figure 26: *SSC over time from February 2017 to December 2018. The coloured lines stand for the mean SSC calculated for the 4 seasons (blue = Winter, red = Spring, green = Summer, pink = Autumn)*

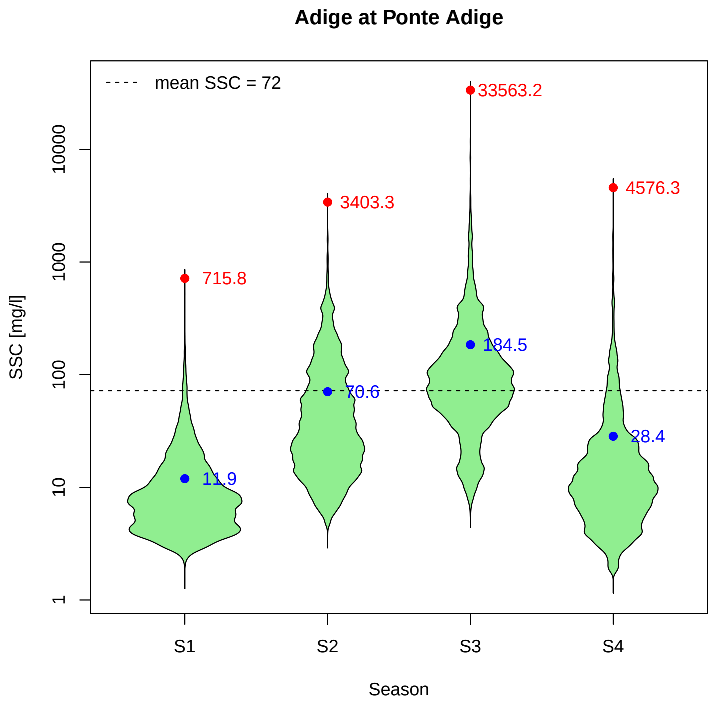


Figure 27: *Turbidity trend as a function of seasonality. The seasonal maximums are in red and the seasonal averages in blue. The dotted line stands for the overall average SSC*

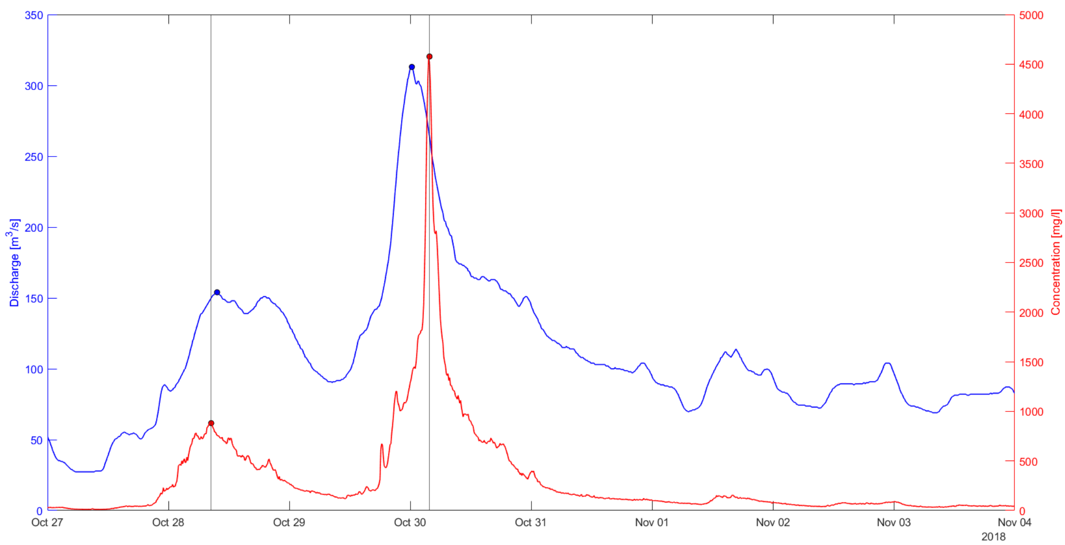


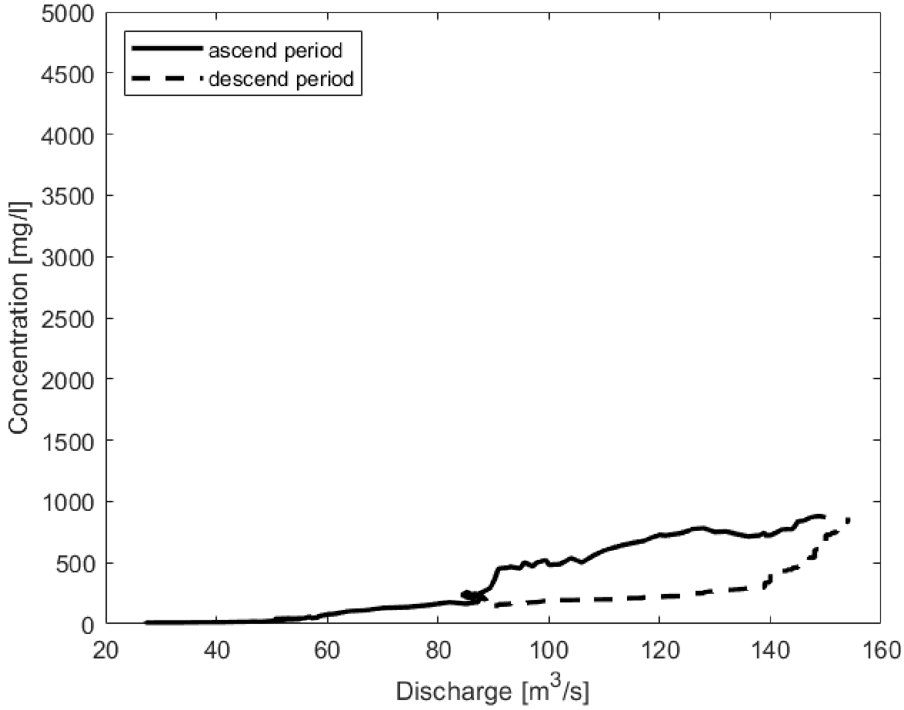
Figure 28: *Flood event occurred on October 2018. Comparison between the discharge (left y-axis) and SSC (right y-axis)*

The relationship between liquid and solid transport with respect to the ascending and descending phase of the flood was analysed. As a response to two close precipitation input, two subsequent discharge peaks were identified and studied separately (Oct. 28th and Oct. 30th). Figure 29 represents the hysteresis or the trend of the solid concentration as a function of the liquid discharge, for the two peaks respectively. Figure 29-a shows that the ascending phase is characterized by concentration slightly higher than the descending one. The response of the system in terms of transport is characterized by a clockwise hysteresis. The anticipation of the solid to the liquid peak depends on an immediate availability of sediment, e.g. sediment eroded from the riverbanks or possible breakage of the armour layer that exposes the fine sediment underneath the dragging of the flow.

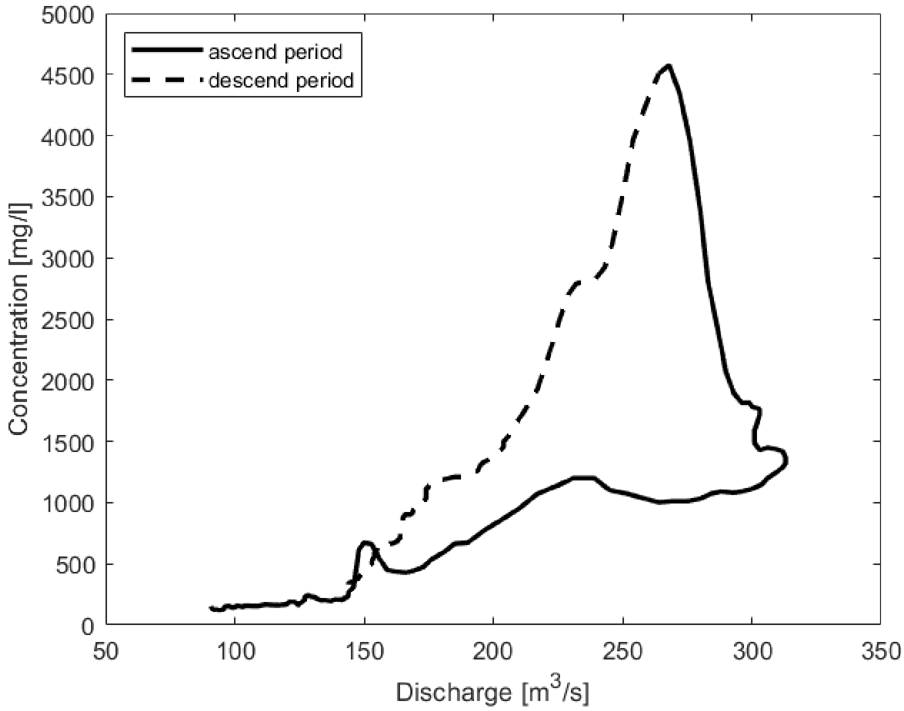
On the contrary, a counterclockwise hysteretic trend of the concentration can be observed on the second peak (Figure 29-b). This means that at a given liquid discharge the SSC is lower during the ascending phase than in the descending one. This phenomenon is due to the limited availability of sediment, which during the second precipitation impulse, was not sufficient to meet the transport capacity.

The dataset allowed a comparison with a more impulsive event occurred on August 13th, 2014. The same analyses were carried out to calculate the SSC mass flown across the gauging station. This value was then expressed as a percentage of the total mass to the years of available data (Table 9). Figure 30 shows the trend of the August event in terms of liquid flow and suspended solids, and the behavior of solid concentration during the ascend and descend phase of the hydrograph. Finally, the main characteristics of the two events are compared in terms of maximum solid and liquid flow, delay between the two peaks and transported mass (Table 10).

The flood event of August 2014 was more impulsive and intense then the one occurred on October 2018. In both cases the delay between the Q and the SSC peak was around 3.5 h and the discharge was characterized by a *supply-limited* condition. Future monitoring can provide a deeper insight into the sediment-supply condition of the Adige River. This information can bring interesting know how for future restoration plans, e.g. by designing requalification measures involving sediment inputs.

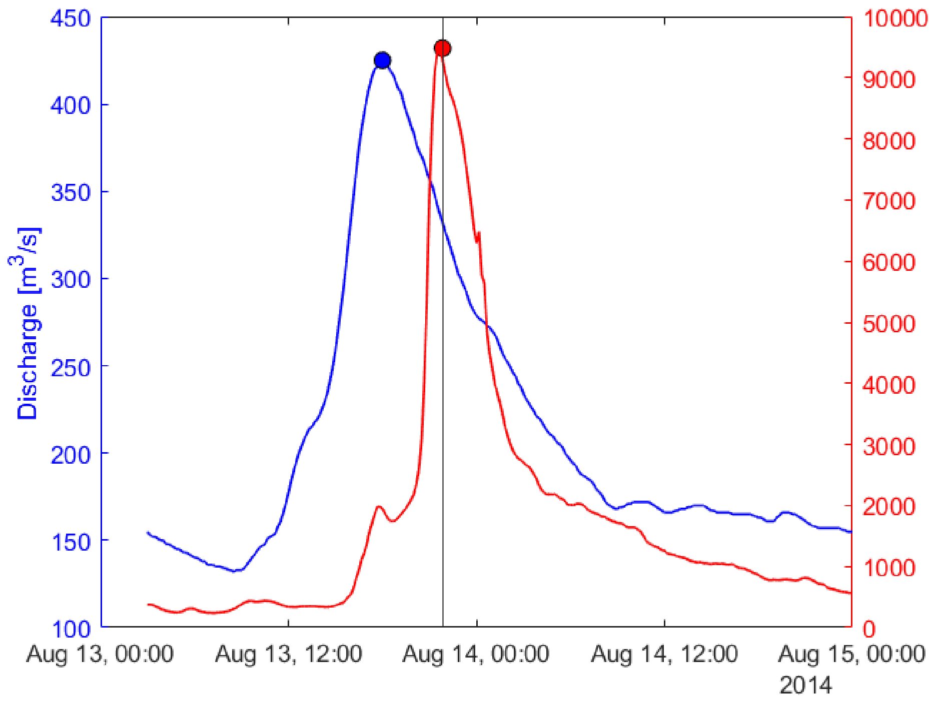


(a) *First Peak - Oct 28th*

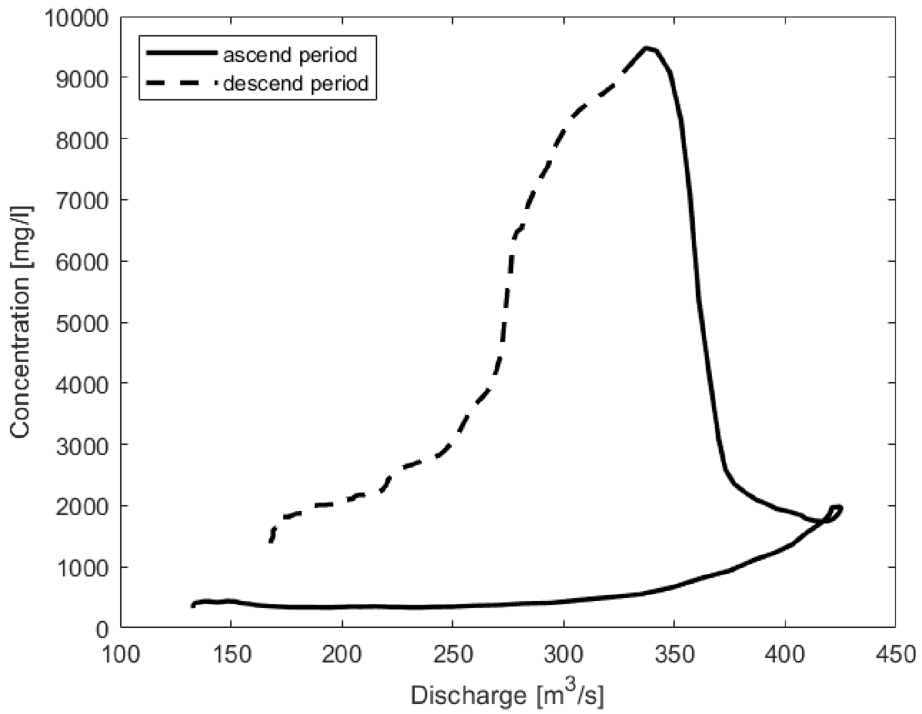


(b) *Second Peak -Oct 30th*

Figure 29: *Comparison of the liquid and suspended solid behavior considering to the ascending and descending phase of the flood event (October 2018)*



(a) *Behavior of the discharge (left y-axis) and SSC (right y-axis) during the event*



(b) *Comparison of the liquid and suspended solid behavior considering to the ascending and descending period of the hydrograph*

Figure 30: *Heavy rainfall event of August 2014*

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5.5 Groundwater results

Restoration works such as river bank re-shaping can alter the connectivity between the riverbed and the groundwater. To investigate this aspect considerations have been made based on the work carried out by Cainelli (2018). Figure 31 shows the study area in red, whereas the orange square identifies the area where the restoration took place. A relevant aspect when investigating the connection between the river and the watertable is the geological structure of the valley floor, which in this study was reconstructed from the analysis of the available stratigraphies (Figure 32).

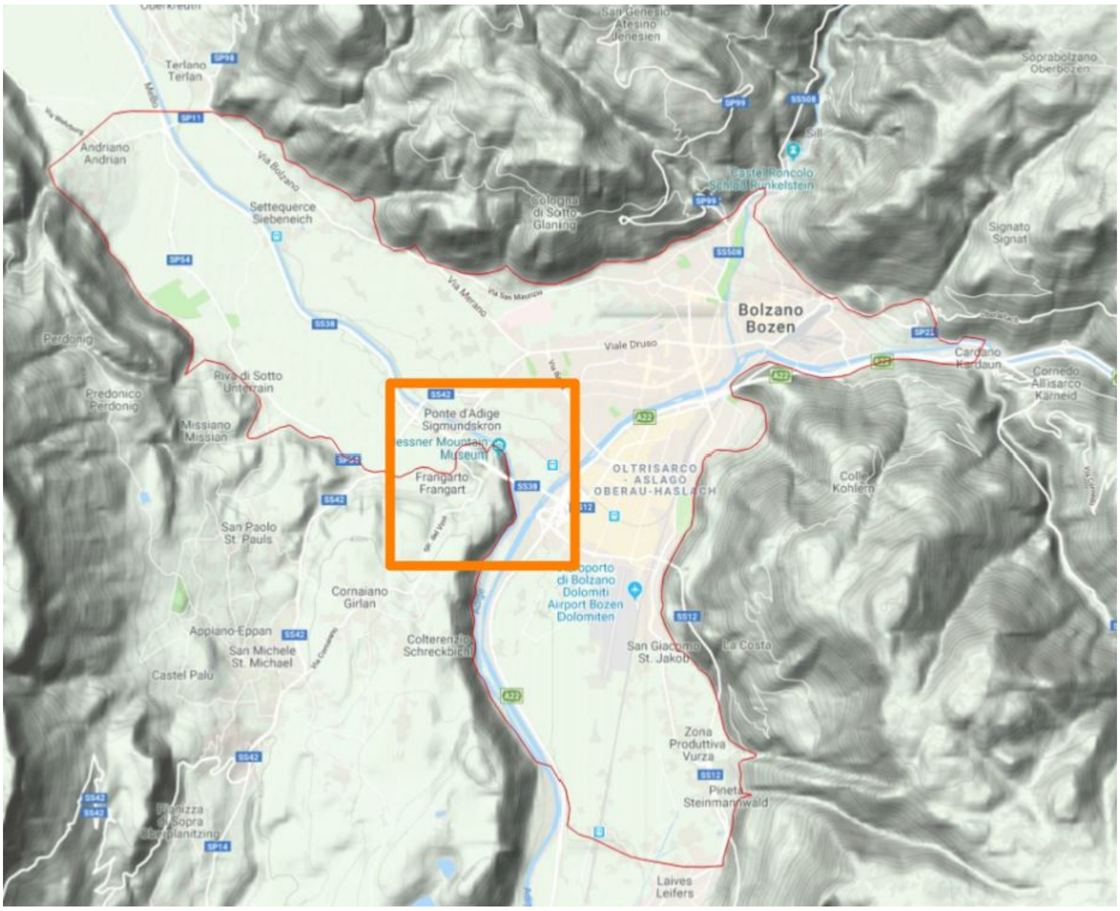

Figure 31: *Bolzano valley. The study area is outlined in red (Cainelli, 2018) while the area where the restoration took place is confined inside the orange square*

Cainelli (2018) showed that the Adige valley floor from Andriano to Ponte Adige is characterized by an extended layered structure, with the presence of massive silty layers, not conductive, which seem to end where the fans of Isarco and Talvera intersect.

Due to the prevalence of loamy layers, in this area many wells have been bored to depths of 50-60 meters;

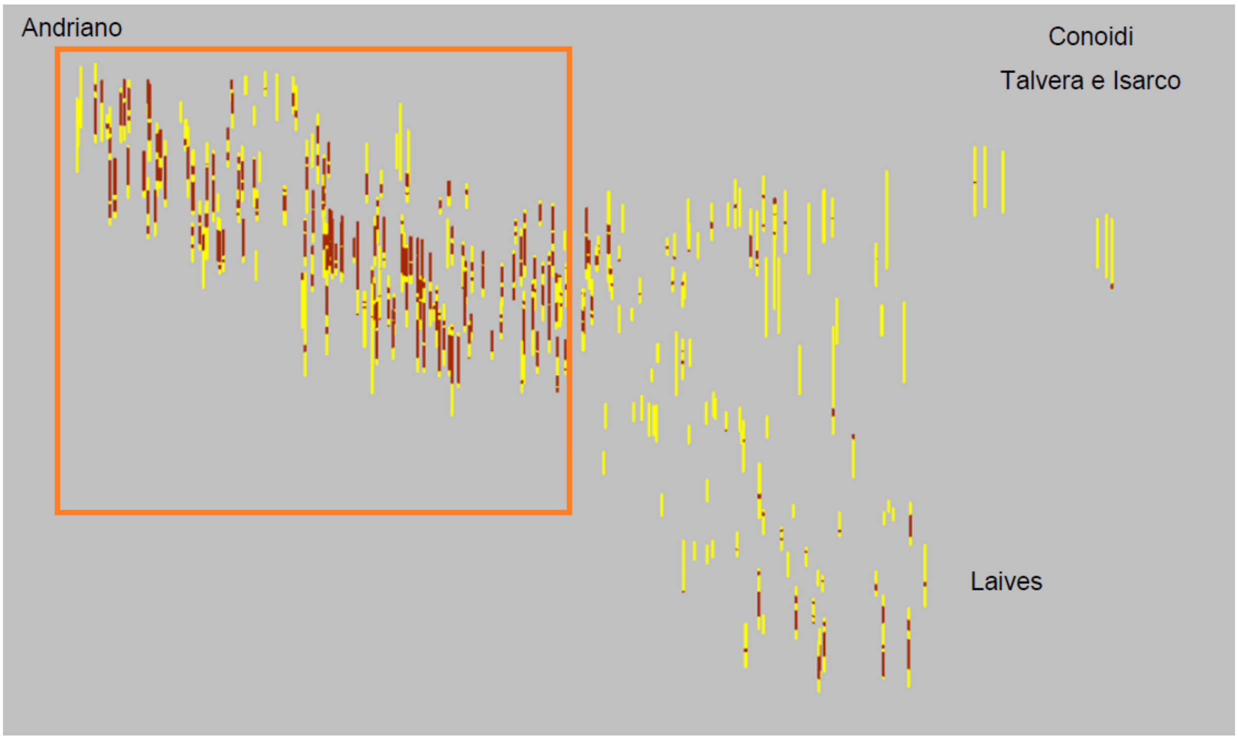

Figure 32: *Simplified representation of the layers of the geological structure (Cainelli, 2018). In brown the less permeable layers (with silty contents) and in yellow the more permeable ones (with mainly sandy or gravelly contents)*

this emphasises that the most productive layers (in terms of water withdrawal) are located at this depth or beyond. Aquifer withdrawals in this area are mainly for irrigation purposes. Previous studies, cited in Cainelli (2018) have described the hydrogeological structure of the aquifer underneath the valley floor to the West of Bolzano as a multiplatform system, with a shallow groundwater followed by various artesian aquifers, placed at various depths and disconnected from the Adige River.

This characteristic of disconnection between groundwater and river is confirmed by the chemical analyses carried out in previous studies (Cervenca ed al., 1993), and by the analysis carried out by Cainelli (2018) on the hourly monitoring data managed by the Hydrographic Office from 1/2/2011 to 31/12/2017. In particular, both the correlations between piezometric and hydrometric altitudes and the reciprocal position of the data between the groundwater and the watercourse show how the Adige does not appear to be connected to the groundwatertable.

In conclusion, the presence of many silty layers extending from the near-surface to a depth of 50-60 m from the valley floor, discard the hypothesis that the restoration works could have somehow affected the groundwater, given the scarce connectivity between the shallow groundwater and the riverbed.

6 Assessment of the Ecological Effects of the Restoration

6.1 Postal study reach

6.1.1 Effects on Chemistry

The analyses of the chemical data reveal a substantial similarity before and after the restoration. All the available parameters were analysed finding no significant differences. The only exception is the increase in the Nickel concentration, which however is low in absolute value (increasing from 2.5 to 4.3 μg/l) and probably has negligible ecological effects (Figure 33). In fact, according to the quality standard for surface water, the Nickel concentration must be lower than 20 μg/l, which is about 10 times less than the analysis outcome.

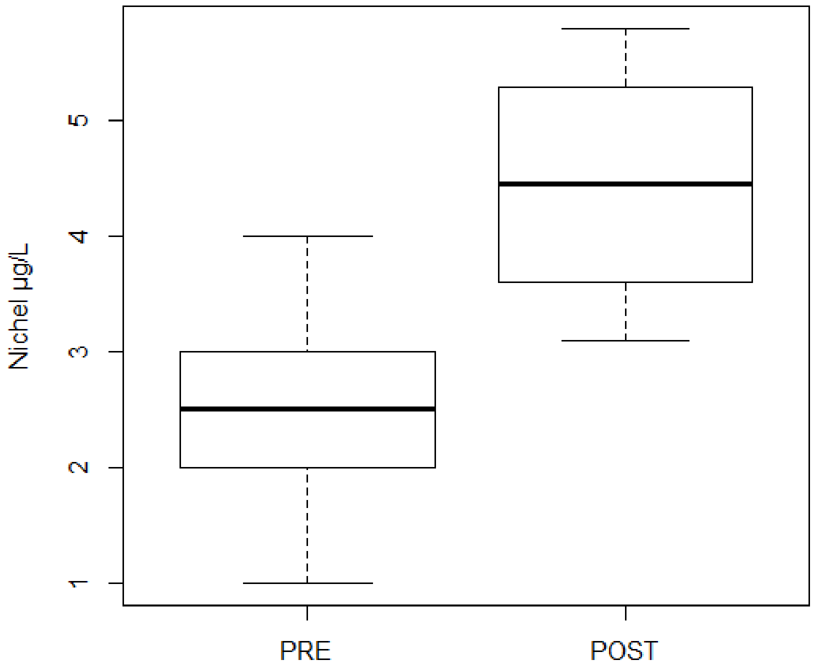

Figure 33: *Results from the chemical data analysis: boxplot showing the difference for Nickel concentration in water. The lower and the upper line of the box correspond to the first and third quartiles (the 25th and 75th percentiles); the middle line is the median density*

6.1.2 Effects on Macroinvertebrates

The macroinvertebrate population is quite similar comparing pre- and post-restoration conditions. Neither the assemblages (ANOSIM R = 0.111; p = 0.300) nor the taxa richness (t = 1.48, df = 7, p = 0.181) show significant differences; this is outlined by the point clamped in Figure 34. Indeed, a not clear compartment between red (before) and black (after) labels indicates a lack of significant differences. It was expected that the improvement of bank and river heterogeneity (by macroforms creation, large boulders introduction) would enhance species diversity. Actually, the available data are not suited to disproof the hypothesized robustness; they only suggest that at the monitoring point the effects are not evident. A more comprehensive sampling within the restored reach can reveal the expected differences when compared to an unrestored stretch.

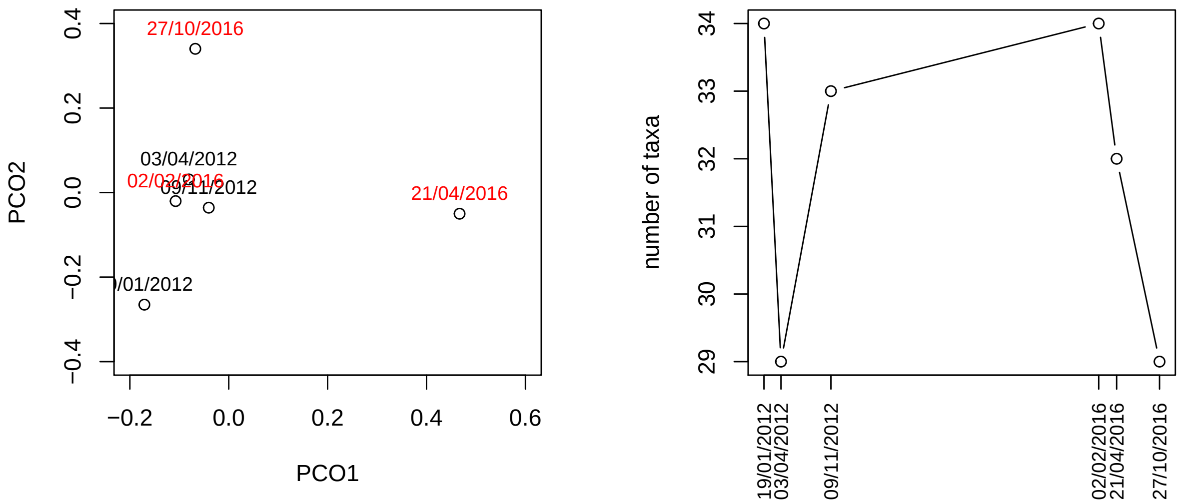

Figure 34: *Results from the macroinvertebrate data analysis: (Left) PCoA ordination of the macroinvertebrate taxa sampled before (black labels) and after (red) restoration. The macroinvertebrate assemblages do not change significantly before and after restoration, as showed by close-to-each-other labels (unclear compartment of red and black labels). (Right) the taxa richness of macroinvertebrate changes in time, however no clear trend or differences are evident*

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6.1.3 Effects on Fish population

Electrofishing carried out along the shore of restored and control stretch suggests a positive effect of restoration among the juvenile fish population, as 904 and 98 individuals were found respectively in the restored and control sites. In particular, the most positive effect was on *Thymallus thymallus* (Table 11), while for trouts the effect is less clear.

	N. individuals	
	Restored	Control
Thymallus thymallus	855	68
Trout spp	49	30
Total	904	98

Table 11: *Results of electrofishing in the restored and control reaches. Trout data include both Salmo trutta trutta and Salmo trutta marmoratus, since they cannot be separated at the juvenile state*

6.2 Ponte Adige study reach

6.2.1 Effects on Chemistry

The analyses of the chemical data indicate a substantial similarity before and after the restoration. All the available parameters were analysed finding no significant differences. The only exceptions is a slight increase in BOD_5 and Nickel concentration and a decrease of nitrites (NO_2) and ammonia (NH_3) concentration. Since these differences are significant but very low considering the absolute values, probably they have negligible ecological effects (Figure 35). Results from the statistical analysis are dispalyed in Figure 35 and outline the following features: BOD_5 (t = - 3.22; df = 117.9; $p < 0.005$); Nickel (t = - 7.46; df = 104.5; $p < 0.0001$); NO_2 (t = 4.80; df = 83.1; $p < 0.0001$); NH_3 (t = 3.42; df = 78.9; $p < 0.001$).

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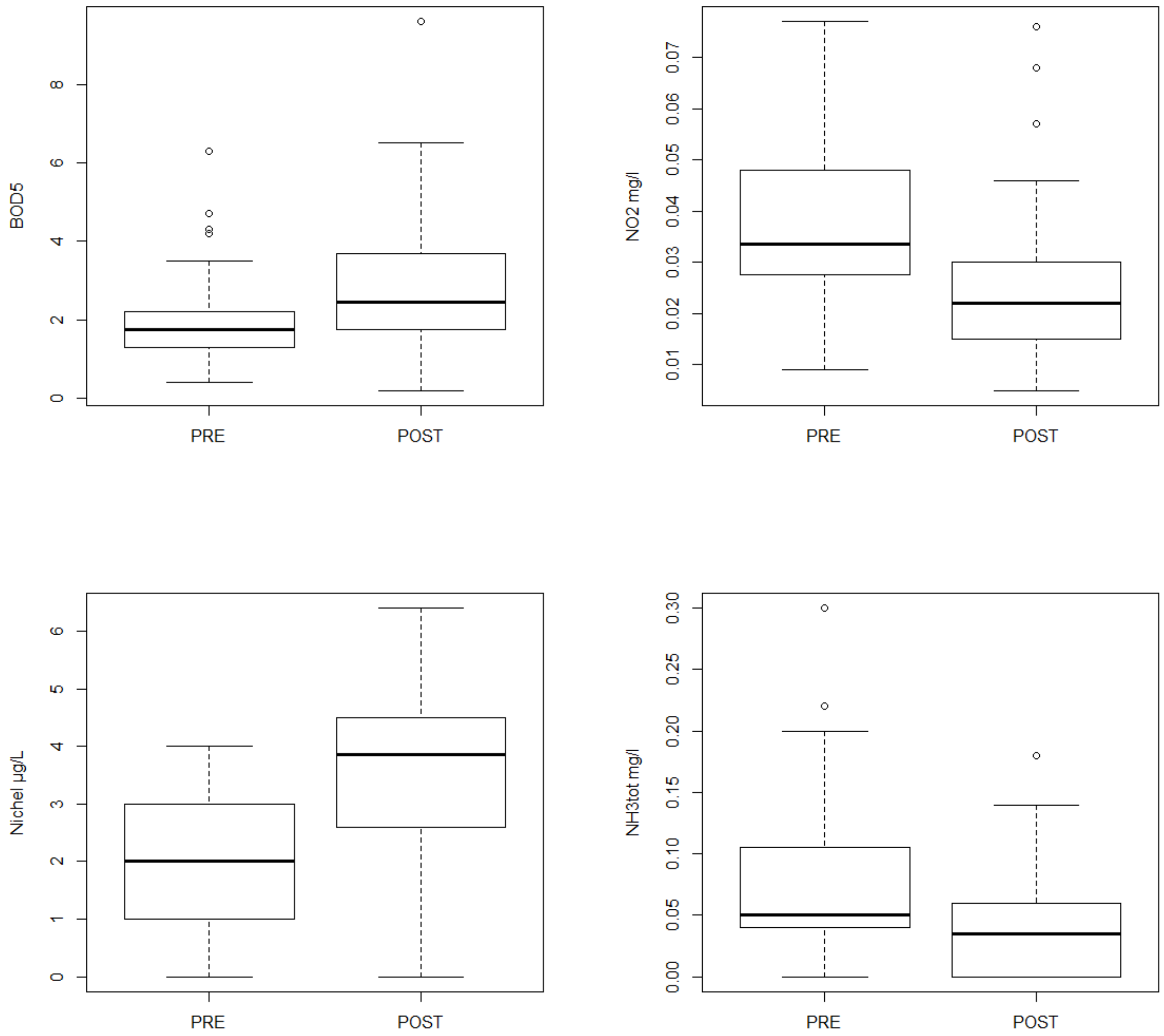

Figure 35: *Results from the chemical data analysis: boxplot showing the difference in organic loads pre- and post- restoration. The lower and the upper line of the box correspond to the first and third quartiles (the 25th and 75th percentiles); the middle line is the median density*

6.2.2 Effects on Diatoms

According to the PCoA statistics, the diatom assemblages observed in the pre-and post-restoration are quite similar; this is outlined by the point clamped in Figure 36. Indeed a non clear compartment between red (before) and black (after) labels indicates a lack of significant differences. ANOSIM test supports the same outcome (ANOSIM $R = 0.365$; $p = 0.145$). However, the reliability of the test is very low due to the limited sample size. Thus, these results are preliminary, a well-designed monitoring program is necessary to really assess the effects of restoration.

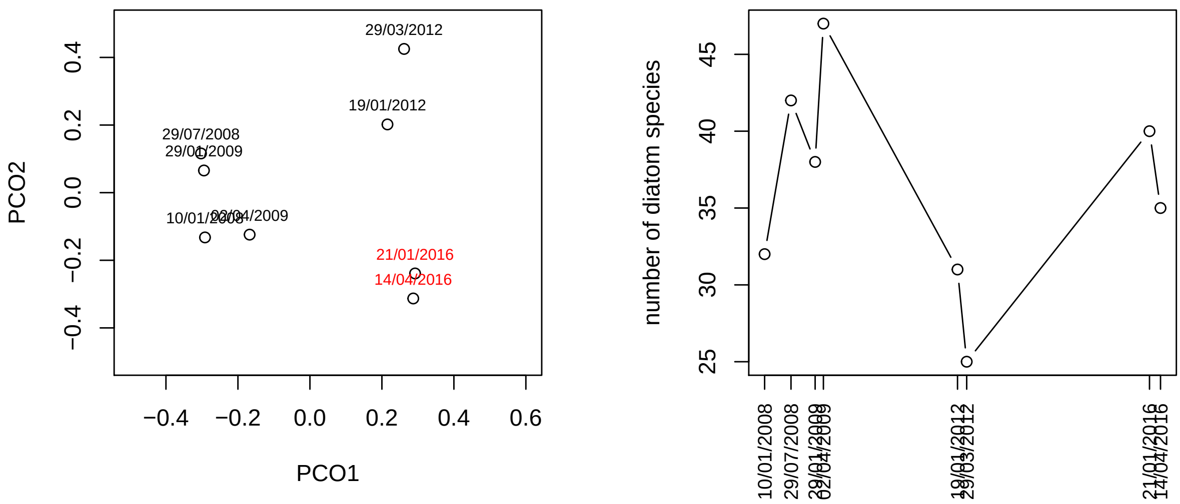

Figure 36: *Results from the diatoms data analysis: (Left) PCoA ordination of the diatom assemblages sampled before (black labels) and after (red) restoration. The diatom assemblages appear quite similar before and after restoration, as outlines by the mixed labels (no clear compartment of red and black labels). (Right) taxa richness change in time: no clear trend is observed*

6.2.3 Effects on Macroinvertebrates

The macroinvertebrates population was quite similar comparing the pre and post restoration data. Neither the assemblages (ANOSIM $R = 0$; $p = 0.579$) nor the taxa richness ($t = 1.48$, $df = 7$, p-value $= 0.181$) show significant differences (Figure 37). It was expected that increasing of bank and river heterogeneity would have enhanced species diversity. Unfortunately the current available data are not suited to disproving the hypothesis robustness; they only suggest that at local scale the effect is not evident. A more comprehensive sampling within the restored reach can reveal the expected differences when compared to unrestored stretches.

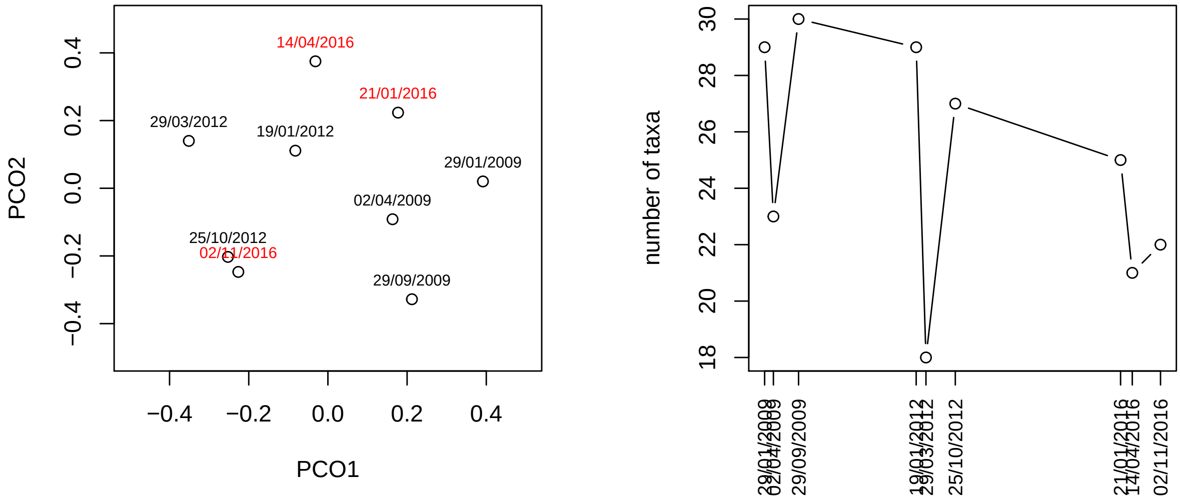

Figure 37: *Results from the macroinvertebrate data analysis: (Left) PCoA ordination of the macroinvertebrate taxa sampled before (black labels) and after (red) restoration. The macroinvertebrate assemblages do not change significantly before and after restoration, as showed by mixed labels (unclear compartment of red and black labels). (Right) taxa richness of macroinvertebrate change in time: a decreasing trend can be observed*

6.2.4 Effects on Fish population

The electrofishing carried out along the shore of restored and control stretches suggests a positive effect of restoration among the juvenile fish population, as 111 and 43 individuals were found respectively in the restored and control shores. In particular, the most positive effect is on *Thymallus thymallus* (Table 12 and Figure 38), while for trouts the effect is less clear. However, considering the density of individuals, the positive effect on *Thymallus thymallus* is less evident, and for trouts it seems to be negative. In order to obtain more robust results, it is strongly suggested to repeat the monitoring and increase the sampling effort.

Reach characteristics	Restored	Control
Width [m]	4	1
Length [m]	200	200
Area [m^2]	800	200
	N individuals	
Thymallus thymallus	69	9
Trotus spp	4	12
Alburnus alburnus	1	/
Lampetra planeri	2	1
Cottus gobio	35	20
Pseudorasbora parva	/	1
	Density (ind/100 m^2)	
Thymallus thymallus	8.6	4.5
Trotus spp	0.5	6.0
Alburnus alburnus	0.1	/
Lampetra planeri	0.3	0.5
Cottus gobio	4.4	10.0
Pseudorasbora parva	/	0.5

Table 12: *Results from the electrofishing in the restored and control shore. Trouts include both Salmo trutta and Salmo trutta marmoratus, as they cannot be separated when juvenile*

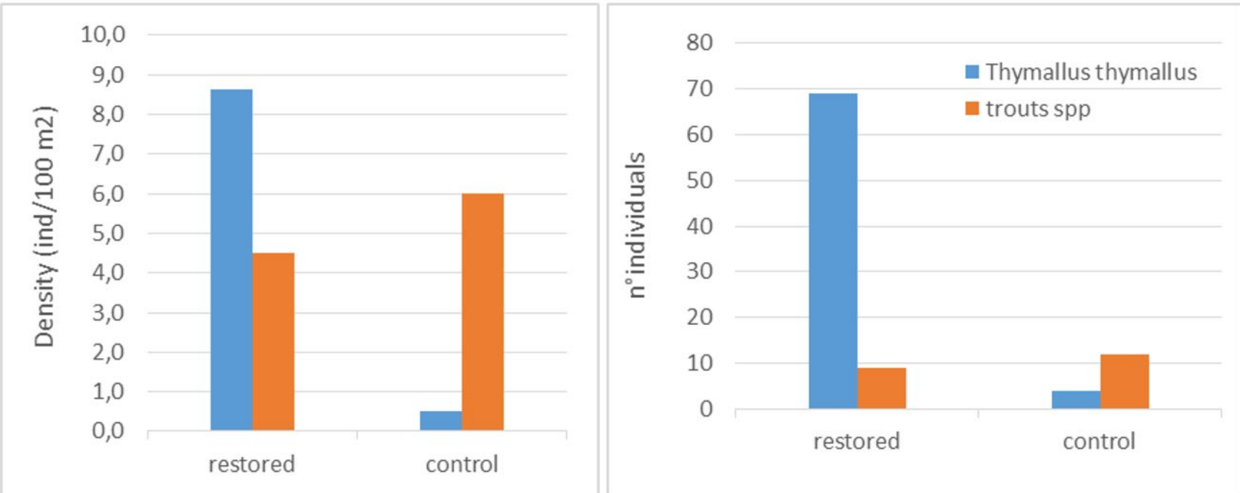

Figure 38: *Comparison for the juvenile fish in the restored and control shore: data expressed as raw abundance and density*

7 Conclusions and perspectives

Within the HyMoCARES project, the WPT3 aims at evaluating the effects of river restoration works both in physical and ecological terms. The monitoring design implemented by the Autonomous Province of Bolzano, based on a **B**efore **A**fter approach, allowed for data collection and elaboration; these data have been analysed to assess the restoration efficiency of the renaturalization interventions along the Adige.

From a physical point of view, the main outcomes, for both the study reaches at Postal and Ponte Adige, are the following:

1. **Effects on the morphology - DoD**: the analysis outlines the morphological changes associated to the riverbanks smoothing and renaturalization. Despite the restoration works could not further improve the Adige morphology, due a lack of public land which forces the river to remain channelized and straight, they do improve the ecosystem by introducing new habitats, suited for juvenile fish, and by enhancing the river recreational functionality.

2. **Effects on Discharge Alteration - IARI**: the restoration was not conceived to address the hydrological regime alteration. However, this index provides information about the river hydrological regime and therefore its natural (or altered) status which directly affect river ecology.

3. **Effects on the Morphological Quality Index**: the morphological quality associated to the reaches at Postal and Ponte Adige is respectively *Bad* and *Moderate*. This is due to the channelization and rectification of the Adige which brought about a loss of river morphology. In general, the restoration works had no major influence to the morphology and functionality of the river, because of their limited extension if compared to the length of each MQI reaches. However, the MQIm is a more appropriate tool to detect morphological changes associated to restorations, being applyed on an confined area. In fact from this index results some morphological improvements of the restored reach.

4. **Suspended Sediment Concentration**: the analysis of the SSC characterizes the seasonal variability of the SSC in terms of mean and maximum values, that can be used as reference for planning future restorations. The identification of periods characterized by natural high or low sediment transport, suggests which are the most suitable time to carry out, for example, restoration measures involving the mobilization of material. In addition, reservoir management can benefit from the knowledge of

seasonal natural trends and maximum values of SSC, since the maneuvers can be planned optimizing the flushing efficiency and minimizing the envirnmental effect.

The analyses regarding the event of August 2014 and October 2018 show that a large quantity of suspended solids is concentrated in few intense events during the year and that a counter-clockwise hysteresis describes the relationship Q-SSC. This implies a *supply-limited* condition which might depend from upstream consolidation and retention check dams. However, to get a complete picture of the solid transport features, bedload data are necessary to complement the analysis.

5. **Effects on the groundwater**: the results show no connection between the Adige riverbed and the aquifer, because of silty layers which segregate the shallow water-table from deeper aquifers. This geological feature prevents the effects of the restoration works from interfering with deep aquifers.

From an ecological point of view, the effects of restoration occur at a larger scale and for this reason results are separately summarized for the two study reaches:

- **Postal** study site:

1. **Chemistry**: the analyses of chemical data revealed a slight increase in the Nickel concentration, which has a negligible ecological importance, being far from the legal threshold. The major sources of trace of metal pollutants in aquatic ecosystems come from domestic wastewater refluxes.

2. **Macroinvertebrates**: the assemblages before and after restoration are quite similar. It was expected that the increase of bank and river heterogeneity would have enhanced species diversity and composition. Unfortunately the current available data are not suited to disproof the robustness of the hypotheses; they only suggest that at the local scale the effect is not evident. A more comprehensive sampling including habitats developed after restoration (if any), can reveal interesting differences between the restored and a control site. The scope of the future ecological monitoring should be better focussed to assess the effects of the restoration with a specific sampling design.

3. **Fish population**: juvenile fish are overall more abundant in the restored stretch than in the control one. *Thymallus thymallus* is ten times more abundant in the restored site; for trouts results denote a slightly positive trend. Considering the high natural spatial variability, results are positive, however

they need a further sampling to be confirmed. It particular, the newly-created habitats along the river bank is expected to be suitable also for trout recruitment; this needs to be monitored.

- **Ponte Adige** study site:

1. **Chemistry**: the analyses of chemical data revealed substantial similarity between before and after restoration (more BOD_5 and Nickel and less NO_2 and NH_3 after restoration). However, considering their absolute values, the expected ecological effect is not relevant, being far below the legal threshold. The source of Nickel is probably domestic wastewater refluxes.

2. **Diatoms and Macroinvertebrates**: the assemblages of both groups are quite similar before and after restoration. It was expected that the increase of bank and river heterogeneity would have enhanced species diversity and composition. Unfortunately the current available data are not suited to disproof the robustness of the hypotheses; they only suggest that at the local scale the effect is not evident. A more comprehensive sampling including habitats developed after restoration (if any), can reveal interesting differences between the restored and a control site. The scope of the future ecological monitoring should be better focussed to assess the effects of the restoration with a specific sampling design.

3. **Fish population**: the juveniles fish are overall more abundant in the restored stretch than in the control one. *Thymallus thymallus* was nearly the double in the restored site compared to the control, while for the other species, including trouts, results are still a work in progress. Considering the high natural spatial variability, results are positive, however they need a further sampling to be confirmed. In addition, it is strongly suggested to optimize the total sampling area to make comparable data collected from restored and control sites.

In general, the effects of the restoration works are positive, bringing improvements to the river habitat both in physical and ecological terms. However, this outcome mainly relies only on the BA (Before-After) monitoring approach. Designs without spatial and temporal replication, control and reference sites, are in essence case studies where the inferences (conclusions) are generally weak. Confidently ascribing changes to a treatment or to a cause, without a proper sampling design, is hard and fragile. Including at least one control site (portion of the river not restored), and one or more reference sites (the target condition) in future monitoring design is highly recommended to minimize the possibility of confusing restoration effects with natural variability.

The minimum essential sampling design is the Before-After Control-Impact (BACI), where both a control and treatment site (impact) are monitored before and after restoration. A better choice is however to include also the reference sites, if available: if not, it is possible to identify a priori a target condition, which identifies the goal of the restoration. Control and reference sites must be selected taking into account the nature of the river, since poorly chosen sites may add noise to the data, further complicating the interpretation of results. It is a common belief that these sampling designs are robust but expensive, for this reason they are rarely applied because of resource shortage. However, considering the costs of restoration projects, even a robust ecological monitoring program, often does not affect more than the 10% of the total budget.

As concluding remark, the major points for developing a successful monitoring approach are summarized in the following (also supported by the CIRF - Centro Italiano per la Riqualificazione Fluviale).

- Clear identification of criticalities for the water body.
- Clear identification of the objectives of the restoration scheme.
- Clearly determining whether effects are actually a consequence of the restoration measures or rather of external factors. In this respect, control or/and reference sites are fundamental for the robustness of the monitoring.
- Spatial and temporal scales of the processes involved have to be considered.
- Monitoring the pre- project conditions has to be performed.

In conclusion, if monitoring is intended to produce useful information, it should be implemented in the preliminary stage of a restoration project. Understanding primary goals, objectives and identifying the right parameters to be monitored is crucial. The collection and the elaboration of data regarding wrong parameters are time and cost consuming.

7.1 Future monitoring and good practices

Long term monitoring of river morphology and ecology allows to understand whether the restoration works meet the expected results or rather ephemeral ones. If the morphological changes carried out along the watercourse are vanished by the first flood event and the river goes back to its original (pre-restoration)

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configuration, it can be concluded that the restoration works were not the most suitable for that specific site. On the other hand, the monitoring of a positive response indicates that the restoration works are appropriate and can be applied to similar watercourses. Regarding the Adige River, the outcomes of this study suggest the following monitoring actions to check the effectiveness and the evolution in time of the restoration works.

- **Eco-Morphological monitoring**: in order to assess whether the restoration works are self-maintaining and whether they have an effect on improving the habitat quality and the abundance, the following monitoring actions are recommended: a) TLS surveys which provide information on the river bank evolution; this is important to assess whether the restoration works of channel widening are persistent and offer to the fluvial fauna suitable habitats. This monitoring action should be carried out on average every 2 years or after an intense event. b) grain size distribution analyses along the banks; this is useful to assess the substratum type and whether it suits fish and macroinvertebrate (MZB) communities. Sorting can be performed using the technique explained in Bunte and Abt (2001). The analysis of the fine fraction is also important; c) surveys to assess the effective habitat suitability and its variations. The classification of the different HMU should be carried out along the restored and the unrestored reaches, so that results can be compared. The analysis must be performed at different discharge rates, according to the methodology described in **sum**. The assessment aims at evaluating the habitat from an abiotic point of view, without performing any biota modelling (e.g. correlation between habitat and fish availability). It should be carried out on average every 2-3 years or after an intense event.

- **MQIm monitoring**. The evaluation of the Morphological Quality monitoring Index is designed to assess the MQI at local scale, i.e. at the scale of a renaturalization action, and to monitor its effectiveness in time. The MQIm investigates the trend of the river morphology after restoration works, and therefore whether they have enhanced or deteriorated the river morphology. It should be performed once every 2-3 years.

- **Fish monitoring**. The most significant restoration works have been mainly carried out along the riverbanks, hence fish should be assessed in this part of the river. Electrofishing should be performed in the restored and in control stretches (not restored) to compare and evaluate the real effect of restoration (Figure 39). Moreover, to account for the natural variability of populations, fish should

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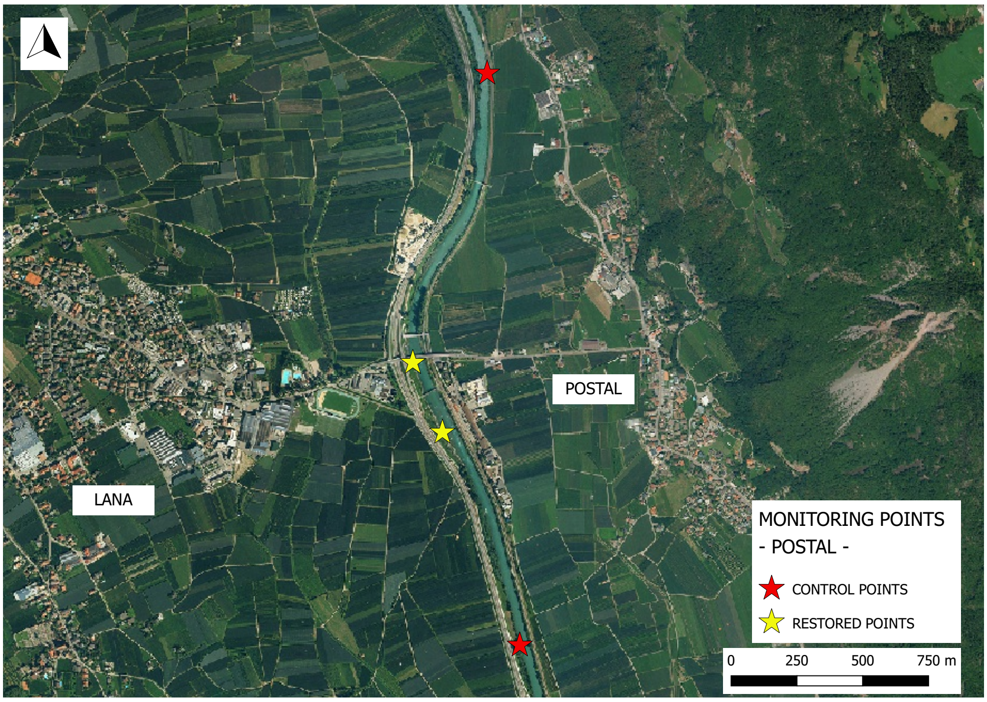
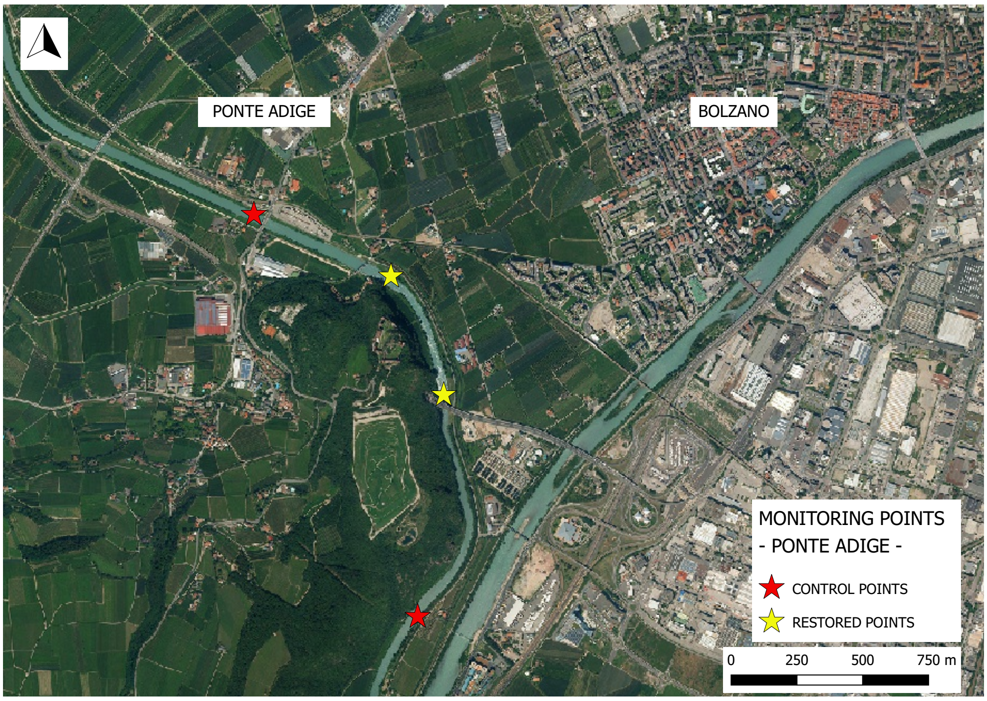
be assessed at least along two river bank portions (two in the restored sites and two in the control sites). The most suited period to perform the sampling is late autumn-early winter, because of lower discharges (which facilitate the sampling operations) and because the juvenile fish (both of trout and grayling) are effectively captured as they are large enough. Sampling should be carried out once a year for at least 5 consecutive years. For a good data comparison, sampling stations and field guidelines should be clearly written and shared among the technicians. The effects of restoration should be assessed using univariate (e.g. ANOVA) and multivariate statistical numerical approaches.

- **Macroinvertebrate monitoring**. This population is significantly sensitive to restoration works modifying the substrate composition and increasing the flow heterogeneity. The ecological monitoring should follow the same approach previously described for the fish community: samples should be taken in the restored and unrestored riverbanks along at least two replicates, to account for the natural variability of the populations. Macroinvertebrates should be sampled following the multihabitat approach as indicated by ISPRA (2014). Sampling should be carried out once a year (in the same period of the fish sampling) for at least 5 years. Data analysis should be performed using univariate and multivariate statistical numerical approaches. Since the macroinvertebrate community includes more individuals and species than the fish community, the assessment of the restoration effects might be more complex. For this reason, the data analysis should include both multivariate statistics but also approaches considering ecological guilds, traits and biomass.

See Table 13 for further details.



(a) *Location: Postal*



(b) *Location: Ponte Adige*

Figure 39: *Proposed monitoring points for future fish surveys*

	Monitoring	Frequency	Where	How	What	Data analysis
PHYSICAL	Eco-Morphology	Every 2 years	Riverbanks, (Riverbed*)	Visual inspection, TLS, GPS, velocimeter, (Echo boat*)	Topographic and bathimetric* survey, grain size analysis, habitat assessment	DEM analysis, sieving and sorting, Bunte and Abt (2001), ISPRA
	MQIm	Every 2-3 years	T1 and T2	ISPRA methodology	Funcionality and Artificiality parameters	ISPRA fieldsheets
ECOLOGICAL	Fish	Every year	See Figure 39	ISPRA manual	Fish density	ISPRA manual
	MZB	Every year	See Figure 39	ISPRA manual	MZB density	ISPRA manual

Table 13: Summary of the recommended monitoring actions (*this action is recommended even though not fundamental)

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