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

CASE STUDY: TALVERA RIVER (ITALY)

Project: HyMoCARES
Work package: WPT3. Effects of hydromorphological management and restoration measures
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1 Introduction

1.1 The study site: Talvera River

The Talvera River flows through the region of South Tyrol, North-Eastern of Italy. It is one of the main tributaries of the Isarco River and its main characteristics are summarized in Table 1. Along its course, the Talvera is diverted several times, thus presenting a reduced flow rate until the point where the diverted water is returned to the river in Bolzano (downstream the S. Antonio hydropower plant). The Talvera has been channelized and confined during the years mainly for flood risk mitigation, modifying the natural ecological conditions. In addition, due to the River high transport capacity, several check dams were built in the past in order to foster sediment and woody debris deposition and retention and thus to protect Bolzano from floods.

Pilote Site	Talvera River
Total catchment area (km^2)	429
Minimum elevation of the Talvera catchment (m a.s.l.)	260
Maximum elevation of the Talvera catchment (m a.s.l.)	2781
Start coordinates (East, North)	681402.524, 5155581.475
End coordinates (East, North)	680244.098, 5151556.126
Length of the study reach (km)	5.0
Active channel width (m)	20-50
Channel slope (%)	2.0
Planform morphology	Single-thread

Table 1: *Main physical features of the study reach and general catchment information*

The stream reach target of the restoration within the HyMoCARES project includes the last 5 kilometres of the Talvera before the confluence with the Isarco River (Figure 1). It starts at the Sill consolidation check dam and it ends at the confluence. Before the restoration, the average stream width along the study reach ranged between 20 m to 50 m. However, originally the Talvera river cross sections used to be as twice as its actual breadth. The recovery from river channelization and narrowing was one of the major goals of the restoration project, which aims at promoting sediment continuity by the removal of man-made cross section structures and at enhancing the longitudinal connectivity for the fish population.

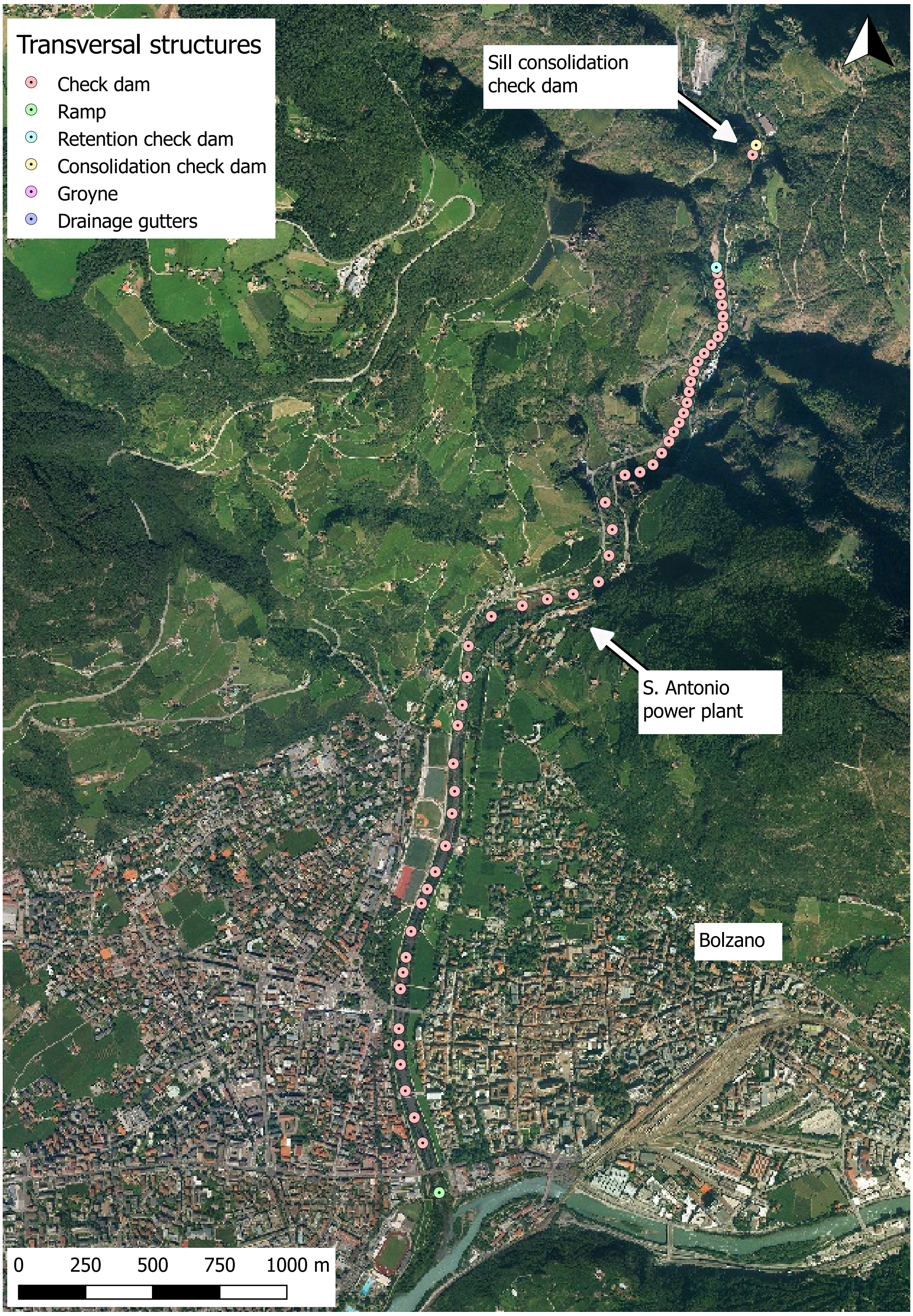

Figure 1: *Overview of the study reach along the Talvera River*

1.2 Human alterations

The main human alterations affecting the restored river reach of the Talvera are river channelization, hydropeaking due to the hydropower plan activities and hydro-morphological alteration due to a series of check dams and bank protections. The channelization of the Talvera occurred between the 60s and the 80s, when the cross section, up to 180 m wide, was confined to a roughly constant width of 20 to 50 m. The reduction of the stream velocity was achieved by building a series of 43 transversal structures whose height ranged between 0.40 m to 6 m. These check dams cut the longitudinal connectivity of aquatic populations along the river reach; as a consequence a loss of habitat occurred, which contributed to a decrease in the number of individuals. Moreover, a selection of fish species occurred according to the check dams height, since some of them are less skilled to jump obstacles: for example, the common barbell *(Barbus barbus)*, the European bullhead *(Cottus gobio)* and all the juveniles individuals cannot overcome obstacles higher than 0.8 m. Since the construction of those check dams, sediment transport and supply have been deeply reduced; this brought about a loss of gravel areas, which provided habitats for several fish species. One of those check dam, downstream the Sill gorge, has already been removed and replaced by a retention check dam with a filter permeable to small size cobble and gravel. However, sediments tend still to be retained within the Sill gorge (which corresponds to the area upstream of the studied stretch) by a large retaining dam, planned to be removed in 2019. Another one is located upstream the Sill gorge. Further projects might concern the removal of this last check dam leading to even higher longitudinal connectivity. The hydropower plant along the Talvera in Bolzano relies on a storage reservoir located in Auna valley in the Renon community. Depending on the price of electricity and production, there are sharp and abrupt fluctuations in discharge downstream the S. Antonio power plant (hydropeaking effect). The fluctuation between high and low discharge values brings an additional burden to the aquatic life, especially in the spawning period and during the juveniles development. In addition the hydropeaking, due to shear stress along the river bed has an effect also on bed armouring and vegetation removal. Figure 2 and Figure 3 show how the hydropeaking affects the discharge fluctuations in different seasons. Generally, the Talvera discharge in 2017 varied between 1 and 20 m^3 s^{-1} at least a couple of times per day.

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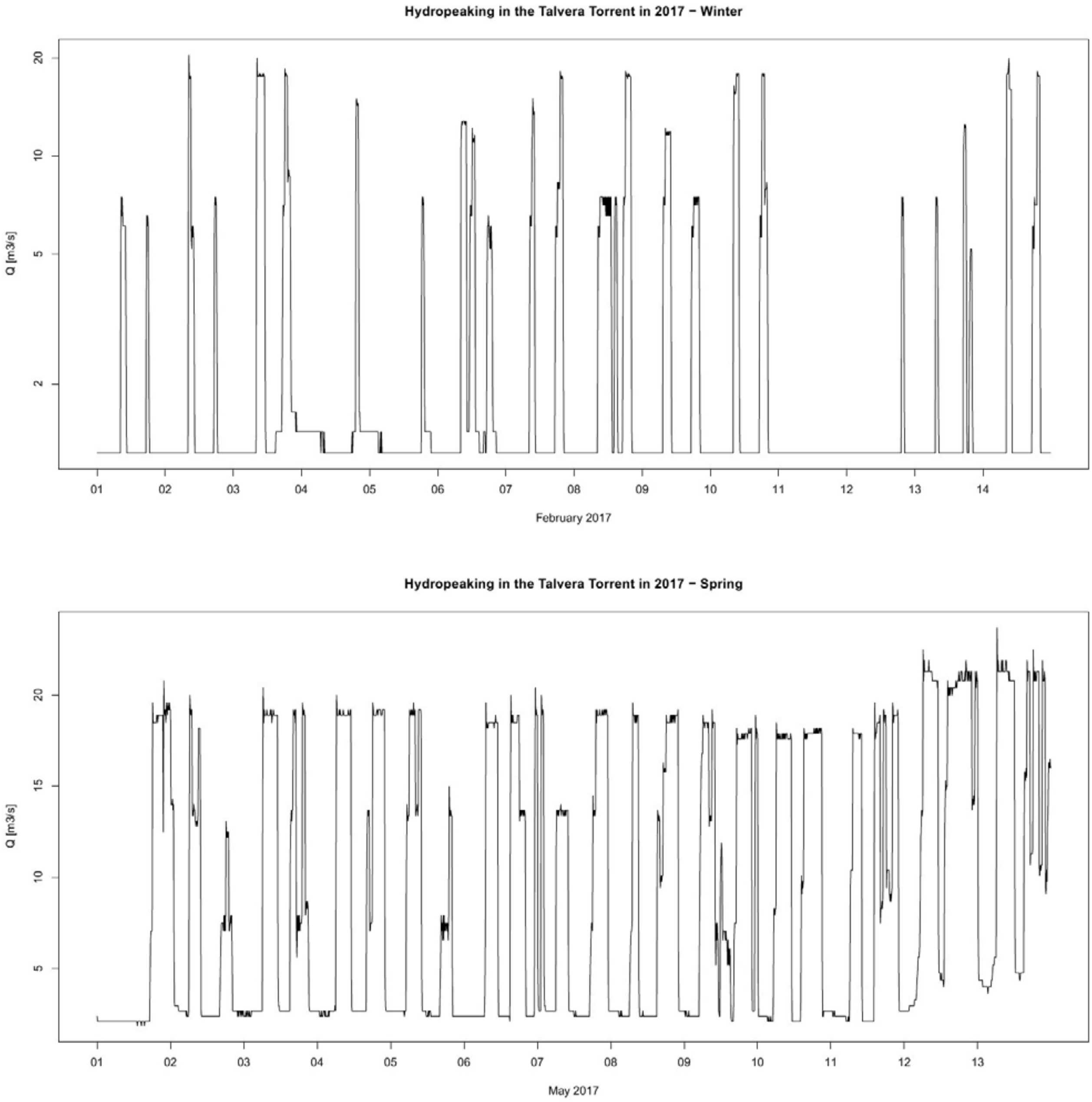
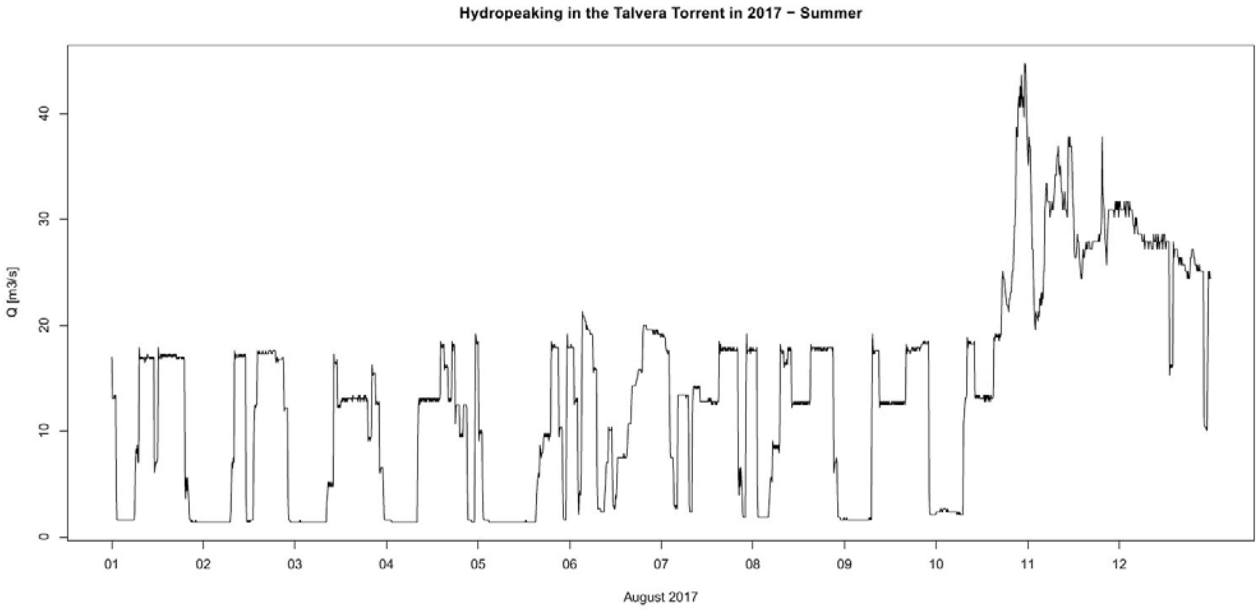


Figure 2: *Discharge fluctuations recorded at the beginning of February (top) and May (bottom) 2017. The x-axis shows the day of the month, while the y-axis shows the discharge ($m^3\ s^{-1}$)*



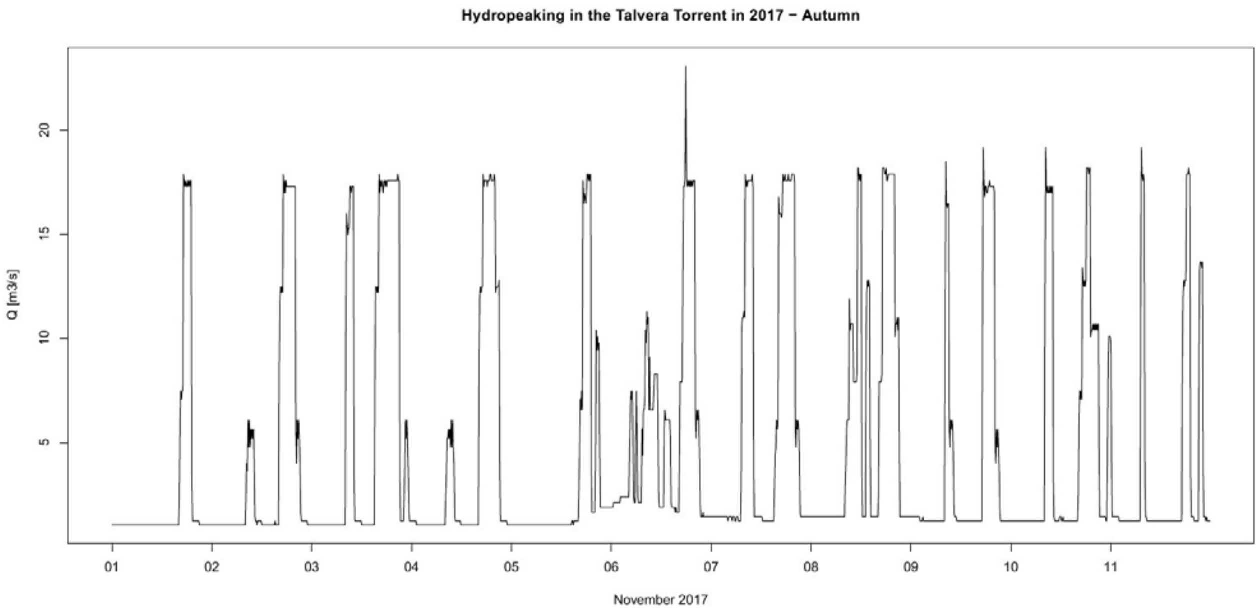


Figure 3: *Discharge fluctuations recorded at the beginning of August (top) and November (bottom) 2017. The x-axis shows the day of the month, while the y-axis shows the discharge ($m^3\ s^{-1}$)*

1.3 The restoration project: goals and measures

The Talvera in the area of the S. Antonio power plant has a huge ecological potential providing spawning areas and good habitat for the juveniles of like grayling *(Thymallus thymallus)*, common barbell *(Barbus barbus)* and marble trout *(Salmo trutta marmoratus)*. The main goals of the restoration project are the improvement of the longitudinal connectivity for the fish population, the increase of the number of habitats, the enhancement of stream physical heterogeneity and of flow variability.

The restoration works started in 2014 and went on up to spring 2019; the revitalization measures aim at:

- Weir removal. The removal or partial opening of the weirs all along the stretch, in order to allow longitudinal connectivity. The openings were obtained by alternating right- and left-openings to provide a sinuous pattern to the watercourse. Using the material from weir removal, the holes created by erosional processes in case of a lack of sediment were filled. This measure brings advantages for both aquatic populations and river morphology (higher sediment connectivity and diversity) avoiding sediment or wood accumulation and dangerous areas formation.

- Dam removal. Removal of a consolidation check dams in the upper reach, which was substitute with a retention check dam (Figure 4), where fish migration is ensured also in low water regime. A retention basin was build upstream guarantying sediment entertainment. Further measures have been deployed during the winter 2018/spring 2019 regarding the demolition of a check dam at the Sill ice rink area. The 5 m jump will be substituted by means of an ascending fish ramp.

- The establishment of a medium water profile to solve problems due to low water level (hydropeaking).

- Dead wood introduction and recreation of natural macroforms (e.g. flow deflectors, bars, pools).

- Identification of the target species, the European bullhead (Cottus gobio), whose spread can be used to evaluate the efficiency of the restoration measures.

- The recreational value of the Talvera is enhanced by the described restoration action. The longitudinal connectivity of the stretch allows recreational activities such as kayaking and fishing.

Due to the natural redesign of the streambed and the removal of anthropic obstacles, the good state of the water body should be achieved from a water-morphological point of view, according to the EU-WFD.

Additional temporal measures involves the hydropower plants management, which should limit discharge fluctuations during the most sensitive periods of the year (spawning and juveniles months). Further details are explained in the next Paragraph 1.4.

Figure 4: *Consolidation check dam previously on site (left) and lately substituted by a retention check dam (right)*

1.4 S. Antonio hydroelectric power plant

The hydroelectric power plant of S. Antonio is managed by the southtyrolean company Eisackwerk Srl. It produces 270 millions of kWh per year and serves 100000 users in the province, which makes it the fifth plant of South Tyrol. A pipe starting from Bagni di Serga, in the Sarentino valley, collects the water from the Talvera River and other three tributaries, Rio Danza, Rio Madonnina e Rio d'Auna (Figure 5). At the S. Antonio power plant the energy of the falling water, flowing inside a penstock, is transformed into mechanical and then electrical energy. The water outflow is located in the Talvera River, few kilometres before its confluence with the Isarco River. The hydropeaking associated to the hydropower plant production negatively affects the river ecology and the safety of the people enjoying the river ecosystem (in the last 70 years 21 people have drowned in the Talvera). In order to diminish this issue, the managers of the Eisackwerk Srl decided to invest 55 millions € on the construction of a 95000 m^3-buried reservoir. The project forsees that, the water flowing inside the new penstock (in red in the planimetric map shown in Figure 6) arrives to the power house, it goes through the turbines and it is partially accumulated in the new buried reservoir and partially discharged into the Talvera (see also the longitudinal profile in Figure 7). The information included in the definitive project (not the executive) reports that the maximum flow depth inside the reservoir is 12 m and the total length corresponds to 935 m. This will allow to store water, avoid dangerous flooding peaks and ensure a constant water level of the stream. The hydropeaking factor is expected to drop from 1:10 to 1:4 (Figure 8). This innovative solution will not only bring benefits to the ecology of the river but will also increase the company energy production from 73 MW to 90 MW.

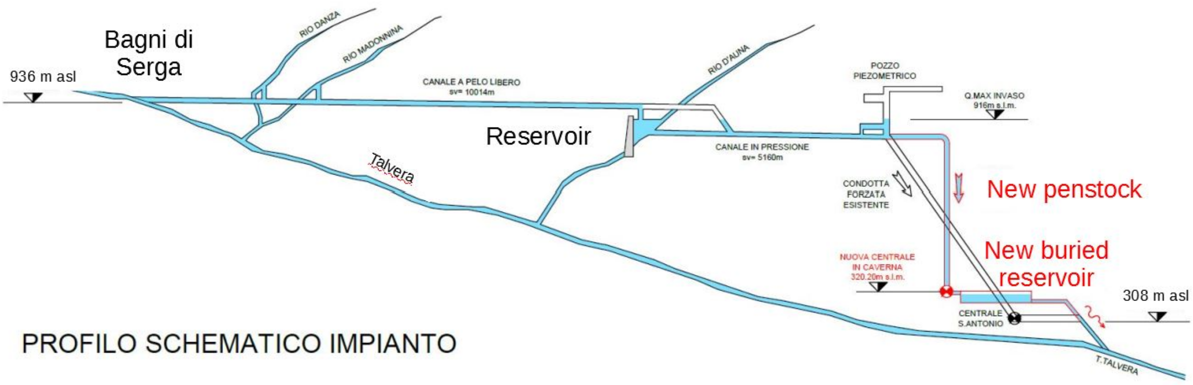


Figure 5: *Hydraulic scheme of the S. Antonio hydroelectric power plant. In red the new penstock and the planned buried reservoir (from Zancan, 2016)*

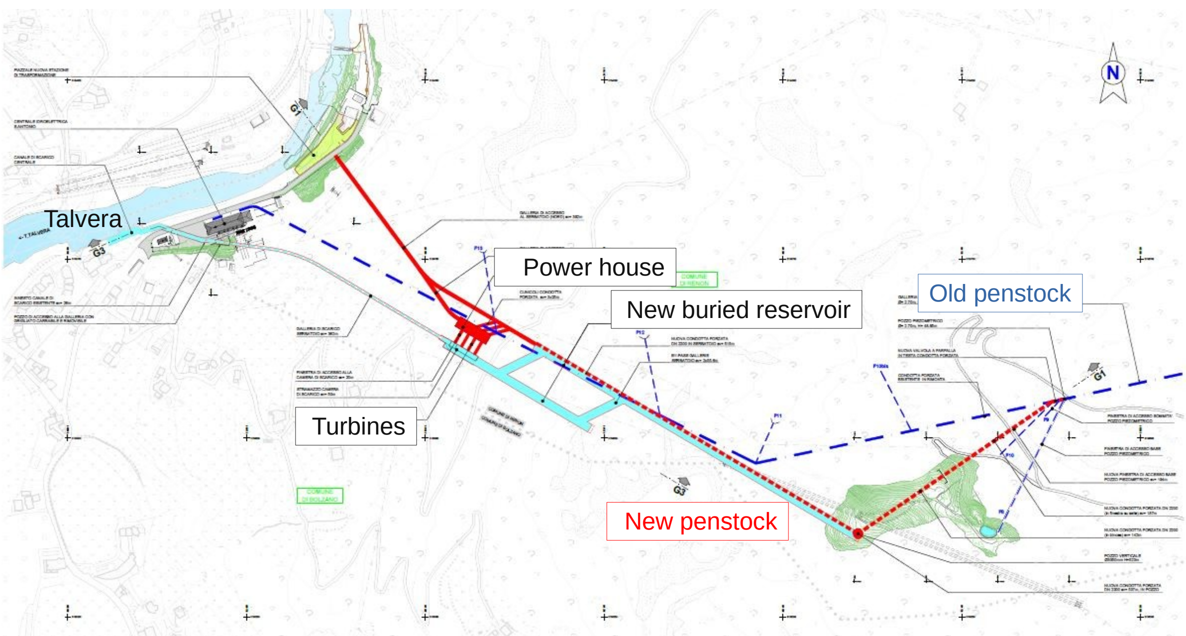


Figure 6: *Planimetric view of the new hydraulic scheme of the S. Antonio hydroelectic power plant (from Zancan, 2016)*

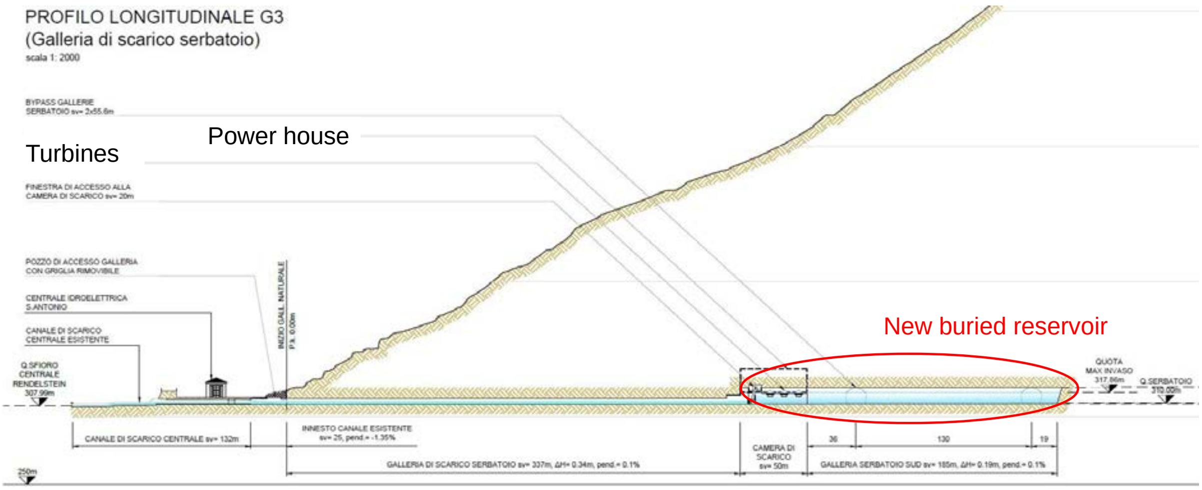


Figure 7: *Longitudinal profile of the new power house and the buried reservoir (from Zancan, 2016)*

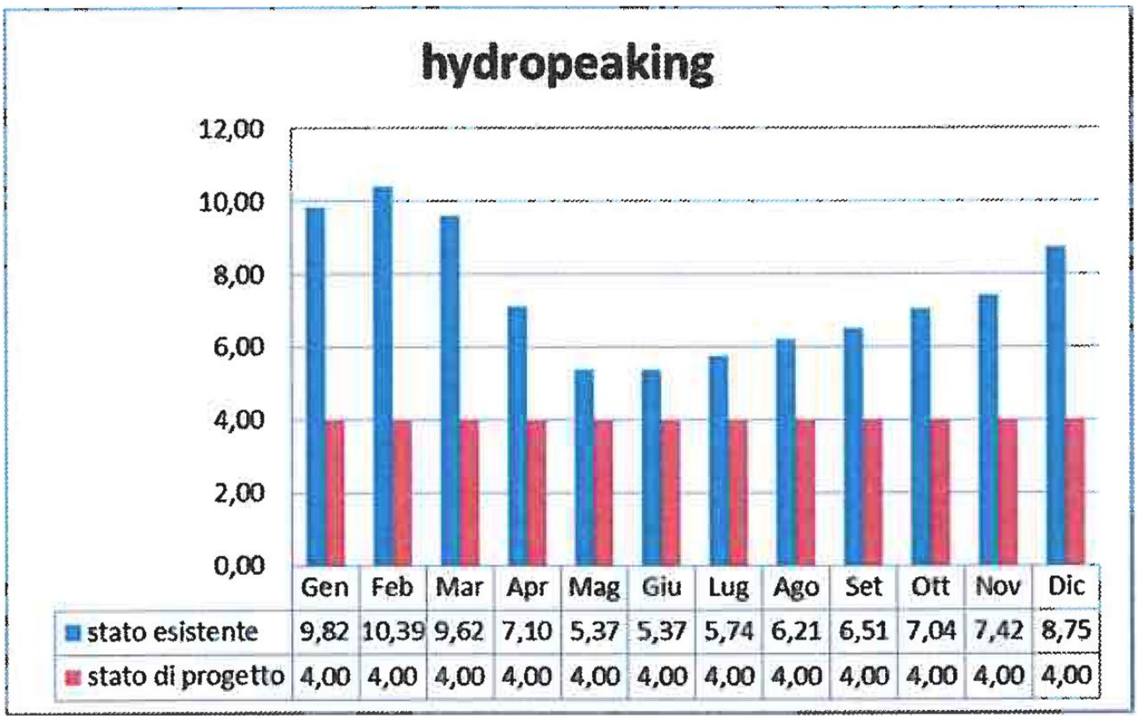


Figure 8: *On the y-axis is represented the hydropeaking factor (calculated as max outflow discharge divided the min outflow discharge) before (blue) and after (red) the commissioning of the buried reservoir. Stato esistente refers to the situation before the installation of the reservoir, while Stato di progetto refers to the expected results after the project has been completed (from STUDIO G, 2015)*

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 favour 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 10). 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 9.

Figure 10 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 11).

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 prioritisation process. **Effectiveness monitoring** refers to assessing 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).

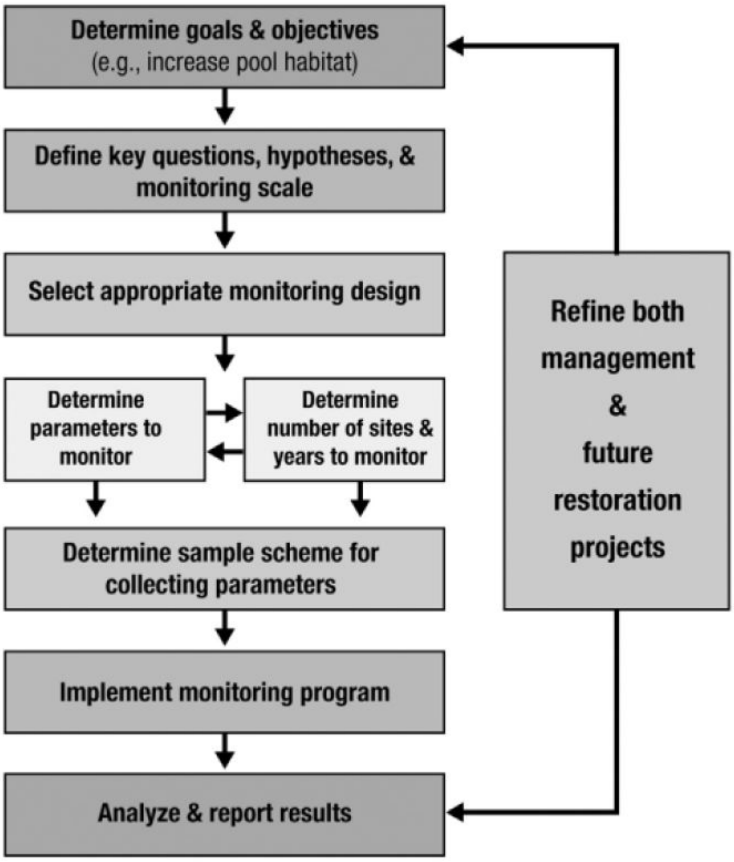


Figure 9: *Steps for designing a monitoring program (Roni and Beechie, 2013)*

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 restoration action.

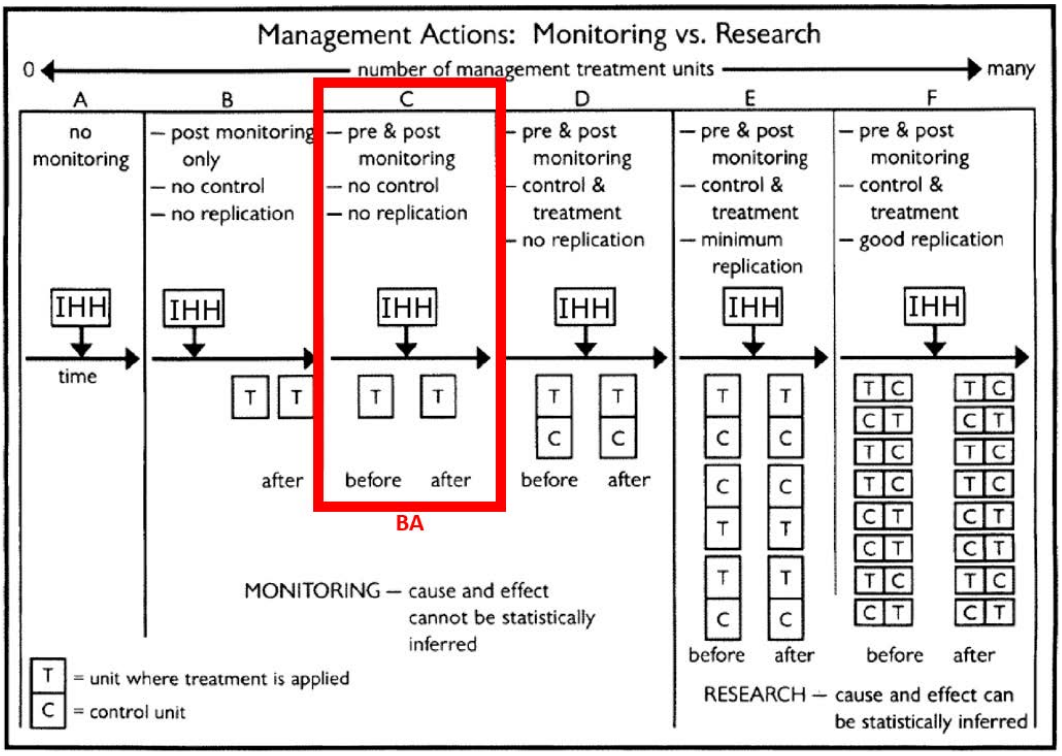


Figure 10: *A comparison of monitoring and research approaches for detecting a treatment effect (e.g. Increase of Habitat Heterogeneity, IHH, in rivers). In this case study the general design is based on the BA approach. From Elzinga et al. (2001)*

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. Both for the physical and the ecological parameters, data are available pre- and post-restoration. The scheme represented in Figure 12 shows the monitoring design used to assess the objectives achievement of the main restoration measure performed along the Talvera River. The available data and relative year in which the survey took place are summarized in Figure 13

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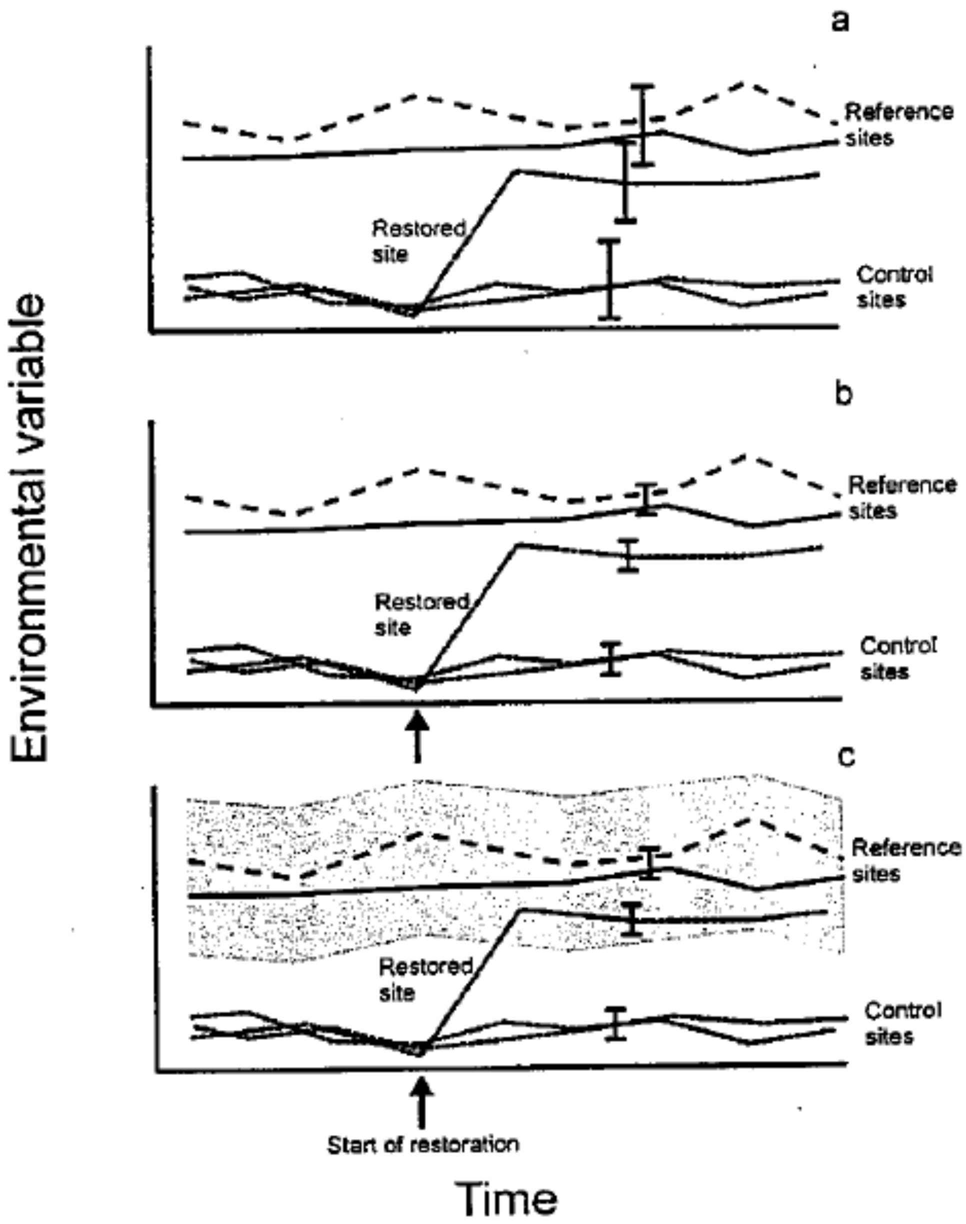

Figure 11: *Measurement of the restoration effect: (a) the large confidence intervals, due to imprecise sampling, cause the conclusion that the site being restored is not different from the reference sites; (b) more precise sampling, with smaller confidence interval, would reveal the failure of restoration; (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 (Underwood, 1997)*

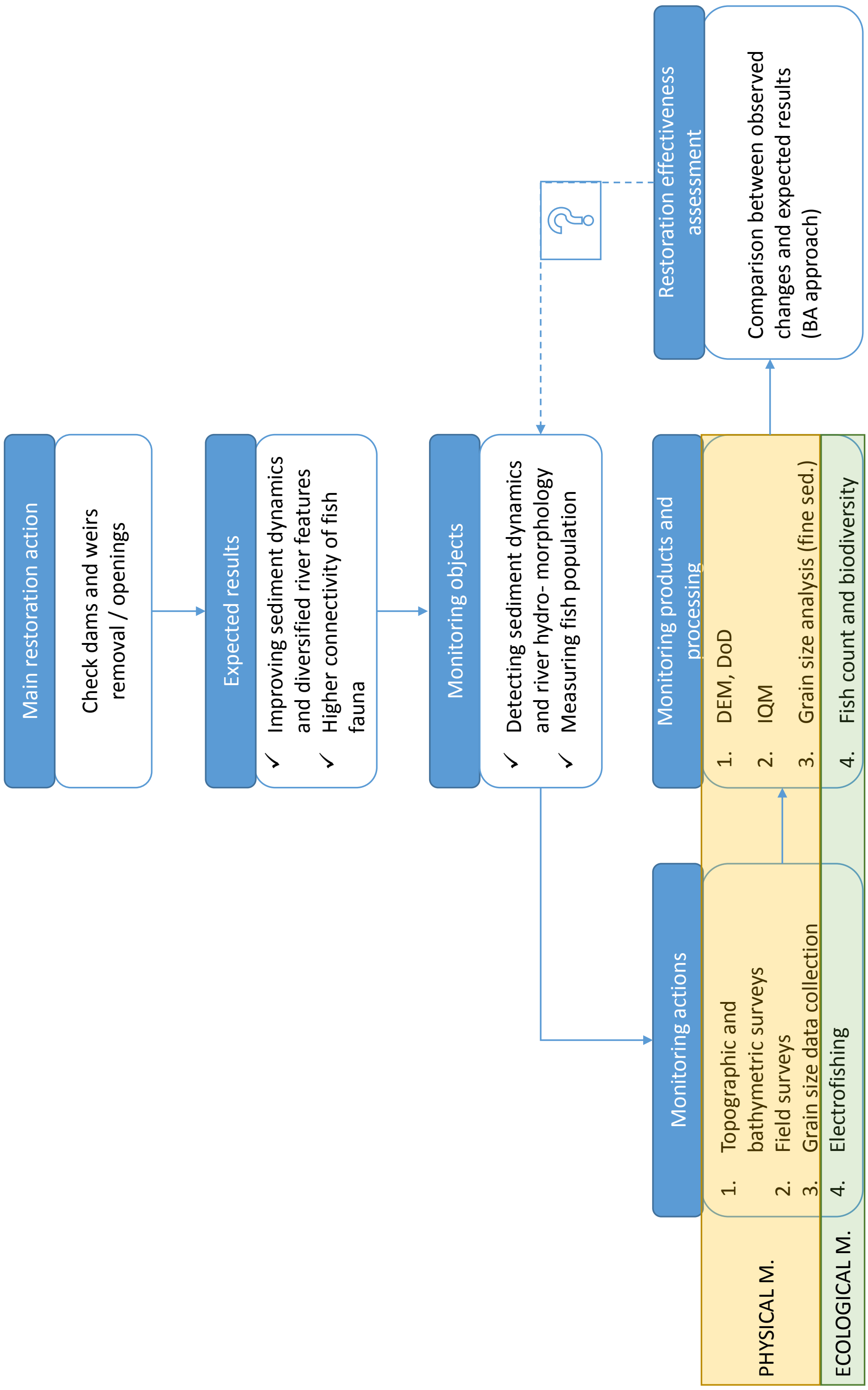

Figure 12: *Main restoration measures, expected results and monitoring design for the Talvera River case study*

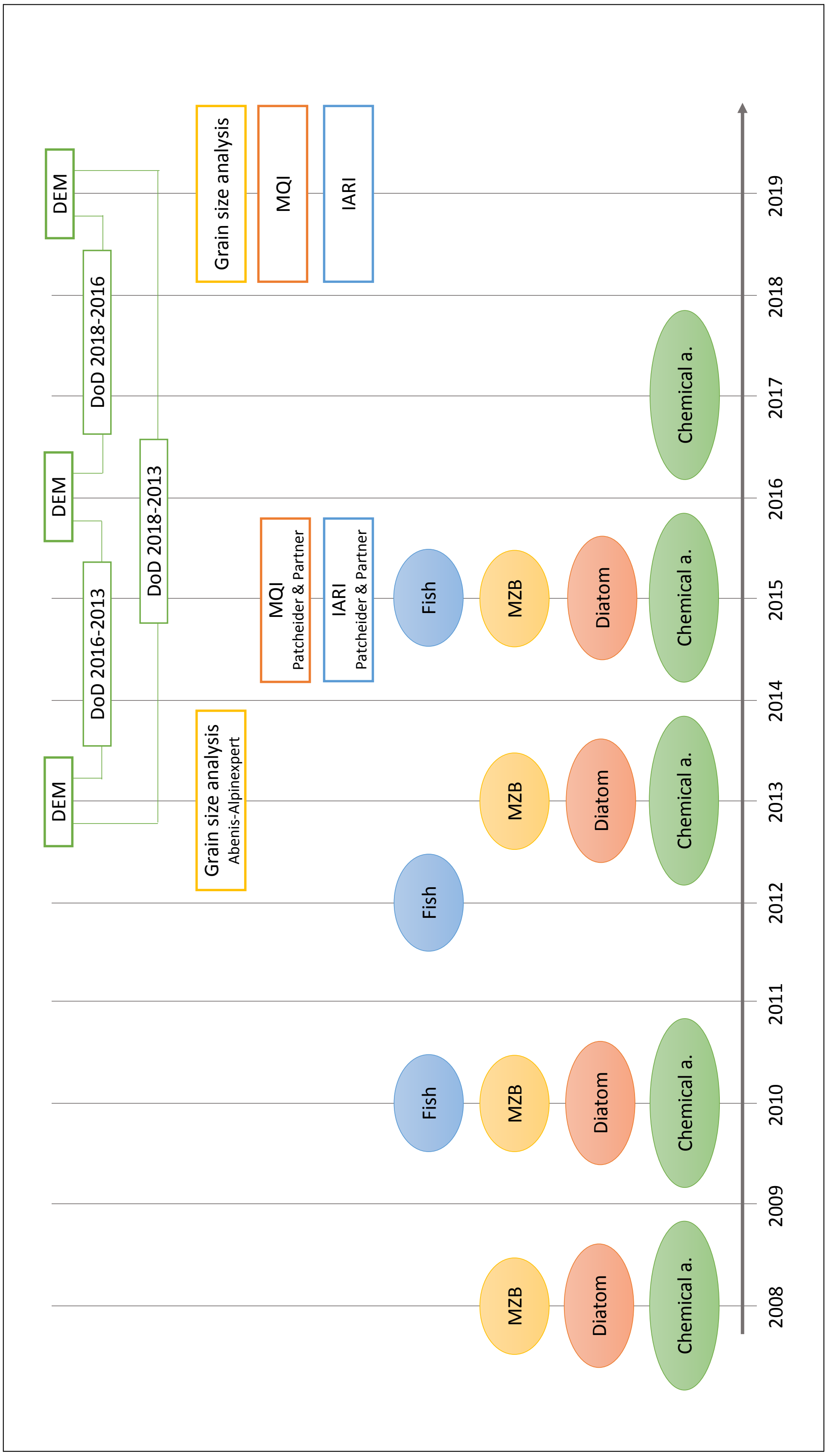

Figure 13: *Available data for the morphological and ecological monitoring and relative years. Restoration works within the HyMoCARES project started in 2014 and ended at the beginning of 2019*

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3 Physical monitoring

The physical monitoring on the Talvera River was based on the BA (Before-After) approach and consisted in different actions:

- Topographic and bathymetric surveys: the detection of variations on the riverbed (i.e. erosion or deposition) through a DoD (DEM of Differencing) is useful to evaluate the sediment balance within the river reach, to understand river dynamics and to observe the variation of the bed slope after weir removal and check dams openings.
- Discharge data collection from the gauging station located in a Talvera cross section about 2 km upstream the confluence with the Isarco River. 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), which quantitatively analyses the river hydro-morphological status.
- Grain size data evaluation. Photos capturing the in-loco sediments were analysed with the software Basegrain and the results, integrated with the fine sediment analysis, help understanding the grain size distribution within the study reach.

3.1 Topographic and bathymetric surveys

The first topographic survey along the Talvera River took place in 2013. In particular, 5 river reaches have been surveyed, which are characterized by an average length of 160 m (red strips in Figure 14). Two of the five reaches belong to the last part of the Talvera River and characterize the rectified part of the watercourse; the other three reaches, which are further upstream, are more representative of the Talvera part confined between the mountain flanks. For all reaches, the survey was confined to the river bed.
The second bathymetric and topographic survey along the Talvera River took place on December 2016 and covered the area between the Sill check dam and the confluence with the Isarco River. The third survey was performed on November 2018. These last surveys were done by the Austrian company AHM (AirborneHydroMapping) GmBH which uses water penetrating laser beam at high resolution to get the river bed elevation with an accuracy under water around 5 cm. The data collected by this technology consists on a point cloud filled of varying elevation values, which was later elaborated into a DEM. DEM dating

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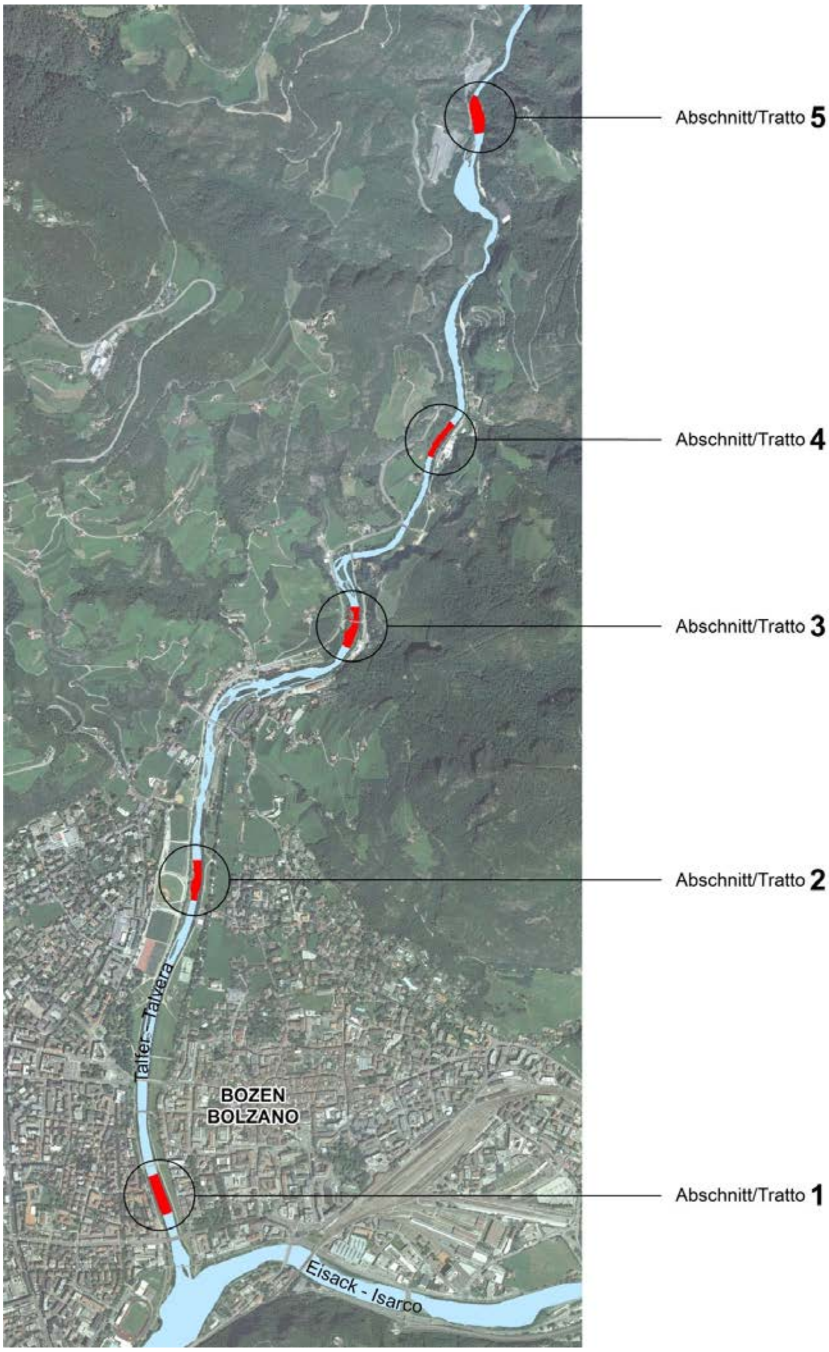

Figure 14: *The location of the five sections in the lower reach of the Talvera River. From Abenis-Alpinexpert (2013)*

back 2016 and 2018 are available and a DEM of Difference (DoD) approach allowed assessing elevation changes in time by comparing pre- and post-restoration DEMs. Restoration works, such as check dams opening or removal, alter flow patterns and sediment dynamics, which were evaluated through the DoD and confirmed by visual inspection. The challenge of this method is due to the large scale on which the analysis is performed. Erosion or deposition detected through the DoD are of orders of tens on centimeters and 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.

Furthermore, a GIS analysis on the DEMs aimed to assess the variation of the bed slope pre- and post-restoration: smoother slopes were expected due to the interventions on the check dams.

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 15).

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 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

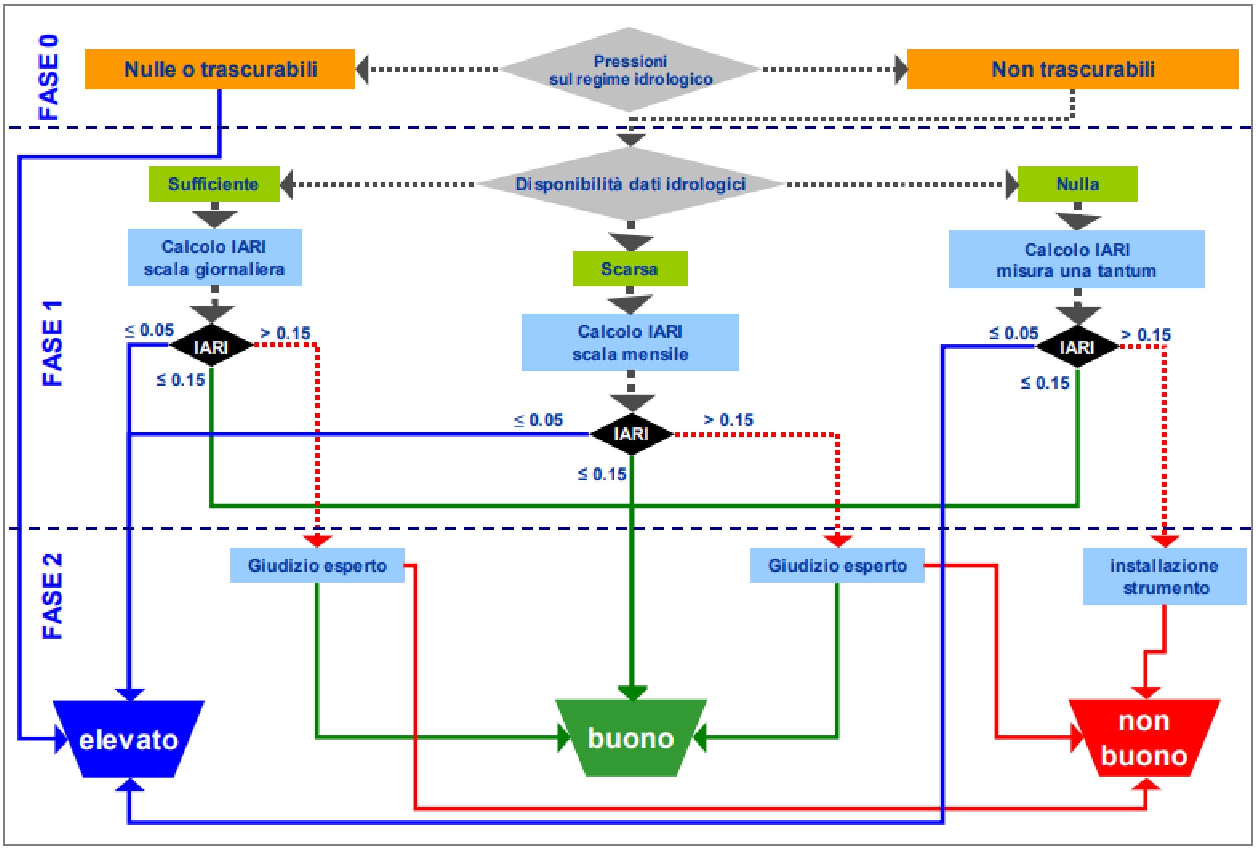

Figure 15: *Workflow diagram for the application of the ISPRA methodology for the IARI evaluation (from ISPRA, 2011)*

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.

Phase 2. This phase takes place when the IARI evaluated in Phase 1 reveals criticalities. Expert judgement 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).

* 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 ≤ IARI ≤ 0.05	High
0.05 ≤ IARI ≤ 0.15	Good
IARI ≥ 0.15	Critical

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

In this case study, the gauging station is located in a Talvera cross section about 2 km upstream the confluence with the Isarco River. Flow depth and discharge data are collected at this station with a sampling rate of 10 minutes; the available time series is 7-year long. Recent data are therefore available to assess the actual hydrological regime, however historical data are missing (*scarce data availability*). The natural regime has to be estimated by considering the hydroelectric power plants activities of water withdrawal and release within the Talvera catchment.

3.3 The 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 (www.isprambiente.gov.it, 2015).

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 fieldsheet through a guided procedure divided into three sections that cover fundamental aspects of: geomorphological functionality, artificiality and morphological variations. The reports differ according to two river types: confined and unconfined (or semi-confined) riverbeds. The method involves GIS and field analysis. 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 (Figure 16).

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	$0 \leq MQI < 0.3$

Figure 16: *Morphological Quality Index classes*

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3.3.1 The segmentation of the study reaches

A first MQI evaluation was performed by Festi and Adami (2013). The last 5 km of the Talvera River were studied, between the confluence with the Isarco river (258 m a.s.l.) and the Sill consolidation check dam (353 m a.s.l.). This stretch was divided into 5 reaches according to specific hydromorphological considerations and the associated MQI is shown in Figure 17.

	MQI
T1	Poor
T2	Moderate
T3	Moderate
T4	Bad
T5	Moderate

Figure 17: *Segmentation on study reaches and associated MQI (Festi and Adami, 2013). Note that the enumeration of the reaches starts from downstream*

At the beginning of 2019, after the restoration works, a new MQI evaluation along the Talvera took place. In particular, a different segmentation of the study reaches occurred. In general, the subdivision identifies segments that have homogeneous characteristics from a morphological point of view, or elements that represent basic units functional to the subsequent analysis. The driving parameters for choosing the sub-reaches are: the type of confinement, the variations in morphological units along the reach, the presence of hydrological discontinuities and artificial discontinuities.

Since the aim of the restoration focuses on weir removal, the segmentation was carried out in detail, dividing the reach into a greater number of sub-reaches compared to a normal application of the MQI. The degree of confinement has a dominant role for the subdivision into reaches, as it is a persistent constraint over time. On the other hand, artificial discontinuities have minor importance, because they might be removed in the future.

The entire study area was divided into four reaches. The sequential number starts from the upstream section and descends downstream (i.e. T4 is the reach before the confluence). The main characteristics of each are summarized in the following table (Table 4).

Reach	Conf.	L [m]	α [%]	EU [m a.s.l.]	ED [m a.s.l.]
T1	C	506	2.1	353	343
T2	SC	971	2.1	342	320
T3	SC	1000	2.0	320	299
T4	NC	2200	1.7	299	258

Table 4: *Macroscopic characteristics of the four sub-reaches. Conf. stands for confinement. The acronyms C,SC,NC indicate the type of confinement: confined, semi-confined and non-confined. L is the length of the sub-reaches, α is the average slope, EU and ED are respectively the upstream elevation and the downstream elevation*

Reach T1 extends from the further upstream section down to the wood retaining weir and is about 20 m wide. This reach is confined between the mountain slopes and its river-bed morphology can be classified as *flat bed*, where pebbles are the predominant grain size.

Reach T2 is semi-confined since the continuity between mountain flanks and riverbanks is not always there (sometimes the confinement occurs along the left-hand side and then along the right-hand side). It is also characterized by a series of check dams, that have been opened on a limited portion of the section and on alternate sides. The reach ends upstream the Roncolo bridge, where the riverbed width widens to ca. 30 m.

Reach T3 runs from the end of T2 until the S. Antonio bridge, downstream the hydroelectric outflow on the orographic left. T3 is characterized by a higher sinuosity that contributes to the presence of bars and vegetated islands and therefore to a more varied morphology.

Reach T4 is characterized by a linear course and a flat bed morphology; it stretches from the S. Antonio bridge to the Talvera confluence with the Isarco River. As the other reaches, it presents a series of check dams, which have been opened during the restoration works. Cyclopean boulders have also been introduced to increase the dynamism of the stream and flow deflectors to create storage areas.

The following figures (18,19,20,21) show the reaches just described.

Figure 18: *Reach T1, upstream view*

Figure 19: *Reach T2, downstream view towards Castel Novale*

Figure 20: *Reach T3, downstream view. End of confined reaches*

Figure 21: *Reach T4, upstream view. Detail of a flow deflector in the foreground*

3.4 Grain size data collection

The main effect expected from the weir opening and check dam removal, is an improved longitudinal sediment connectivity. The effectiveness of this restoration measure can be estimated through a gran size characterization.

On the basis of a previous work done by Abenis-Alpinexpert (2013), on April, 8^{th} 2019 two field surveys took place: one aimed at characterizing the sandy sediment and the second the gravelly grains. The particle size classes investigated are not representative of the entire reach, however a change in their composition highlights the effects of the restoration.

The evaluation of the finer sediments consisted on collecting sandy samples from the riverbanks, which were later on analysed by the laboratory of Geology and material tests Office of the Autonomous Province of Bolzano. The analysis of coarser particles was instead based on photos taken along the banks and the younger bars to characterise the grain size recently moved along the surface. The photos were processed using a photogrammetric technique. In particular, the BaseGrain software was used, an automatic detection algorithm based on Matlab and developed by the ETH Zurich, which allows particle size analysis for non-cohesive sediments (www.basement.ethz.ch, 2015). The advantages of the algorithm are the speed at which the data is acquired and the speed at which images are processed to obtain grain size curves. If compared to a manual survey, where grain size analysis is performed by the gravelometer, this technique produces more granulometric classes and has more detailed curves. Other possible outcomes are information of particle orientation, minimum and maximum diameters and surface of the exposed face of each clast. On the other hand, the photogrammetric technique provides good results on surfaces of limited extension and several measures are necessary to control some key parameters that affect the quality of the acquired data. After these two analysis, the characterization of the river bed through the Wolman count technique (Bunte and Abt, 2011) would complete the grain size analysis. However, the Wolman count needs a fording river to be performed and this is usually not feasible in the spring / summer time.

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Several factors influence the quality of the objects captured in the image:

- The camera must be positioned perpendicular to the bottom to avoid distortion effects.
- Shadows should be avoided by using sunshades on sunny days.
- The grain should have a homogeneous chromatic pigmentation (e.g. wet areas can be an obstacle to processing).
- Samples should be characterized by a sediment matrix with no or limited amount of snow, grass or leaves.

The first step was the validation of the algorithm, which allowed to understand the reliability of the method and therefore the error made on the determination of the characteristic sediment diameters. Operationally, areas with a reduced extension of 50 cm x 50 cm have been delimited and camera images have been taken. On the same area all the sediment of the surface layer was manually screened by using a field gravelometer (Figure 22).

Figure 23 (a, b) show the differences between the algorithmically processed curves and the manually screened curves for one of the chosen calibration points in reach T4.

Table 5 shows errors on diameters d_{50} and d_{90} at the points used for calibration.

T4	Sieve [mm]	BaseGrain [mm]	Error
d_{50} caseA	27.5	19	32%
d_{90} caseA	50.8	44	14%
d_{50} caseB	24.7	22.6	9%
d_{90} caseB	50.1	44.9	10%

Table 5: *Value of the characteristic diameters and errors in the validation procedure*

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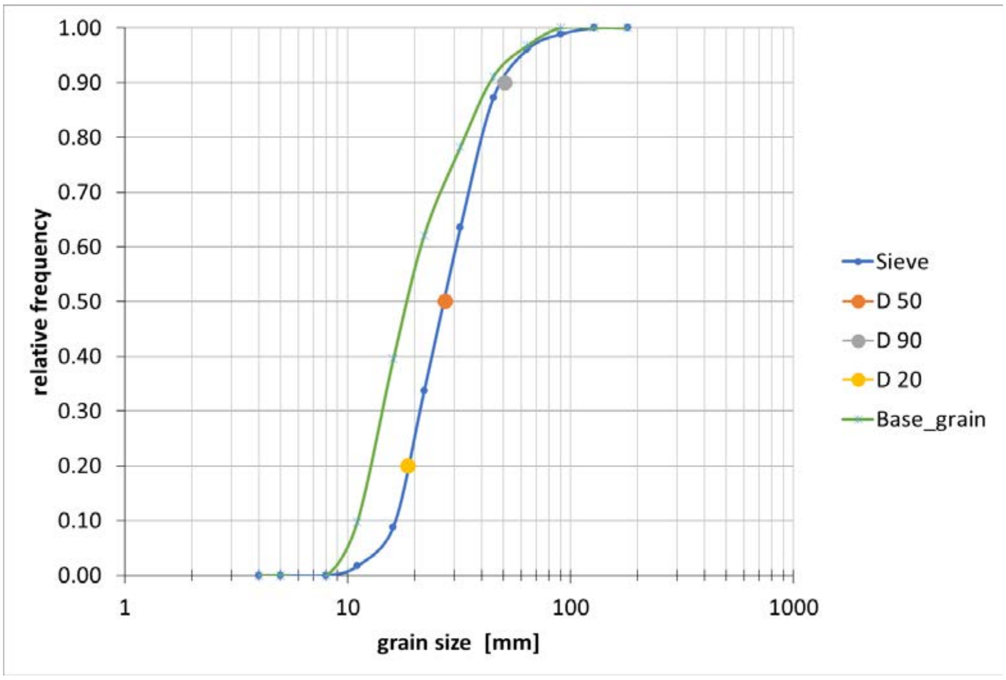
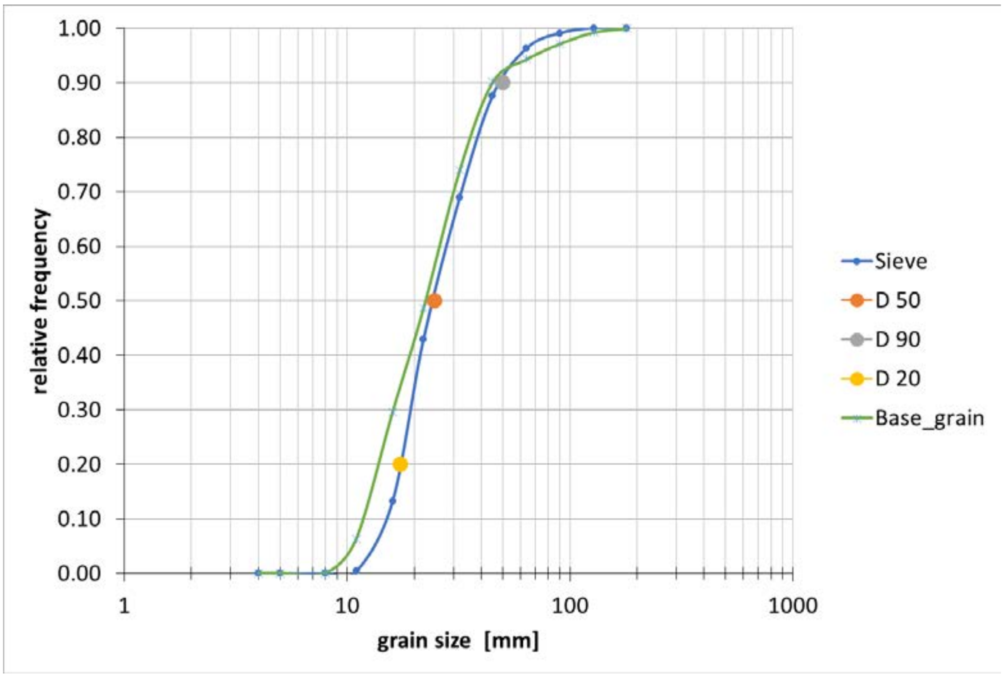
(a) *Identification of the sampling area and positioning of the mount supporting the camera*

(b) *Gravelometer used to define grain diameter in the field*

Figure 22: *Field survey based on photos and grain size measurements*



(a) *T4 case A*



(b) *T4 case B*

Figure 23: *Differences between the algorithmically processed curves and the manually screened curves*

Based on this result it was possible to identify and manage the parameters that mostly influence the final product. This preliminary analysis also showed that:

- Any overlap between particles may limit or reduce the accuracy of the estimation of the diameter of the partially hidden particle.
- Smoother or rounder particle are more easily identified than sharp or jagged surfaces.
- Angular shapes tend to be fragmented by the algorithm.
- Particles with strong chromatic pigmentation tend to be segmented into sub-particles.
- Shadowed faces of the same particles are recognized as different clasts.

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4 Ecological monitoring

The ecological effects of the restoration works in the Talvera River were evaluated by analysing chemical and biological data collected before and after the interventions (BA approach). In particular, hydrochemical, diatom and macroinvertebrate samples were collected by the monitoring station 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 collected for the same purpose in a neighbour stretch as shown below (Figure 24).

The WFD requires member states to assess the ecological status of its rivers based on appropriately informative aspects of the biota at the 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 metrics to be used 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 Agency (APPA) of the Autonomous Province of Bolzano, uses phytobenthos (diatoms), macroinvertebrates and fish to determine the ecological status of the water bodies.

In his master thesis, Valorzi (2012) carried out a study regarding the eco-morphological characterization of the Talvera River. During the previous year (spring 2011), an approximately 750 m long stretch of the Talvera in Bolzano was renaturalised. The research project of Valorzi (2012) aimed at detecting possible differences in terms of habitat between requalified and not-requalified reaches. The habitat modelling program CASiMiR (Computer Aided Simulation Model for Instream Flow and Riparia) was used for ecomorphological characterisation. A topographical survey provided the basis for a two-dimensional model of the study reach. Flow depth and velocity were also measured as well as the composition of the substrate. These models showed a more variable pattern of these fields in the restored reaches. In addition, the results showed that both the number of macrobenthonic taxa and the number of individuals increased in the renaturalized reaches, as well as the hydromorphological variability, which implies higher habitat diversity.

The CASiMiR model focuses on the river micro-scale, which might not always be suitable when assessing restoration effects at larger scales. Recently, instream flow assessment of river conservation and restoration planning have been performed on a larger scale or meso-scale. The Mesohabitat Simulation

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Figure 24: *Map of Talvera River with the monitoring station identified by the blue point and the transect for fish sampling (orange line)*

Model (MesoHABSIM) is an effective approach to model instream habitats at river and site specific scale (meso-scale). It uses a computer model, Sim-Stream, that predicts the quantity of habitat for aquatic communities in rivers and streams for watershed management scenarios. The advantages of the MesoHABSIM with respect to CASiMiR are:

- more extensive and representative surveys of the watercourse;
- habitat suitability criteria defined by more environmental variables;
- valid in different river morphologies.

4.1 Chemical data

Water samples for chemical and bacteriological analyses were collected from 2013 to 2017 by the Environmental Protection Agency (APPA) of Bolzano at irregular intervals for a total of 29 samples, both in the pre- and post-restoration periods. The ecological restoration carried out in the Talvera River probably had not a direct effect on the water chemistry. Notwithstanding some chemical variations might have occurred during the monitoring period for other unknown reasons than restoration: these data may aid interpretation of possible biological effects of restoration.
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 programmes of measures. Protocols of sampling and procedures for chemical analyses are explained with more details in the ISPRA Manuals (IRSA/CNR, 2003; ISPRA, 2018).

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 has to be 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 25). The mesh size of the net is 0.5 mm. More details on the sampling protocol can be found on ISPRA (2014).

Figure 25: *Example of a Surber sampler used for collecting macroinvertebrates*

According to this methodology, macroinvertebrates were sampled at the sampling point displayed on Figure 24, with an irregular frequency as part of the routine monitoring carried out by the Environmental Protection Agency of Bolzano. Between 2008 and 2018 a total of 14 samples were available. 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).

4.3 Diatoms

Diatoms surveys were performed by the Environmental Protection Agency of Bolzano at the monitoring point shown in the Figure 24 with an irregular frequency before and during restoration. A total of 10 samples collected between 2008 and 2018 are available, as part of the routine monitoring carried out by the Environmental Protection Agency.

According to the ISPRA protocol (ISPRA, 2014): ten cobbles were collected from mid-stream and placed into a tray with a little stream water and the top surface of each was brushed with a clean toothbrush in order to remove the biofilm. The resulting suspension was collected in a plastic bottle, fixed with alcohol and stored prior to analysis. Samples were either digested in a saturated solution of potassium permanganate or concentrated. Permanent slides were prepared using Naphrax (refractive index = 1.74) as a mountant. At least 400 undamaged valves of non-planktonic taxa were identified and counted using 1000x magnification (CEN,www.cen.eu, 2003). Taxa were identified at species level as requested by the national protocol.

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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 biomonitoring 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. Electro-fishing consists in catching fish by creating an electrical-field through the water, around an anode and a cathode. Multiple pass-surveys are the most common approach to estimate the 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 more effect the current will have on it. Once the fish has been captured, it is identified, 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 has to be 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).

Electrofishing was conducted in 2010, 2012 and 2015 along a transect of about 110 m long (Figure 24). Fish density was estimated through the k-pass removal method, which evaluates population abundance by sampling the population k times with the same effort. On each sampling "pass", the number of individuals captured (Ci) is recorded and the individuals are physically removed from the population. If the probability of capture (p) is constant for all fish across all samples, then it is possible to estimate the initial abundance (Ogle, 2016).

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 allows to bring the ecological status of communities within 5 classes assessed by the calculation of the deviation between expected and founded fish community. Fish community and population structure were rather analysed by using statistical analyses commonly used in fish ecology.

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 period 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 after-restoration) are not homogeneous. This statistical analysis aims at proofing whether the means of the two datasets (pre- and post-restoration) differ for 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*: degrees of freedom which provides information on the sample size. The higher *df*, the higher the number of available data and more robust the results;
- *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

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index of dissimilarity was used in this analysis). Interpretation of a PCoA plot is the following: points closer to one another represent conditions more similar 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 46), 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[1] 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).

4.6 Habitat characterization by the MesoHABSIM methodology

The MesoHABSIM approach is a physical habitat meso-scale modelling system created for the purpose of in-stream habitat management in applications such as hydro-power and water withdrawals mitigation, as well as river channel restoration planning (Parasiewicz et al., 2013). The MesoHABSIM methodology (ISPRA, 2017) has been complemented with the Geomorphic Unit survey and classification System (SUM), published as "Manuals and guidelines ISPRA" N.132/2016 (ISPRA, 2016).

The underlying philosophy of MesoHABSIM is the recognition that fauna reacts to environmental changes at different scales related to the size and mobility of the species as well as the time of use. Meso-scale units can be defined as the areas where an animal can be observed for a significant portion of its diurnal routine, and it roughly corresponds to the concept of 'functional habitat'. Because of the natural mobility of fish, observations at meso-scale are less affected by randomness than at the micro-scale; therefore it provides a robust estimate of an animal's selection of living conditions (Parasiewicz, 2007).

The method is based on the identification of a sub-reach, which has to be rappresentative of the entire reach from a morphological and hydrological point of view. Subsequently, the different Hydro-Morphological Units (HMUs) have to be identified according to the SUM (Sistema di rilevamento e classificazione delle Unità Morfologiche dei corsi d'acqua; ISPRA, 2016) and are classified as in Figure 26. Depending on the

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

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discharge, different HMUs can be associated to the same area and therefore different fish species are expected to be found. The MesoHABSIM software (SimStream) is endowed with a database of calibrated curves relating the available habitat to the expected fish species, which are used to perform the analysis on the habitat modelling.

For the specific context of the Talvera River, the selected sub-reach has been subject to river restoration and is also affected by hydropeaking. Changes in the riverbed morphology are expected after the improvement brought about on the longitudinal connectivity by the river restoration. Clear effects on grain size distribution, habitat availability, presence of debris will be visible and evaluable in the long term. Instead, the hydropeaking effect consists on heterogeneous discharge fluctuations during the day, which imply high temporal variability of the discharge. For this reason, the Index of Habitat Stress Days (I_{HSD}), which evaluates the temporal variation of the duration of stress events for the fauna, can not be used to assess the stress of the fauna (i.e. the number of days below the threshold $Q_{3}55$) on a time scale by applying the MesoHABSIM methodology. On the other hand, the Index of Habitat Quantity (I_{HQ}), which represents the alteration of the spatial quantity of habitats over a given period of time, can be calculated. In particular, considering the spatial variability of the habitat, the graphical outputs of the MesoHABSIM software identify areas where a given fish species is expected to have optimal, suitable or not suitable habitat. According to ISPRA (2017), the total available habitat (H_d) is calculated as follows:

$$H_d = H_I * 0.25 + H_O * 0.75 \tag{1}$$

where H_I indicates the available suitable habitat and H_O stands for the available optimal habitat.

The intent of a future habitat monitoring is to assess how the available habitats have changed after the morphological variations that the riverbed is undergoing because of the effects of the restoration, but also in case of intense flood events.

It is important to underline that the MesoHABSIM methodology was not conceived to study habitat availability in a environment subject to hydropeaking since it is based on a daily time scale, whereas the hydropeaking has effects on a hourly time scale. In particular, to the Authors'knowledge, studies on the effects due to hourly based variations of discharge are not available yet. As a consequence, neither

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methodologies, nor software has been developed for this purpose yet. Therefore, in this context, the application of the MesoHABSIM methodology is pioneering and only partially applicable; however it can be used to assess the spatial availability of habitats in such a context. In addition, results can be used as a reference for future monitoring.

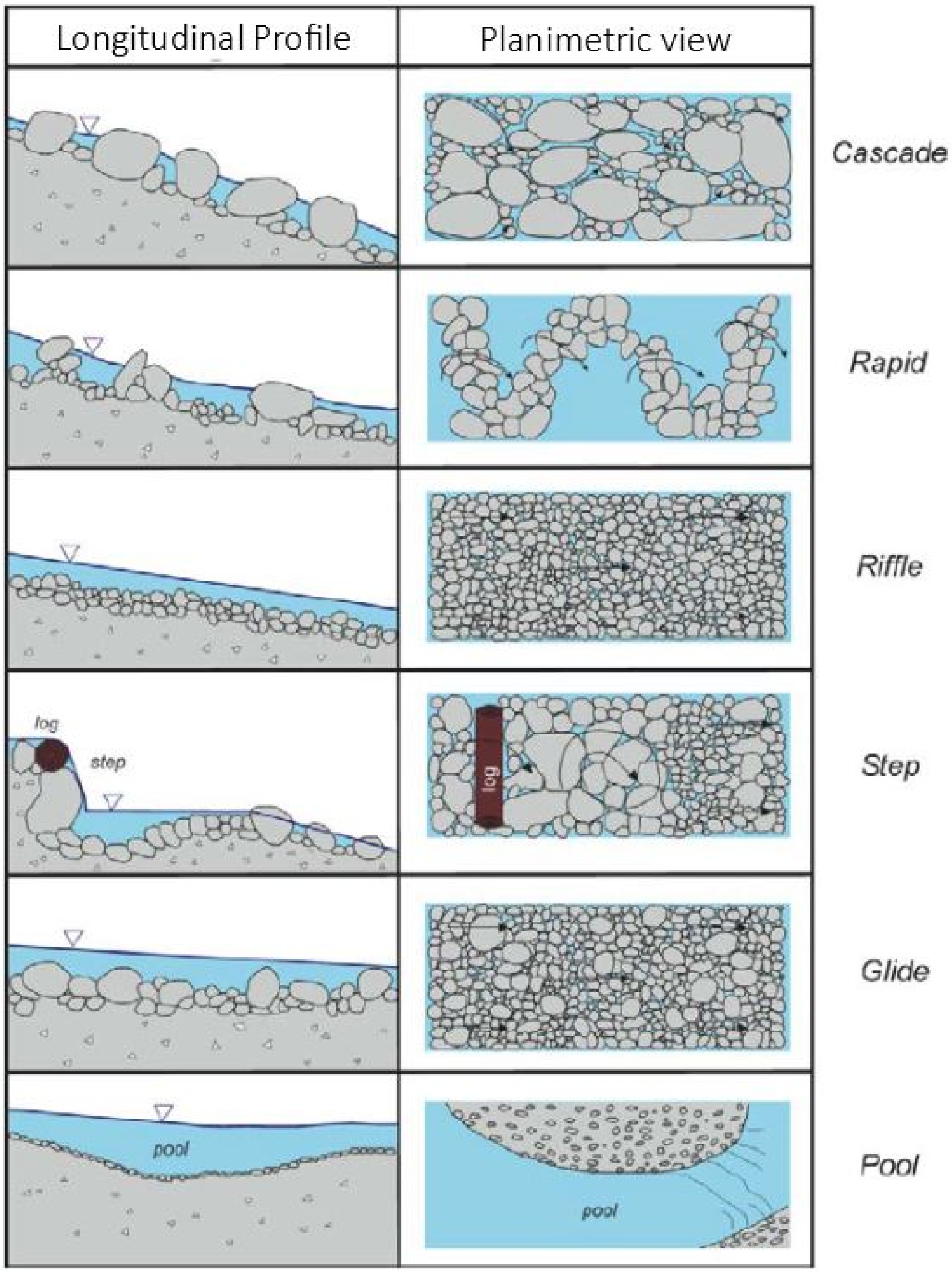

Figure 26: *Hydro-Morphological Unit classification (ISPRA, 2016)*

5 Assessment of the Physical effects of the Restoration

5.1 Effects on Morphology - DoD

Topographic and bathymetric surveys were carried on in 2013, 2016 and 2018. The difference between two different digital elevation models (DEM) performed at cell level provides a DEM of Difference (DoD). This technique is useful to detect changes in the morphology and provides useful information on erosion and deposition patterns on a 2D perspective (area) and 3D perspective (volume).
The 2013-DEM represents the pre-restoration topography, while 2016-DEM and 2018-DEM show the surface elevation during and after the restoration works. In this context, the topographic evolution of the watercourse over time can be reconstructed. In general, a river configuration is not stable and can be significantly influenced by flood events.
The 2013-DEM was carried out during the study conducted by Abenis-Alpinexpert (2013) which analysed five different river reaches along the Talvera, each of them was characterized by an average length of 160 m and an average slope ranging from 1.1 to 2.1 %. The riverbed slope was observed to be heterogeneous because constantly interrupted by the weirs. For the river reach shown in Figure 27, the slope between the weirs was calculated to be around 2.1 %, while next to the weir it decreases to 0 %. One of the goals of the restoration was to restore a homogeneous riverbed profile, which was instead characterized by many discontinuities, detectable as ”jumps”, due to the series of weirs. The alternating opening of the weirs allowed, with the resulting material, to fill the holes downstream each weir formed in conditions of limited sediment supply.

The DoD analysis allows to detect possible depositional and erosional patterns. Figure 28 shows the DoD obtained from the difference between 2016-DEM and 2013-DEM for the upper part of the Talvera. When looking at a DoD map, the red colour indicates erosion, while blue shows deposition. The map shows the weir opening points and in particular aggradation areas downstream the weirs and degradation areas upstream the weirs can be observed. These topographical alteration results from the mechanical work of homogenizing the river profile. The DoD obtained from the 2018 and 2013 DEMs presents the same pattern as DoD 2016-2013 suggesting that the trend is ”stable”. In general, the situation detected in 2016 is similar to the one detected in 2018: i.e. the terrain elevation exhibits the same aggradation and degradation patterns with respect to 2013. On the contrary, when analysing the DoD from 2018 and 2016 DEMs (Figure

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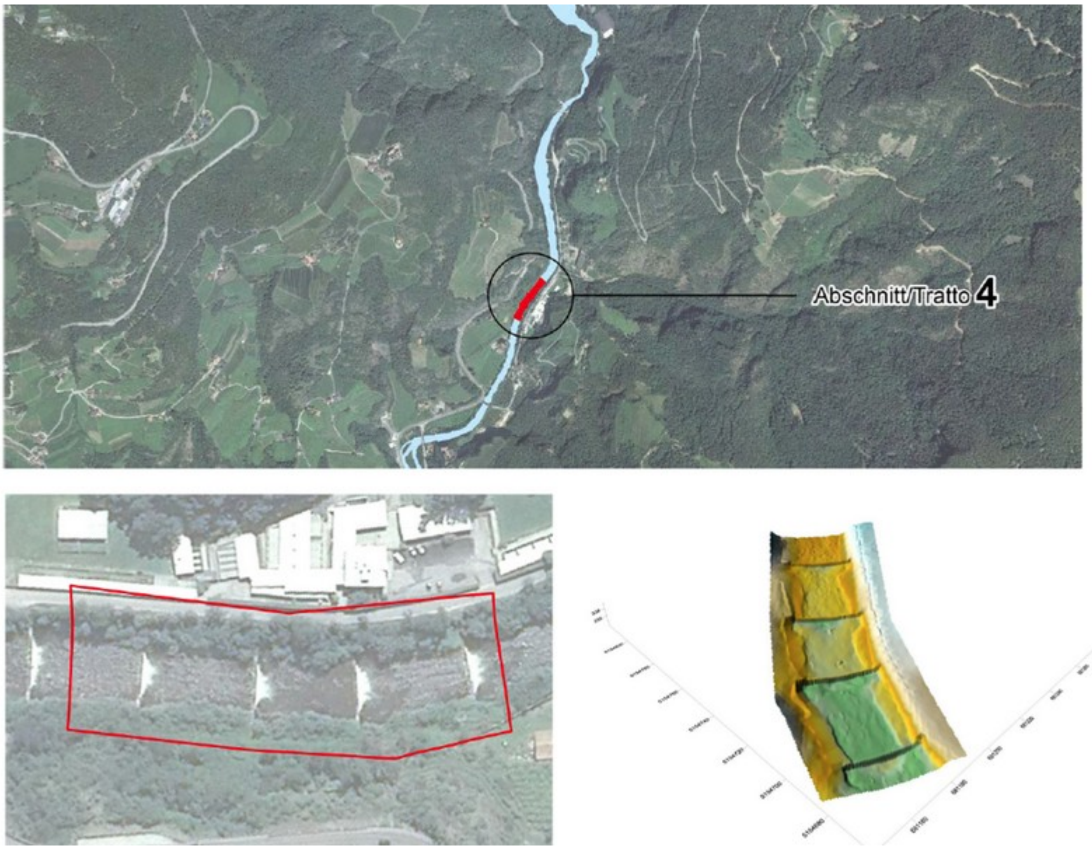

Figure 27: *One of the five river reaches where the study of Abenis-Alpinexpert (2013) took place. The four weirs highlighted in the ortophoto (bottom-left) are clearly visible in the 2013-DEM (bottom-right)*

29), erosional and depositional patterns do not match the previous considerations. This can be explained analyzing the flood event of October 2018. The DoD 2018-2016 presents more homogeneous patterns which are characterized by a countertrending behavior (e.g. the preferential path in the DoD 2018-2016 shows deposits, while in the other two DoDs it was characterized mainly by erosional areas). Figure 30 shows the two cross-sections highlighted in Figure 28 and 29. These cross-sections show what has been just described above. Figure 30 (a) represents the cross section downstream the weir: the accumulation of deposited material is almost 1 m in 2018 when compared to the one in 2013. Instead, Figure 30 (b) shows the cross-section on the weir itself where the opening can be observed.

The lower river reach (Figure 31) shows higher dynamics when comparing the terrain elevation in 2016 and 2018. Due to the alternation (left/right) of the weir openings the flow has chosen a ”preferential” path and a meandering pattern is establishing as it is visible in Figure 32. The difference between 2018-DEM and 2016-DEM is highly influenced by the October 2018 flood. Indeed the amount of sediment brought by the flood provided an unusual supply. Figures 29, 31 and 32 show a significant difference in aggradation-deposition pattern between the upstream and the downstream portion of the study reach. In particular, the reach upstream from the Talvera bridge exhibits a non clear pattern (Figure 29) due to the high energy of the flow (the mean bed slope is 2%); on the contrary the reach downstream the same bridge presents a deposition-erosion pattern which becomes more clear toward the confluence (compare Figures 31 and 32). In this reach the mean bed slope is around 1.2 %. The meandering deposition patterns downstream the Talvera bridge can be explained by the mean slope between alternated weir partial openings being milder than the mean bed slope. The post-event-morphology characterized by meanders is not natural for channelized water courses and it might depend on the strong anthropization of the Talvera. The difference between the eroded and deposited sediment volume (2018 - 2016) amounts to 5500 m^3 of eroded sediment, which might be a good indicator for higher longitudinal sediment dynamics. The removal of one large consolidation check dam in the upper part of the study reach, triggered sediment transport, which was enhanced by the flood occurred on October 2018, which eventually determined a net sediment loss. Finally, Figure 33 shows the downstream effect of the check dam removal in terms of depositional pattern (blue area) and of excavated area upstream the check dam (red area). The picture refers to the upstream area in which material has been excavated to build the retention check dam and its retention basin.

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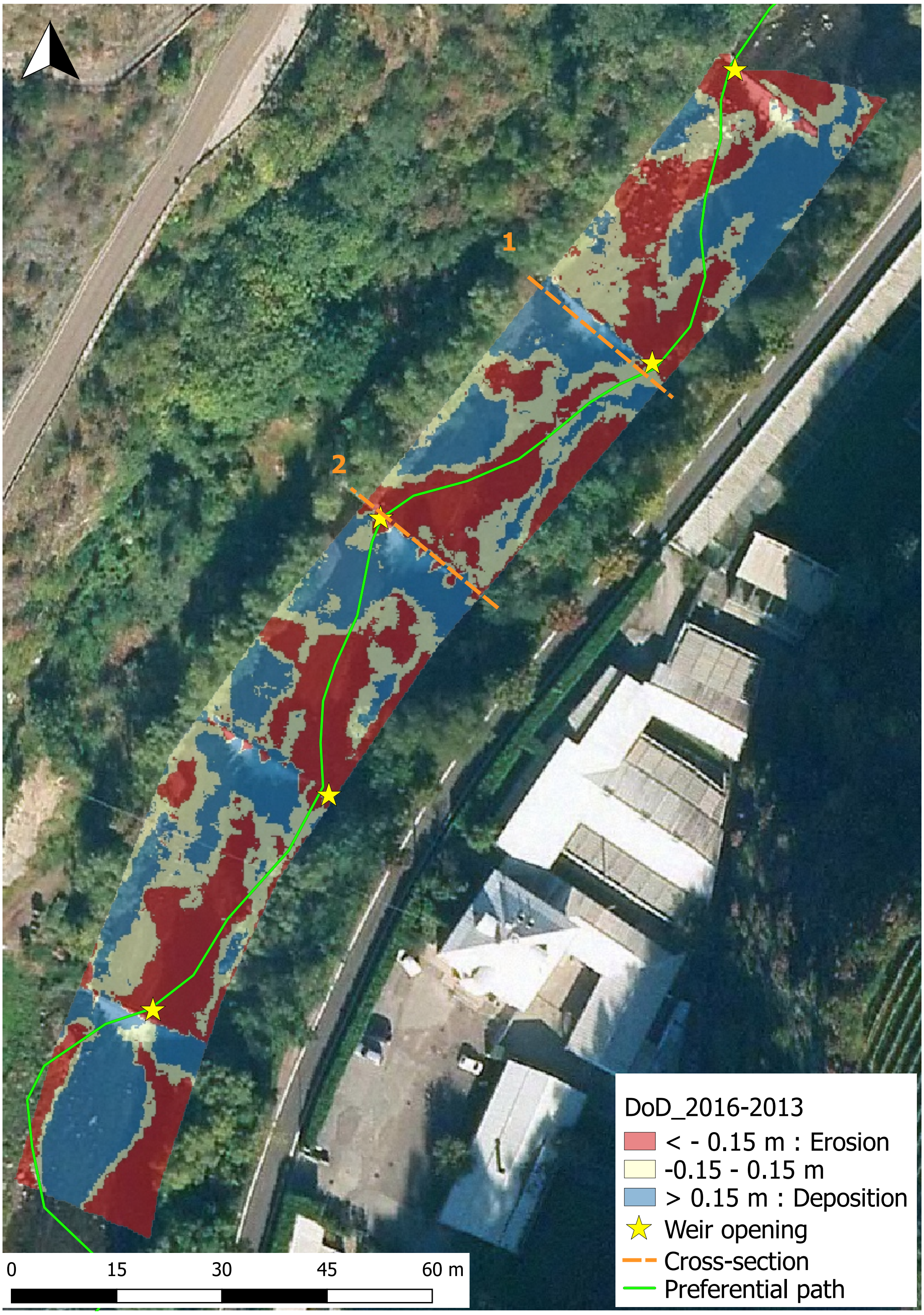


Figure 28: *DoD 2016-2013 of the upper study reach of the Talvera Torrent, next to the city dog shelter, where erosional and depositional patterns can be observed respectively upstream and downstream the weirs*

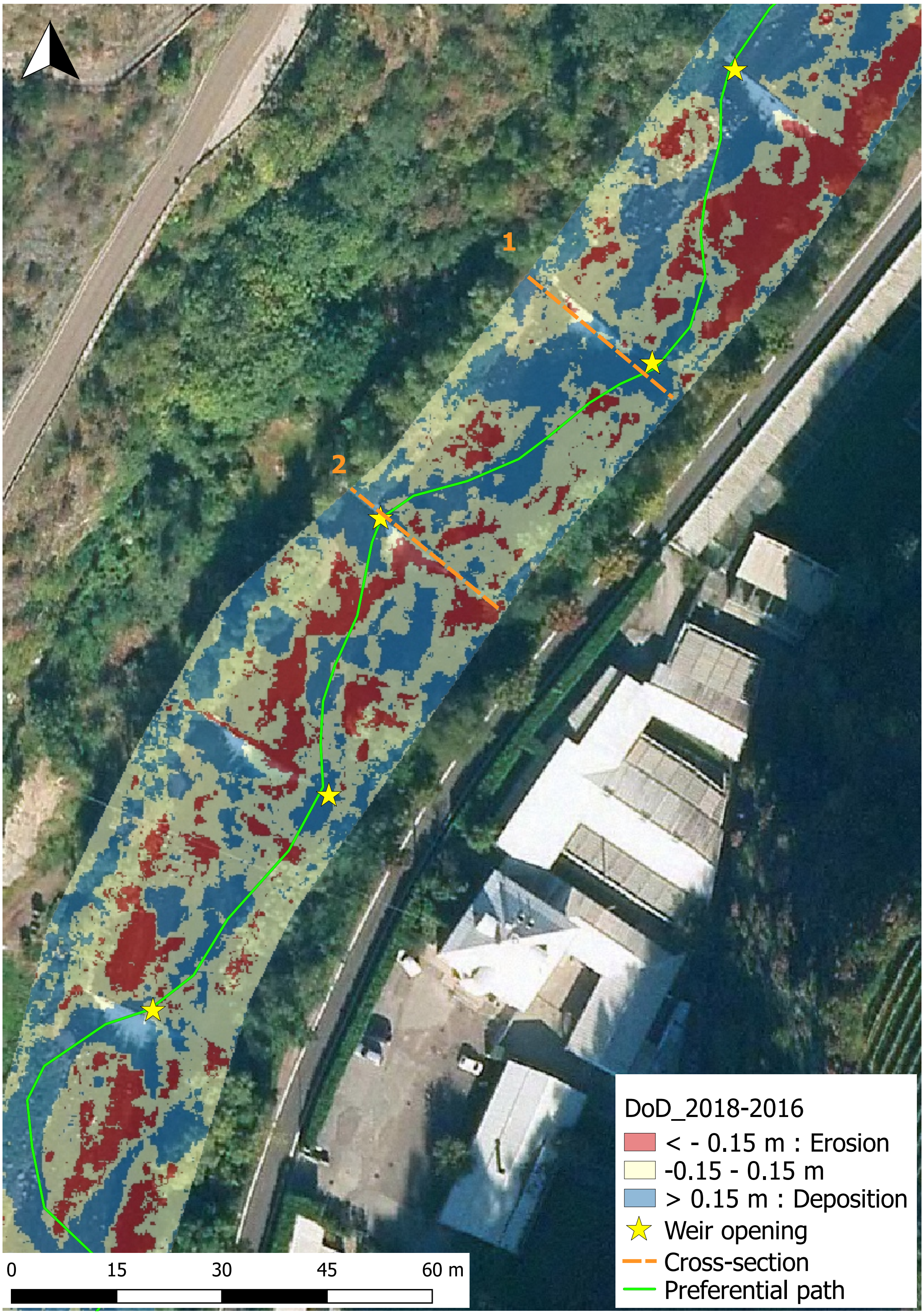
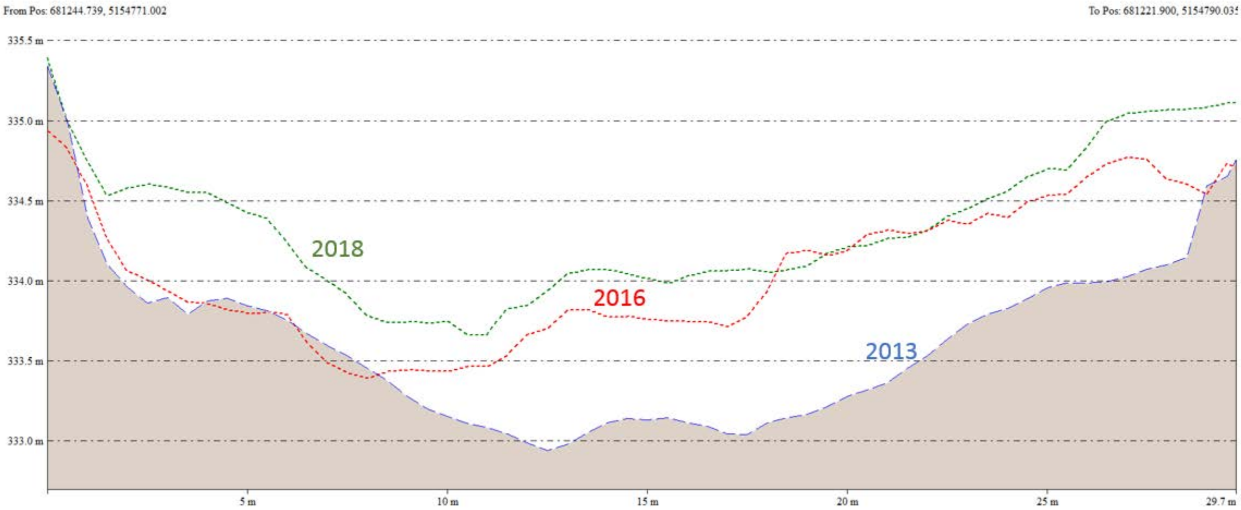
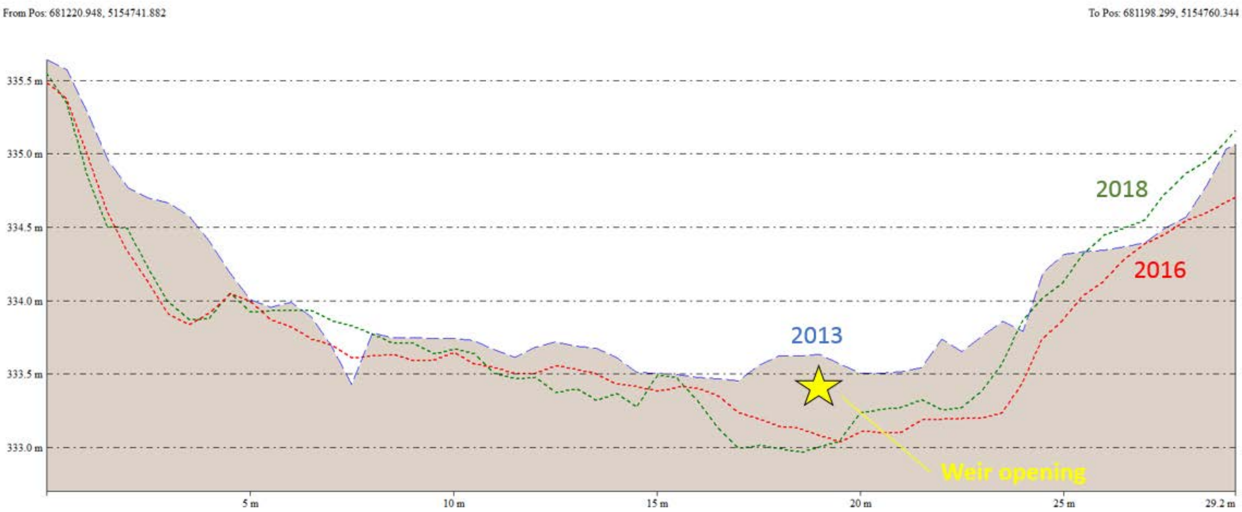


Figure 29: *DoD 2018-2016 of the upper study reach of the Talvera Torrent, next to the city dog shelter. After the October 2018 event, the sediments seem to have been evenly distributed along the river bed and no clear patterns can be observed anymore*



(a) *Cross-section 1 showing the profile downstream the weir*



(b) *Cross-section 2 showing the profile on the weir*

Figure 30: *Cross-sections profile over time. Cross-section 1 and 2 are identified in the planimetric view in the Figures 28 and 29*

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Figure 31: *DoD 2018-2016 of the low study reach of the Talvera Torrent with a picture showing a deposition area*

Figure 32: *DoD 2018-2016 of the low study reach of the Talvera Torrent showing the depositional pattern determined by the weir openings*

Figure 33: *DoD 2018-2016 of the upper study reach of the Talvera Torrent with a picture showing erosion and deposition areas as a consequence of the check dam removal*

5.2 Effects on Hydrological Regime Alteration - IARI

Following the ISPRA methodology and the included definitions, the Talvera has a *scarce availability of data*; i.e. the time series of historical data (pre-impact) is less then 20-year long. In this case the reconstruction of monthly average discharge data was performed through an ex-post reconstruction of discharges (withdrawal and inflow data, effect of man-operated structures, effect of reservoirs, etc.). The IARI was then calculated by comparing the historical monthly mean discharges to the actual ones.

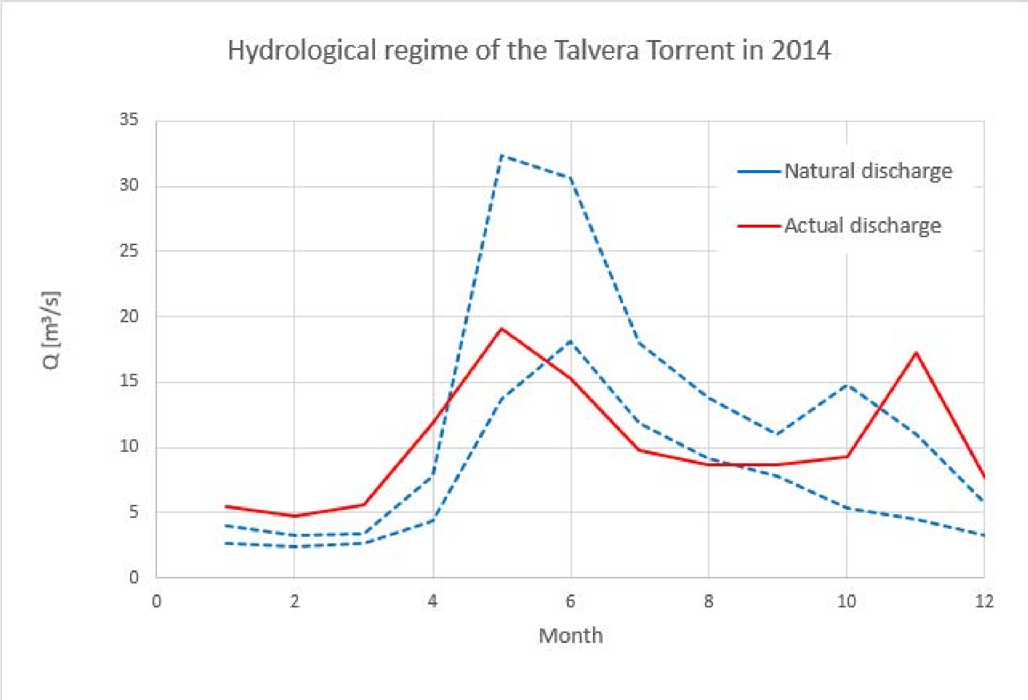
A first IARI estimation for the Talvera was performed in 2015 by the Engineering Consultant Patscheider & Partner; the hydrological status of the river was found to be critical, being the IARI equals to 0.81, a value significantly higher than the threshold of 0.15 (values lower than 0.15 indicate a hydrological regimes slightly altered 0.05$<$ IARI $\leq$ 0.15 or not altered IARI $<$ 0.15).

The IARI calculation carried out in this study uses 5 years of data (from 2014 to 2018) to estimate the actual regime, while the natural regime was taken from the one calculated by the Engineering Consultant Patscheider & Partner in 2015 using 4 year discharge data (from 2011 when the gauging station entered in operation, to 2014). In this analysis, data regarding agricultural and other water uses were taken by the PGUAP[2] of the Autonomous Province of Bolzano. A IARI value of 0.48 was obtained; it is significantly lower than the one previously computed, apparently indicating an improvement in the hydrological regime. However it remains above the threshold, indicating that the hydrological regime of the Talvera is still altered. Figure 34 shows the pattern of the actual discharge (red) compared to the natural one (blue) for both evaluations. The dotted blue lines identify the range of the natural regime of the Talvera Torrent. When the actual discharge does not fall into this range, an alteration of the hydrological regime exists. The further away from the natural band the actual regime is, the more altered the regime. Table 6 shows the average monthly discharge values used for the IARI calculation in 2015 and 2019.

The expert judgment confirms the *critical* condition of the Talvera hydrological regime, which is also negatively influenced by the hydropeaking insisting on the watercourse. In fact, the hydropeaking causes daily discharge fluctuations from 1 to 20 m^3 s^{-1}, which straightforward identifies an altered regime.

In 2015 the Autonomous Province of Bolzano carried out a study to identify the pressure of water transfer due to hydroelectric purposes in the province (Bollettino Ufficiale n. 29/I-II del 21/07/2015 / Amtsblatt Nr. 29/I-II vom 21/07/2015). According to this study, the Talvera Torrent happened to be particularly sensible

[2] Piano Generale Utilizzazione Acque Pubbliche



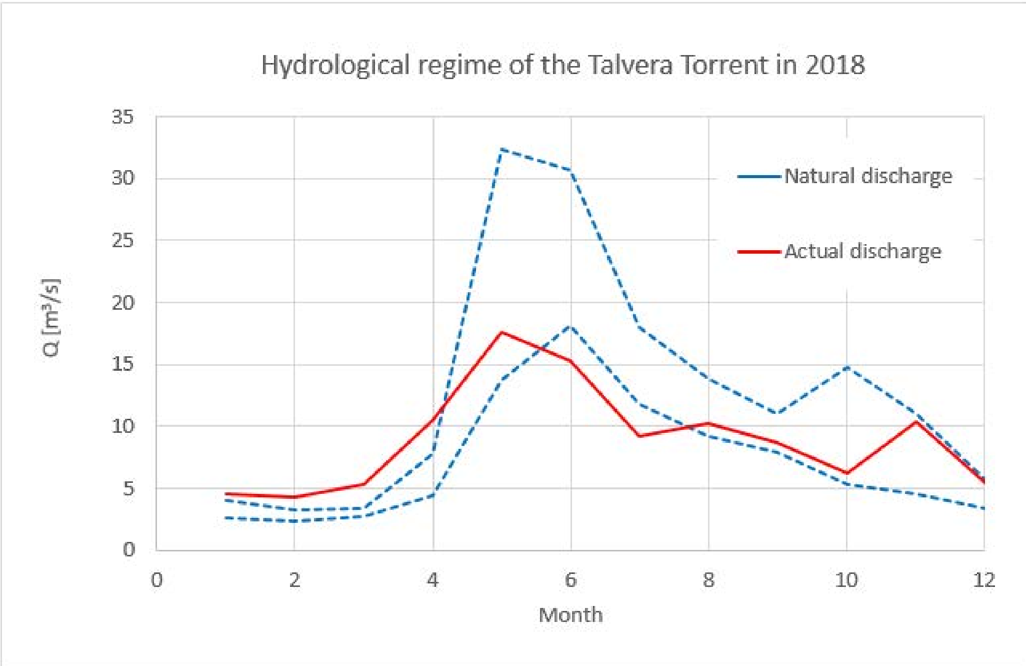


Figure 34: *Identification of the range of natural discharges (area in between the blue dotted lines) for the Talvera and the actual discharge characterizing the torrent (red line). The upper graph is obtained considering the mean monthly discharges from 2011 to 2014 (Patscheider-Partner, 2015), while the bottom graph represents the hydrological regime of the Talvera estimated from mean monthly discharge from 2014 to 2018*

to water use for hydroelectric purposes and no further hydroelectric concessions are allowed. This is an additional proof of the high human pressure insisting on the study reach, which confirms its critical status.

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	Q_{mean} (2011-2014) [m^3/s]	Q_{mean} (2014-2018) [m^3/s]
Jan	5.48	4.54
Feb	4.73	4.25
Mar	5.61	5.35
Apr	11.82	10.48
May	19.07	17.58
Jun	15.25	15.29
Jul	9.82	9.20
Aug	8.68	10.21
Sep	8.64	8.65
Oct	9.24	6.26
Nov	17.19	10.29
Dec	7.74	5.47

Table 6: *The first IARI analysis performed by Patscheider-Partner (2015) considered the mean monthly discharges from 2011 to 2014. The 2019 IARI evaluation considered the mean monthly discharges from 2014 to 2018 which significantly differ from the previous ones for certain months (e.g. November)*

5.3 Effects on the Morphological Quality Index

The application of the Morphological Quality Index resulted in a different classification according to the river reach. In particular, for the upper Talvera reach, subject to less anthropization compared to the others, the morphological quality has been classified as *Good*. The MQI for the reach T2 has been classified as *Poor*, while for the reaches T3 and T4 as *Moderate*. Figure 35 shows the MQI classification by colors for each study reach.

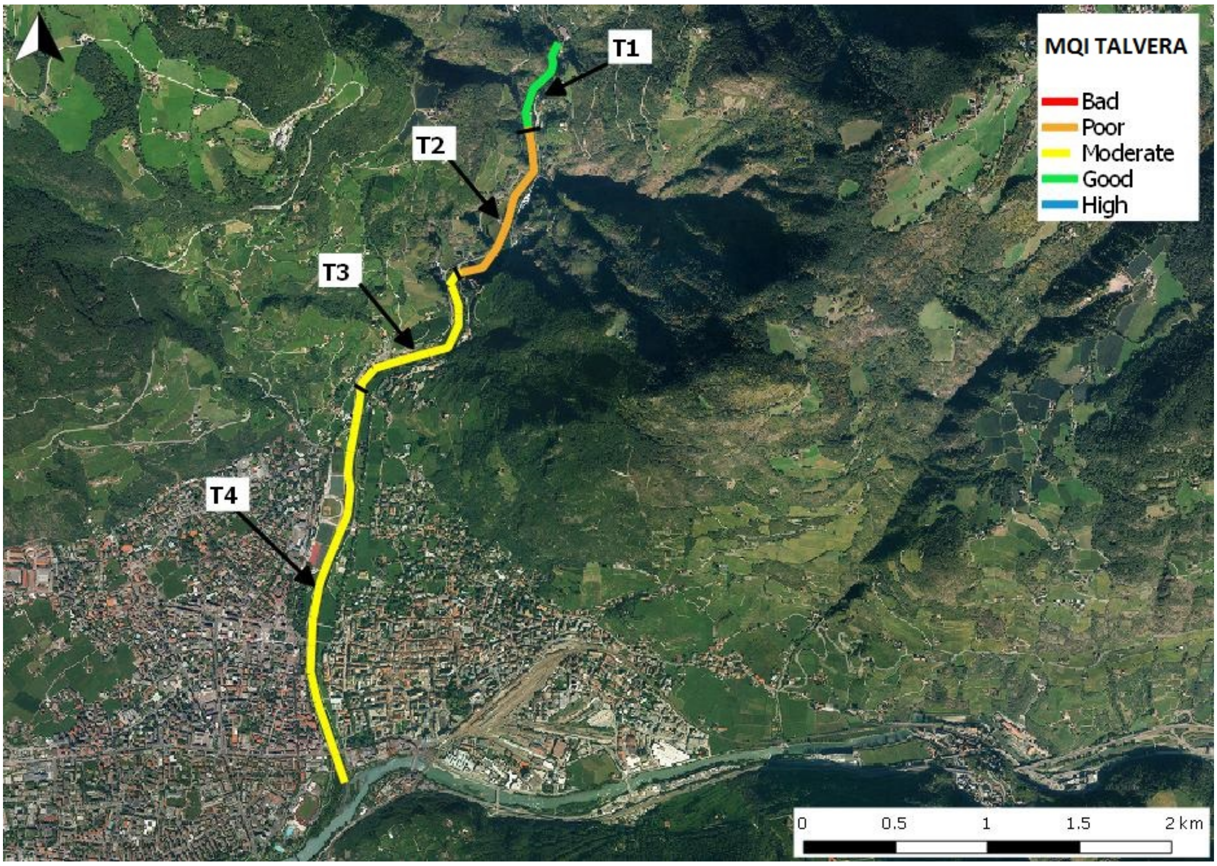

Figure 35: *Final judgment on the MQI classes for each analysed reach*

The positive rating associated to the reach T1 is mainly due to the retention check dam removal and to the natural confinement of the watercourse. The other reaches instead are characterized by a highly anthropized context, which prevents the torrent from restoring its naturalness even after the restoration works.

A deeper interpretation of the results needs to focus on some specific parameters which were particularly sensitive to the performed changes:

- longitudinal continuity in the flow of sediment and wood material (parameter F1);
- the presence of a floodplain (parameter F2);
- the transverse variability of the section (parameter F9).

Retention check dam removal, weir openings and the partial enlargement of the banks have fostered the formation of vegetated bars and islands in the reaches T3 and T4. The reshaping of the sections in reach T4 by placing cyclopean boulders and flow deflectors, resulted in the formation of riffle and pool and, in general, a more dynamic morphology.

However, the persistence of the numerous weirs along the watercourse influences the development of a natural morphology, although they have been opened on alternate sides. A meandering pattern has been observed, which is typically not associated to the actual confined configuration of the Talvera Torrent. Therefore, it is suggested to carefully study and analyse every restoration measure and expected effects to avoid results in contrast to the natural river morphology.

In general, the comparison of the MQI evaluations pre- (Patscheider-Partner, 2015) and post-restoration shows an improvement of some individual indices. Since the aim of the two studies was different, the reach subdivision does not match (2 reaches in Patscheider-Partner (2015) and 4 in this study). Nonetheless a general comparison of the results can still be done. Operationally, a weighted average was performed between the various indices and the relative reach length to obtain a final score through which compare the pre- and post-intervention morphology.

Figure 36 shows the degree of alteration for all parameters considered in the MQI analysis, which are briefly summarised as follows:

- F1 Longitudinal continuity in sediment and wood flux
- F2 Presence of a modern floodplain
- F4 Processes of bank retreat
- F5 Presence of a potentially erodible corridor
- F7 Planform pattern
- F9 Variability of the cross section
- F10 Structure of the channel bed
- F11 Presence of in-channel large wood

- F12 Width of functional vegetation
- F13 Linear extension of functional vegetation and presence of emergent aquatic macrophytes
- A1 Upstream alteration of flows
- A2 Upstream alteration of sediment discharges
- A3 Alteration of flows in the reach
- A4 Alteration of sediment discharge in the reach
- A5 Crossing structures (bridges, ford, manholes, drainage pipes)
- A6 Bank protections
- A7 Artificial levees
- A8 Artificial changes of river course
- A9 Other bed stabilization structures
- A10 Sediment removal
- A11 Wood removal
- A12 Vegetation management

Pre and post intervention evaluations are overlapped on the same graph. The values assigned to each parameter have been normalized by the maximum possible deviation (i.e. the sum of their maximum attributable value, and are shown on the y-axis).

The persistent alterations remain those due to the protection of the banks and the proximity of the levees to the active bed (parameters A4 and A6), which limit its ability to wander planarly. Even parameter A5, which concerns the crossing works, remains almost unchanged in the two evaluations.

Figure 37 shows the improvement achieved by the functionality parameters, which are directly affected by the effect of the interventions.

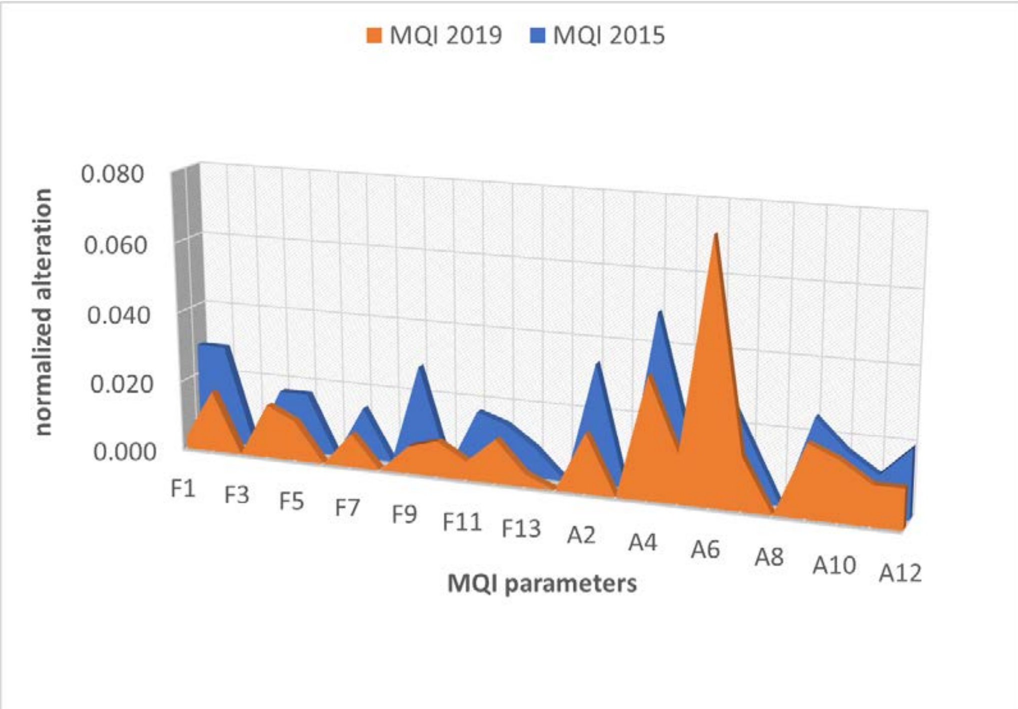

Figure 36: *Pre and during- restoration (blue) and post (orange) intervention MQI evaluations. The parameters considered refer to functionality and alteration. y-axis refers to the score describing morphological functionality alteration (F1 - F13) and artificiality (A1 - A12) normalised by the maximum value. The higher the value, the higher the functionality alteration/artificiality. The x-axis shows the parameters used to evaluate the MQI*

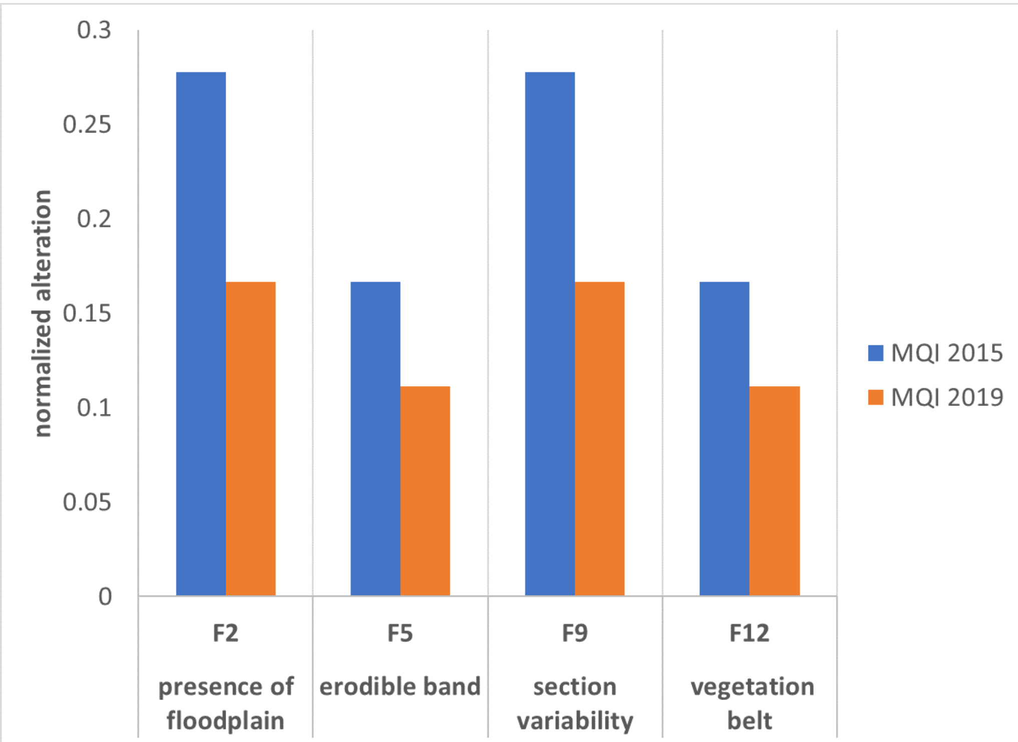

Figure 37: *Parameters of functionality, which are directly affected*

The MQI analysis gives a preliminary assessment of the current morphological status of a watercourse; it refers to a deviation from a reference which is not the complete naturality (see MQI manual for details); Figure 36 and 37 have to be interpreted in this sense. In order to evaluate the effectiveness of restoration measurement at a relatively short time scale, a more appropriate index is the Morphological Quality monitoring Index (MQIm). This is a specific tool for monitoring, and quantifying changes in morphological quality over a short time scales of the order of a few years.

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5.4 Grain size analysis

Based on the calibration previously described, granulometric curves were obtained for the different sampling points. Figure 38 provides an overview of the points where the survey took place along the reaches and the photos on which the particle size curve was built. With the aim of building a good base for comparison, the sampling locations were taken from those selected in Abenis-Alpinexpert (2013).

Reach T3, characterized by a predominantly multi-channel morphology with islands and vegetated bars did not allow the application of this method.

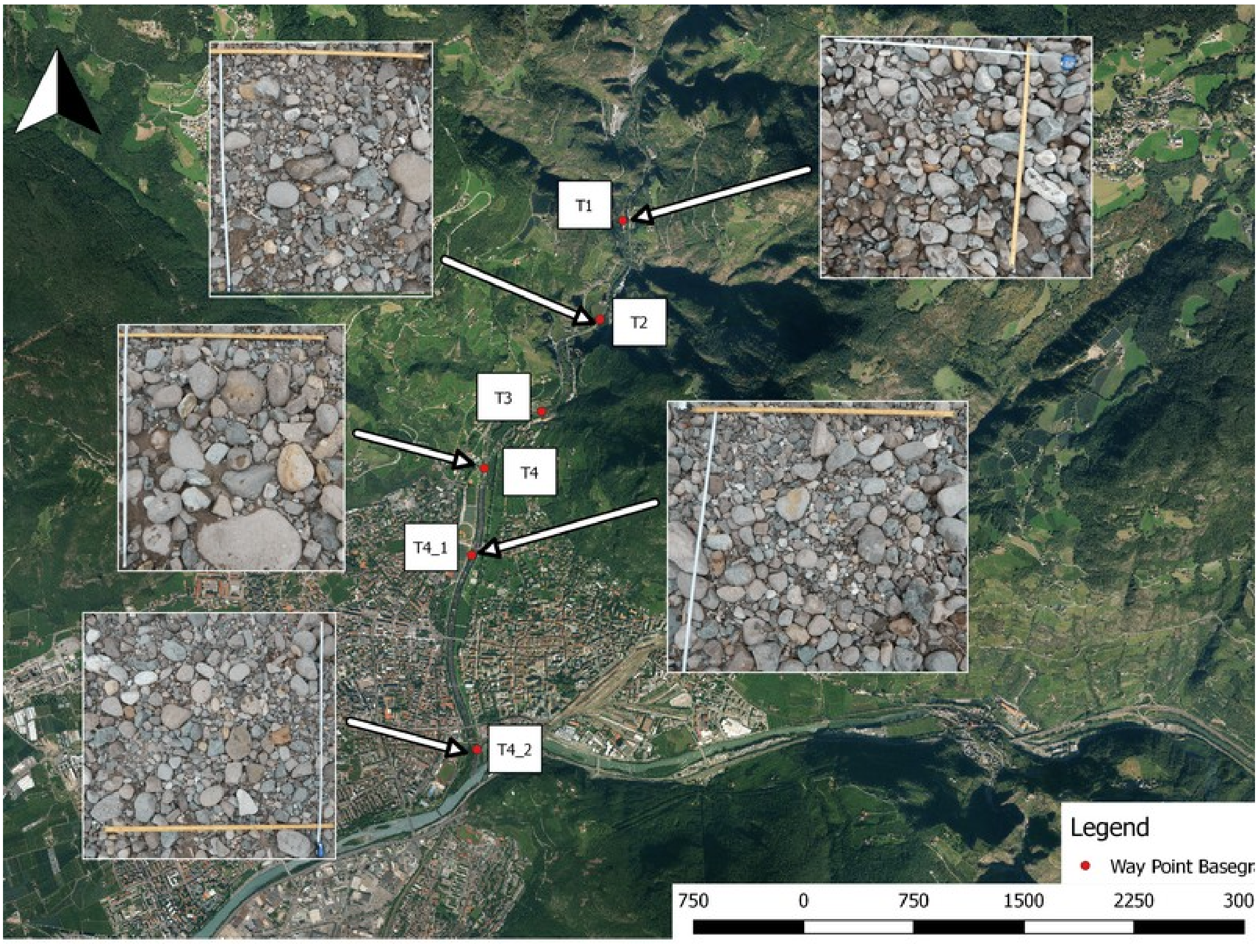

Figure 38: *Photos acquisition points along the reaches*

Each surveyed area had an extension of about 1 m x 1 m. Photos were analysed through the software Basegrain (www.basement.ethz.ch, 2015), which identifies the main diameters, which recognizes objects by separating interstices from grain areas. Figure 39 shows how the algorithm recognizes every single grain. However, the reliability of the Basegrain results needs to be validated through field analysis. Once the algorithm had been calibrated, granulometric curves were obtained for each point, in accordance to Abenis-Alpinexpert (2013) study.

Figure 41 shows the granulometric curves for the four study reaches obtained from the 2019-analysis. The red horizontal line refers to the error associated to the d_{50} and the d_{90} relative to the granulometric curve of the reach T1. Comparing them all conveys that the reach T1 presents a grain size distribution coarser than the other reaches, which instead have a very comparable distribution. This conveys the idea that larger cobbles and boulders have been deposited in the upstream reach (T1), whereas smaller cobbles, gravel and sand have been transported further downstream toward the confluence.

Figure 40 shows the results obtained using the Basegrain algorithm and the sieve analysis applied by Abenis-Alpinexpert, 2013 (top) and the grain size characterization obtained from Basegrain in 2019 (bottom). Comparing the grain size curves obtained using the algorithm, yields the following: in 2013 the majority of the diameters fell within the range of 10 - 60 mm. A similar range is observed in 2019, meaning that the effect of the removal of the retention dam has not affected sediment dynamics in the upper reach yet.

In order to quantify the change in the grain size distribution after the weir removal, the difference, between the most representative diameters pre- and post-restoration, was calculated and normalized to the value pre-restoration (Eqn. 2). Table 7 shows that the variation in the diameters before and after restoration is minimal for the reach T1 when comparing both the d_{50} and the d_{90}. While a significant deviation in the diameters can be observed for the other reaches for both the characteristic fractions.

$$\delta = \frac{d_{50}^{post} - d_{50}^{pre}}{d_{50}^{post}} \tag{2}$$

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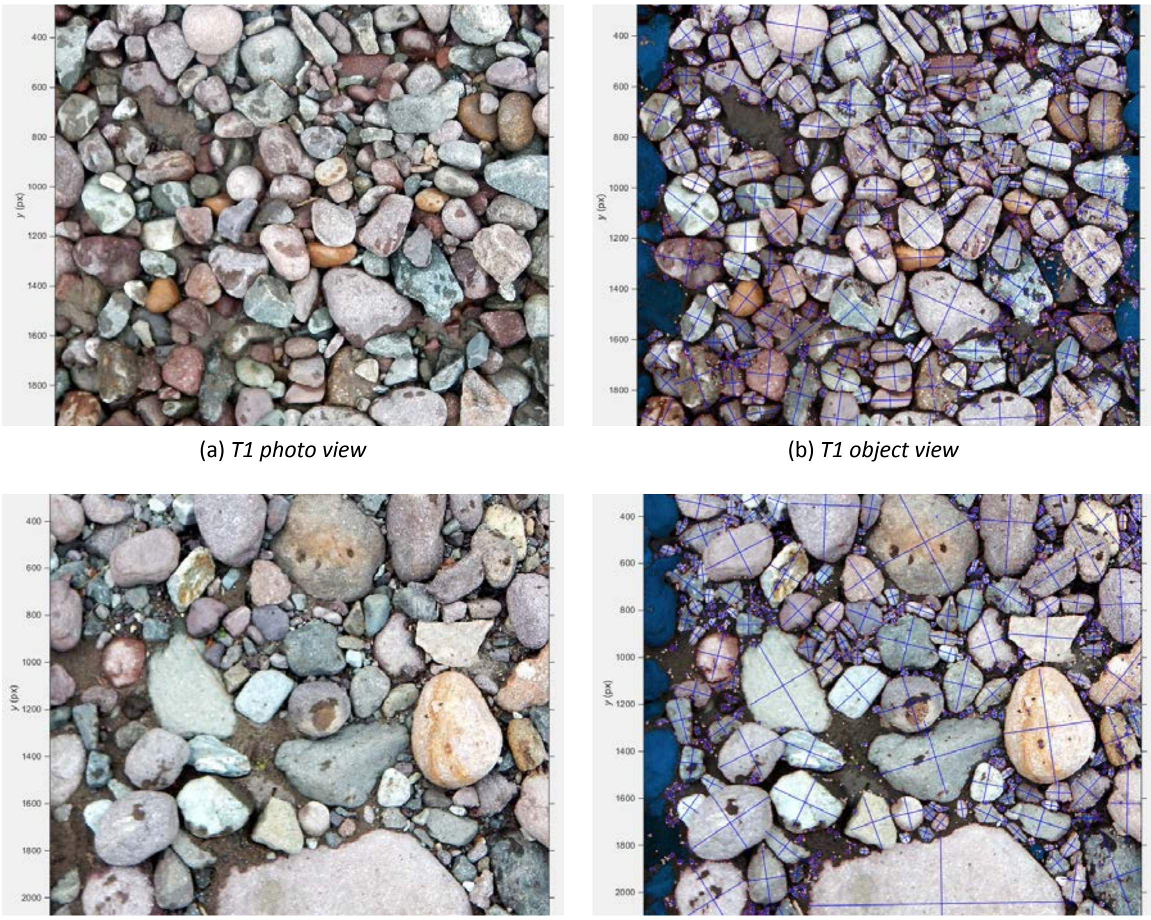


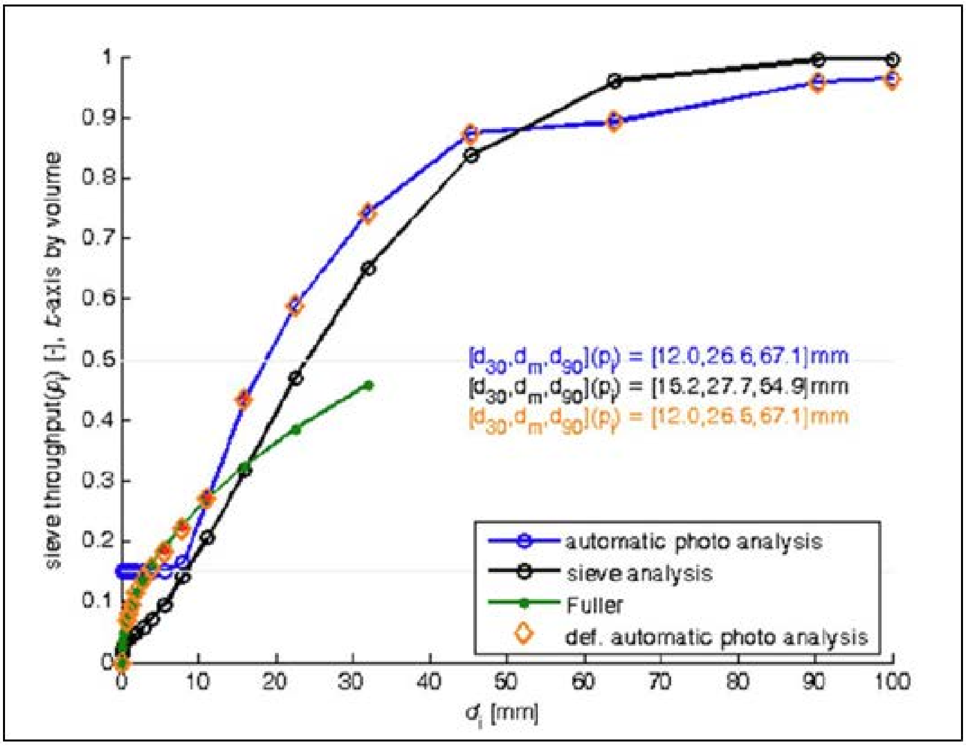
(a) *T1 photo view*

(b) *T1 object view*

(c) *T4 photo view*

(d) *T4 object view*

Figure 39: *Example of pre- and post-processing image for T1 and T4 reaches*



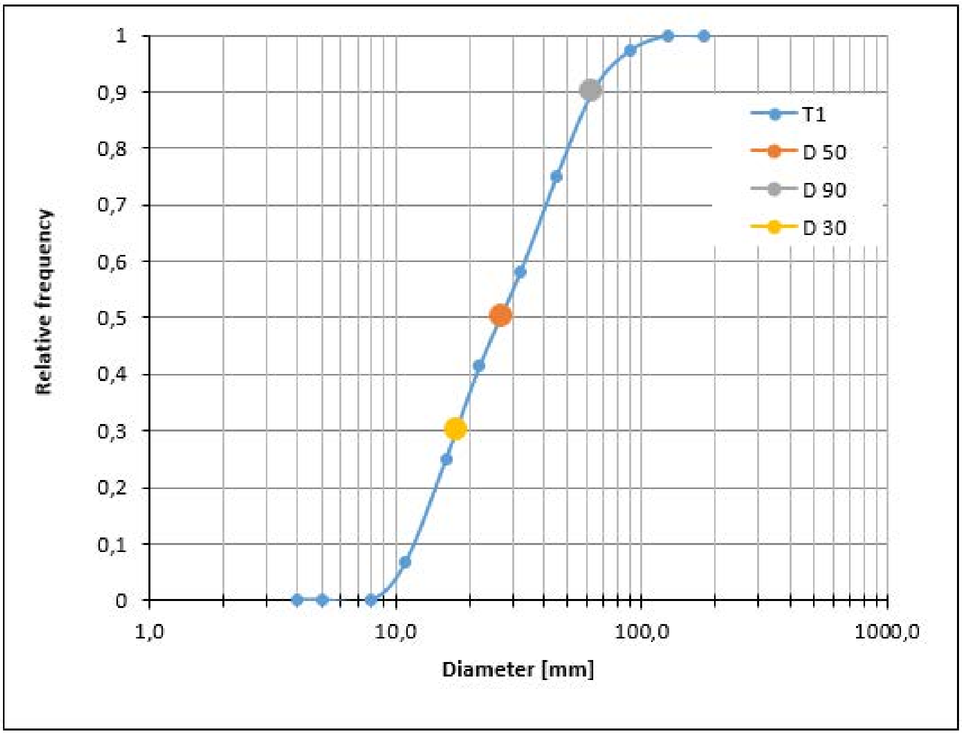


Figure 40: *Granulometric curve (blue) of the reach T1 obtained from the diameters calculated from Basegrain in 2013 (top) and in 2019 (bottom). In particular the image on top from Abenis-Alpinexpert (2013) shows the comparison between the granulometric curve resulted from Basegrain (blue) and the one obtained from the sieve analysis (black). The two curves do not completely overlap, meaning that a certain error must be associated to the software performance*

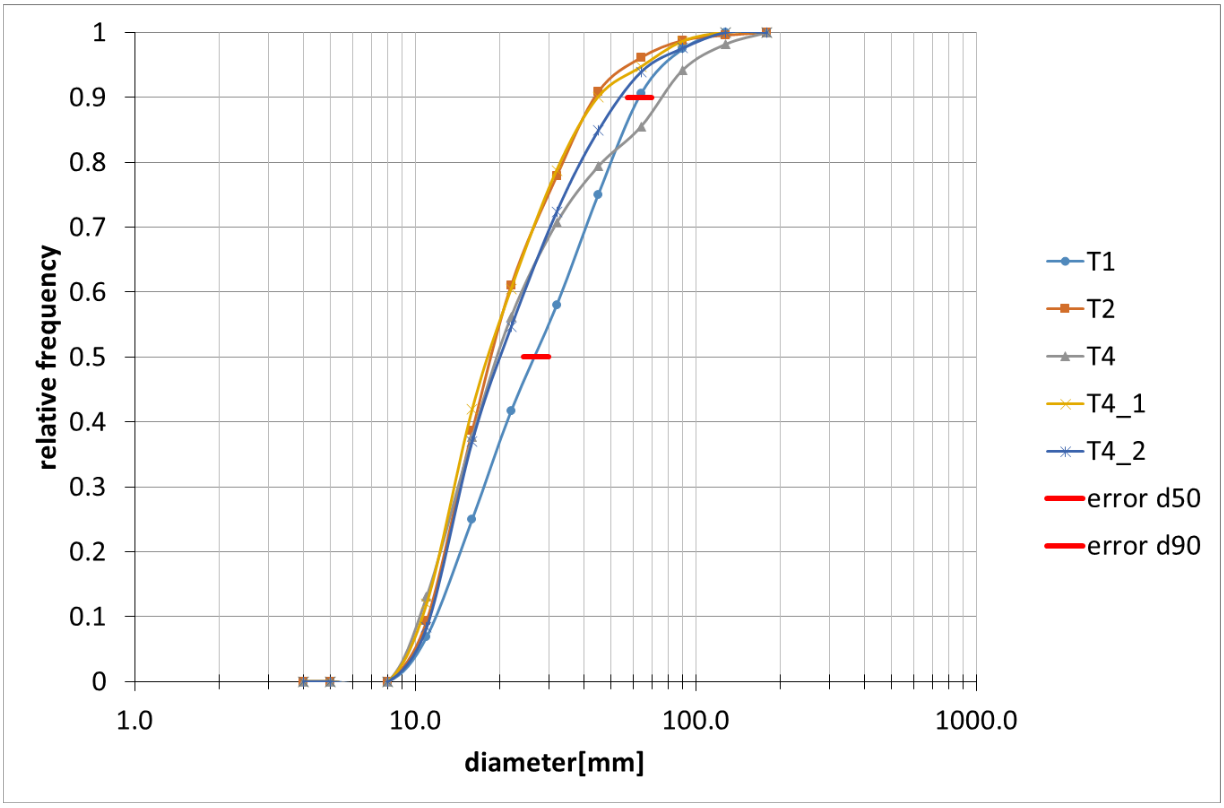


Figure 41: *Grain size curve*

Reach	D50$_{PRE}[mm]$	D50$_{POST}[mm]$	$\delta 50$	D90$_{PRE}[mm]$	D90$_{POST}[mm]$	$\delta 90$
T1	26.6	27.1	2%	67.1	63.3	- 6%
T2	12.6	19.1	52%	21.1	44.1	109%
T3	44.4	-	-	109.1	-	-
T4	-	20.0	-	-	77.4	-
$T4_1$	36.4	18.61	- 49%	80.6	44.9	- 44%
$T4_2$	13.6	20.4	50%	36.7	55.8	52%

Table 7: *Value of the characteristic diameters for each section before and after interventions. The symbol δ is the percentage deviation in relation to the pre-intervention condition*

The comparison of the values of the d_{50} and the d_{90} pre- and post-restoration shows that:

- T1: the variation of diameters before and after restoration is minimal and the situation can be classified as stable. The effects of the flood event of October 2018 cannot be observed being the retention check dam still in place at that time. Changes in the grain size composition are expected in a near future since new sediment dynamics have been triggered.

- T2: the weir opening and retention check dam removal brought about an increase both in d_{50} and in d_{90}, indicating that sediment dynamics have been triggered and already are having an effect on the grain size distribution.

- $T4_1$: a shift of the granulometric curve towards the left side of the graph is observed; this implies an increase of the finer particles in this portion of T4.

- $T4_2$: a shift of the granulometric curve towards the right side of the graphis observed; this implies an higher presence of coarse particles in this portion of T4.

Overall, a clear trend with respect to grain size is not observed in reach T4, however a change in sediment dynamics is detected; this can be interpreted as a positive effect of weir opening and retention check dam removal. The reach T1, which is located downstream the retention check dam removed in March 2019, is the only one showing no or little variation of the grain size distribution pre- and post-restoration. The survey was performed on April 2019 and despite the upstream retention check dam was no longer there, the effects of sediment continuity might have not been visible yet. However, T1 can be considered as a suited monitong site and further investigations would be appropriate to detect grain size variation and the time scale of the changes.

Finally, the values of the Uniformity Coefficient, C_u (Eqn. 3), have been calculated for the samples of 2019 in order to set a benchmark for future surveys. The C_u corresponds to the ratio between the d_{60} and the d_{10} and indicates whether a sample is well or poorly graded. The C_u values are summarised in Table 8; the bigger the number, higher the sorting of the sample.

$$C_u = \frac{d_{60}}{d_{10}} \tag{3}$$

Reach	C_u
T1	2.83
T2	1.96
T4	2.39
$T4_1$	2.08
$T4_2$	2.22

Table 8: *CU values for each river reach calculated as the ratio between the* d_{60} *and the* d_{10}

5.5 Fine sediment analysis

The analysis of the fine sediment fraction was carried out to complement the soil characterization performed with the photographic technique and to assess whether the restoration works had an effect on fines. Operationally, at least one sample of fine sediment from the surface layer was collected for each reach . The sampling points were chosen near the banks or on the bars (sampling excavation depth about 20 - 30 cm). Figure 42 shows the points where the samples were taken.

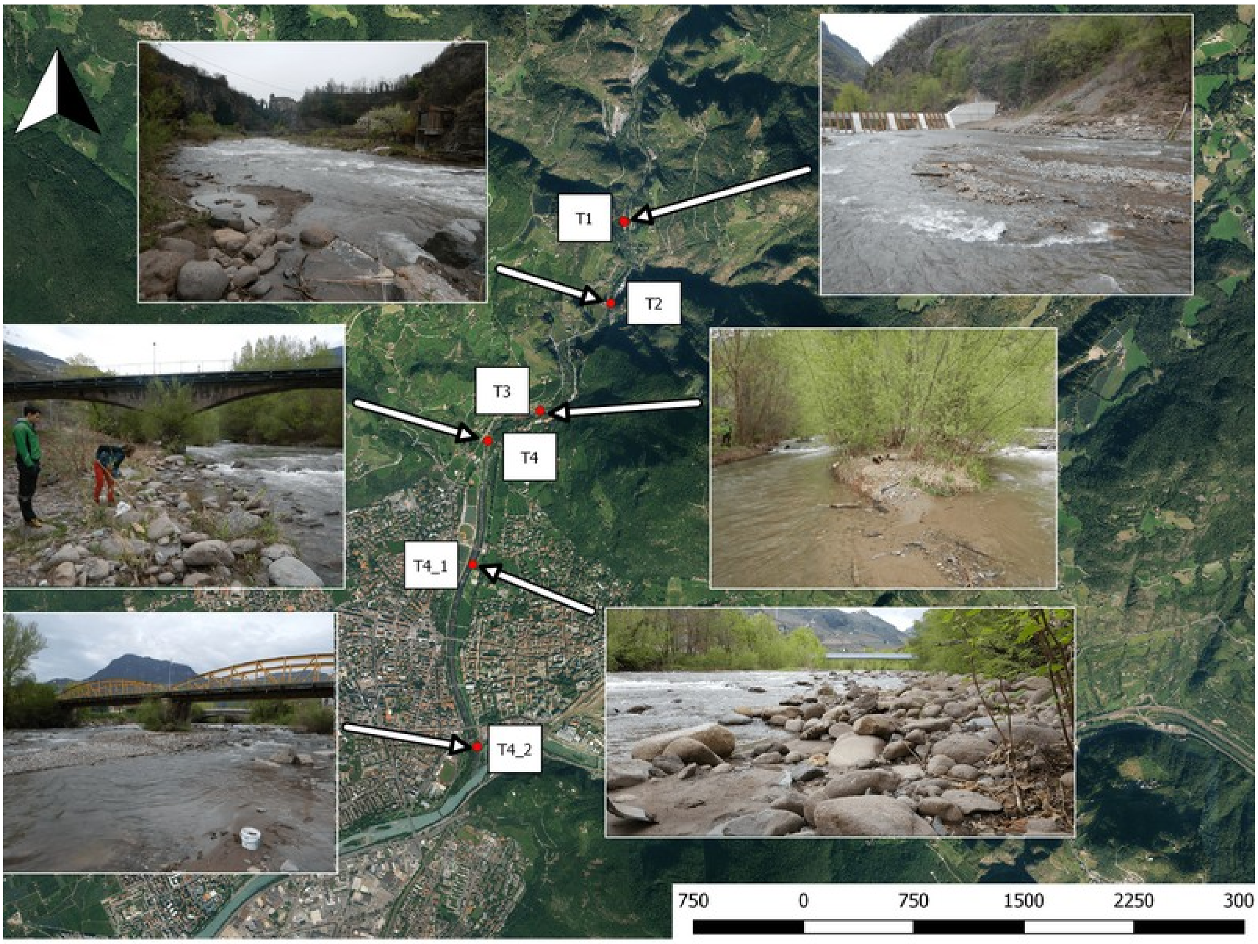


Figure 42: *Sample points along the reaches*

The sieving of the samples was performed by the laboratory of the Geology and material tests Office of the Autonomous Province of Bolzano. Table 9 shows the diameter range of the sieves used in the laboratory. Figure 43 shows particle size distribution of the different samples. The two upstream reaches (T1 and T2) of the Talvera present slightly coarser sediment. The others (T3, T4, $T4_2$) tend to be similarly characterized by

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Sieve diameter [mm]
0.063
0.125
0.250
0.500
1.000
2.000
4.000
5.600
8.000
11.200
16.000
22.400

Table 9: *Values of sieve diameters*

finer sand. The only exception is the curve $T4_1$ which behaviour lies between the curves of reach T1 and T2.

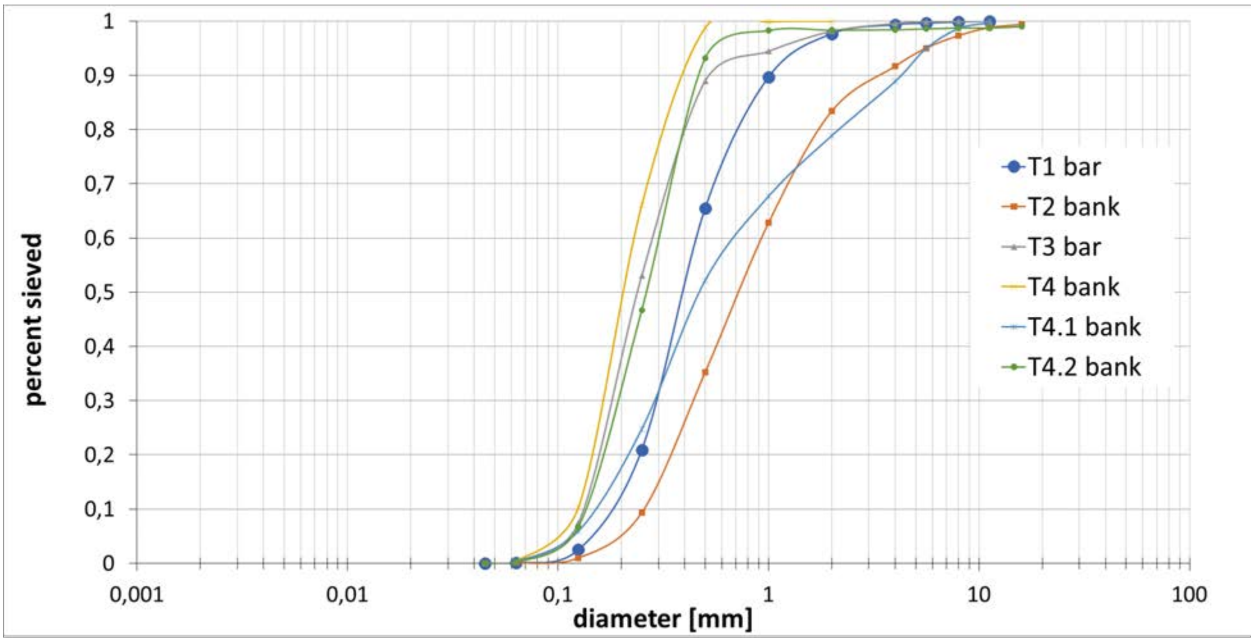

Figure 43: *Grain size curve. Diameters between 0.063 mm to 2 mm identify Sand*

Soil texture was classified according to DIN4023 (Table 11). In general, the main component for all samples is the medium sand (mS), mixed with finer or coarser sand (fs or gs), or fine gravel (fg), depending on the case.

Reach	D50[mm]	D90[mm]	D30[mm]
T1	0.41	1.04	0.30
T2	0.77	3.59	0.45
T3	0.24	0.60	0.19
T4	0.21	0.43	0.17
$T4_1$	0.48	4.29	0.30
$T4_2$	0.27	0.48	4.20

Table 10: *Value of the characteristic diameters for each sample*

Reach	clay	silt	sand	gravel	cobble	DIN4023-1
T1	0	0.3	97.4	2.3	0	mS,gs,fs’
T2	0	0.4	83.1	16.5	0	gS-mS, fg’
T3	0	1	97.1	1.9	0	mS,fs*,gs’
T4	0	2.1	97.9	0	0	mS-fs
$T4_1$	0	2	77.2	20.8	0	mS,gs,fs,fg
$T4_2$	0	1	97.4	1.6	0	mS, fs*

Table 11: *Sediment classification based on grain size (DIN 4023)*

For a given discharge and riverbed roughness, the deposition of fine particles depends on the geometry of the cross section. The geometry can be described by the local riverbed slope and by the cross-section width. The restoration interventions often aim at modifying these two quantities in order to trigger quiescent riverbed dynamics. A correlation between these parameters and the characteristic diameters (d_{30}, d_{50}, d_{90}) has been investigated. In general, the longitudinal riverbed slope has a direct correlation to the transported diameter, while the width is inversely correlated. Within this study, the average width and the local slope of the cross-section where the sampling points are located have been estimated in a range of 100 m from the point of interest. Results show a direct dependence between the cross-section width and characteristic diameters while no relationship occurs between riverbed slope and characteristic diameters. The reason may depend on the low slope characterizing the reach and therefore the ratio slope/width has been introduced as new parameter. This shows the expected trend: the higher the parameter, the larger the transported diameters. However, cross-sections width can be considered as the main parameter to which relate the transported diameters. Figure 44 (a) and (b) shows the correlation described: the

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larger diameters are better correlated to the hydraulic and geometrical variables (cross-section width and longitudinal slope).

This analysis provides a preliminary post-intervention overview, since no data regarding the pre-restoration situation are available and therefore a comparison cannot be performed. Future monitoring are recommended to assess possible changes with respect to the current state.

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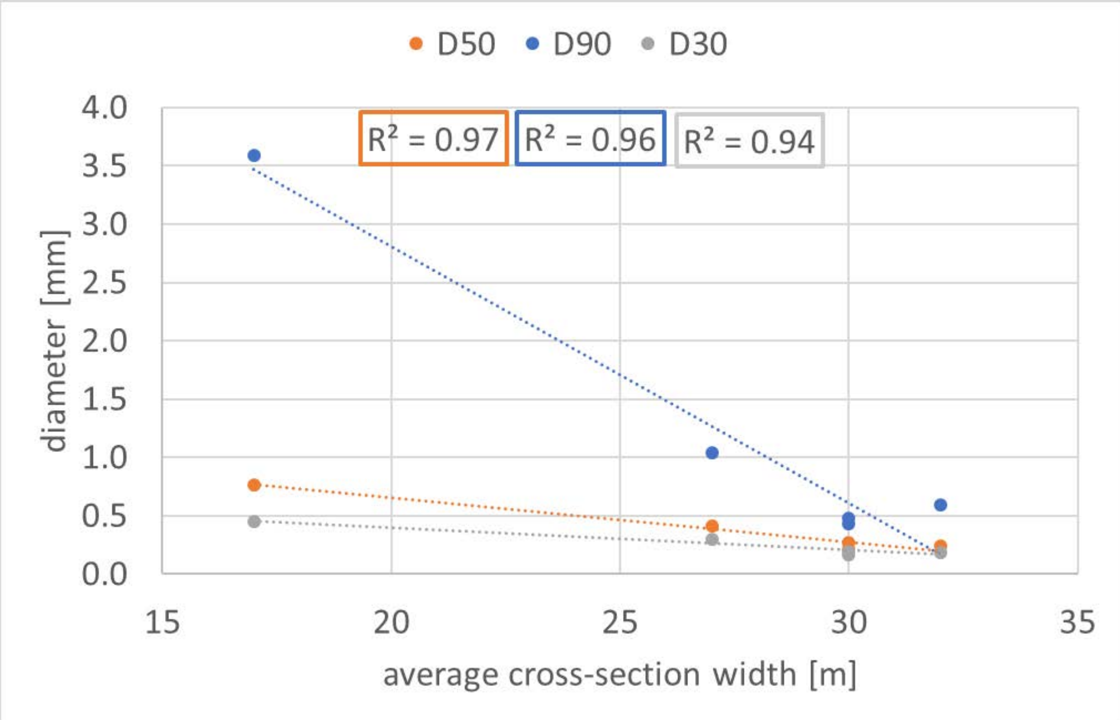
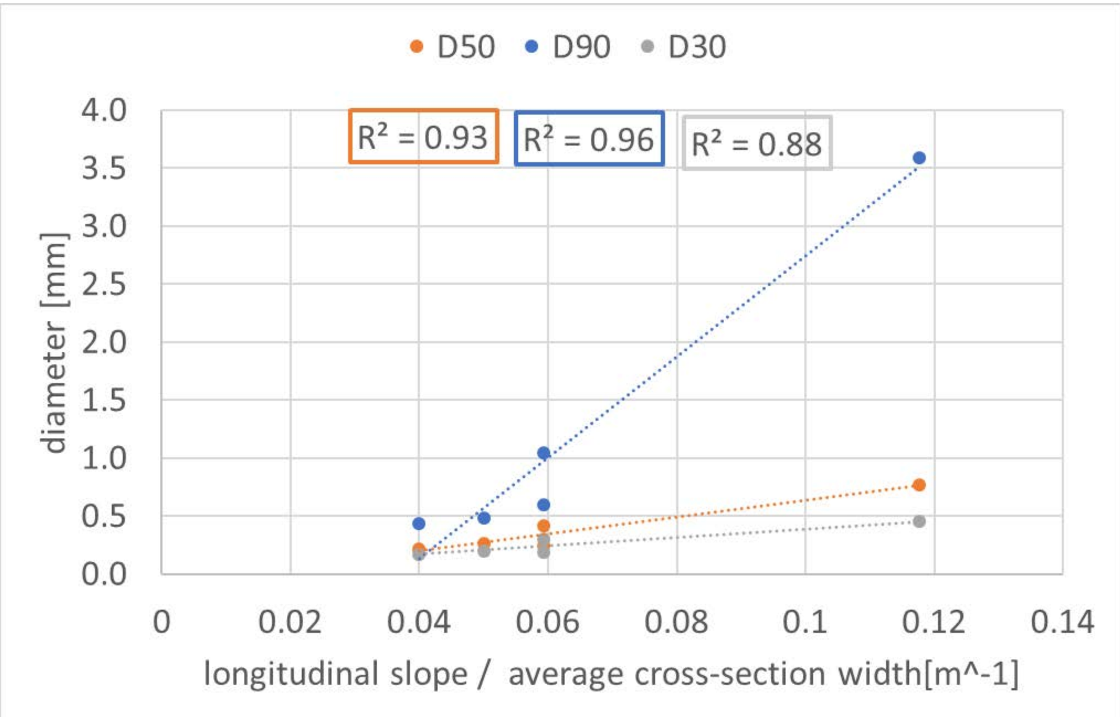


(a) *characteristic diameters vs. cross-section width*



(b) *characteristic diameters vs. longitudinal riverbed slope-cross-section width ratio*

Figure 44: *Experimental trends linking the diameters of the fine fraction to the physical characteristics of the section (slope and width)*

6 Assessment of the Ecological effects of the Restoration

The analyses of chemical data do not revealed substantial variation before and after river restoration measures. All the available parameters were analysed finding no significant differences. The only exception is the Biochemical Oxygen Demand (BOD_5), which was slightly lower before restoration (t-test results: t = -1.95, degree of freedom df = 11.6, statistical significance p = 0.075). In general, an increase in the BOD_5 means a reduction in water quality, due to an increase in organic content. Considering the restoration interventions, the increase in BOD_5 can probably be related to external factors, such as pollution from wastewater. The difference is not high in absolute terms (LIMeco[3] index considers a first class of quality BOD_5 < 2.5 mg/l), and the biological effect is not expected to be significant. However, this has some interest because it can explain some of the differences observed in diatoms and macroinvertebrates. The graph displayed in Figure 45 shows the difference in BOD_5 contents pre- and post- restoration. The thickest line indicates the average value, while the box delimits the interquartile range. The whiskers indicate the minimum value and the maximum value of the sample. The average value in the pre-intervention scenario intersects the percentile variability box in the post-intervention scenario. This translates into a low value of the statistic significance. With respect to the restoration measures deployed along the Talvera, the BOD_5 indicator is not appropriate to assess their effectiveness.

The diatom assemblages observed in the pre- and post-restoration period showed several differences (Figure 46). As suggested by the PCO ordination diagram, samples collected between 2008 and 2013 exhibit a higher dispersion with respect to samples collected between 2015 and 2018 (Figure 46, black points stand clearly out from red points). This means that species identity and abundance could have been affected by restoration. The ANOSIM test confirms that this difference is significant, given an R-value of 0.552 (R-value = 1 suggests similarities) and a p-value of 0.024 (p-value $<$ 0.05 means statistical significance). The intrinsic limit of this analysis is that the trend and the extent of the difference between pre- and post-restoration cannot be associated to a suitable reference condition, which should be indeed identified in the monitoring program to have more reliable results. In other words, it seems that restoration could have been affected the diatom community (for example increasing the microhabitat heterogeneity), but little can be stated on the real underlying causative process. Moreover, part of the observed difference in the pre- and post-assemblages could be due to a slight increase in organic pollution demonstrated by the

[3] LIMeco (Livello di Inquinamento dai Macrodescrittori per lo stato ecologico). LIMeco is an index describing the water quality in rivers as to nutrients and oxygen

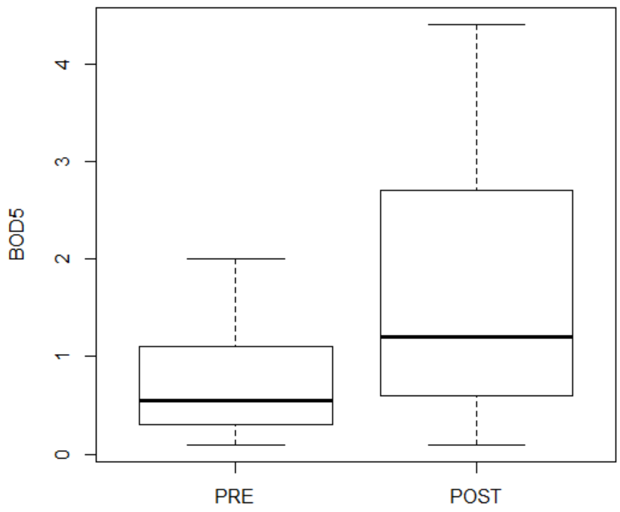


Figure 45: *Boxplot showing the difference in BOD_5 contents (mg/l O_2) pre- and post- restoration*

BOD_5 concentration.

Also the ordination of macroinvertebrate samples, suggests a significant difference between pre- and post-restoration. In fact, the ANOSIM test supports this conclusion with high confidence ($R = 0.348$, $p = 0.006$). However, similarly to the case of diatoms, the ecological meaning of the observed differences is not easy to interpret. Some differences were noticed between pre- and post-restoration (for example the *mayflies-ephemeroptera Baetis* sp, are less abundant after restoration, whereas watermites are more common). The genus Baetis tends to live on the top of stones, and many species of the genus can survive in α-mesotrophic water. Fish are the main predators of mayflies, and according to the top-down control of community, the decrease of Baetis may be even a consequence of fish variation.

Fish sampling showed interesting changes comparing the pre- and post-restoration (Figure 47). In 2010, the fish density was low and the species composition was *Salmo trutta trutta*, *Salmo trutta marmoratus*, hybrid trouts, *Oncorhynchus mykiss*, and *Cottus gobio*. In 2012, the species composition was still the same but the density of fish increased; in particular, the increase regarded mainly the *Cottus gobio*, even though trouts in general also increased. In 2015, *Cottus gobio* still augmented, attaining the dominance in terms of density. In this last sampling, *Thymallus thymallus* was also found with several individuals.

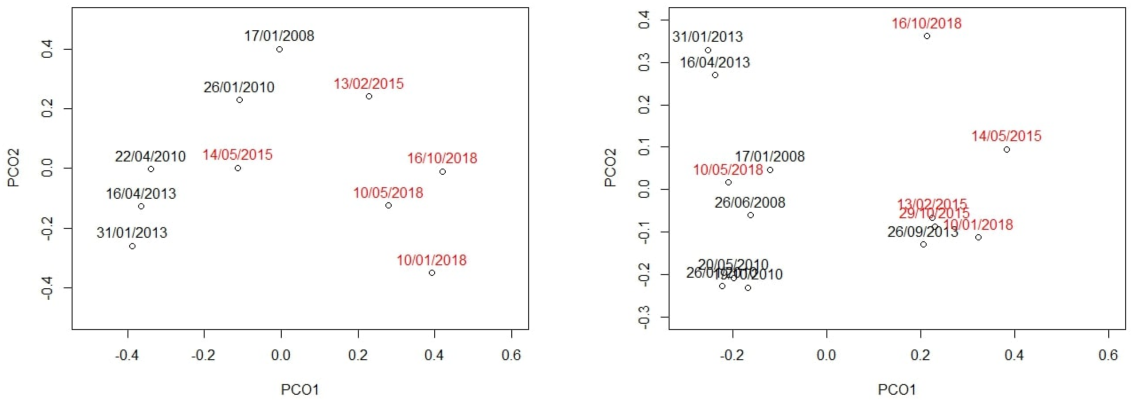


Figure 46: *Ordination of diatom (left diagram) and macroinvertebrate (right) assemblages by PCO. Red labels identify the post restoration dates of sampling. In both diagrams, ordinations suggest an apparent segregation between samples before and after restoration. Point labels indicate the sampling date*

Considering the biomass instead of density (Figure 48), trouts were the most important components of the fish assemblages. No clear trends were observed on the different species across the three years. The only exception was *Cottus gobio*, as already discussed above considering the number of individuals. Total biomass increased from 60 Kg/ha in 2010, to 130 Kg/ha in 2012 and 118 Kg/ha in 2015. Given that restoration started in 2014 and it is still ongoing in several places, interpretation of the underlying causes determining the fish variation is not straightforward. The increase of *Cottus gobius* was detected before restoration, and without a control site it is impossible to identify a cause-effect relationship. The removal or partial opening of the check dams as part of the restoration program, surely improved the longitudinal connectivity. However, no data were available along the river to identify the actual effect. Several sampling stations would have been necessary from the river mouth at least up to the S. Antonio hydroelectric plant to detect the effect of reactivated connectivity. The appearance of *Thymallus thymallus* in 2015 samples may be due to the upward recolonization from the Isarco river. It should be noted that the species prefer large rivers with deep and fast flowing flow (but with clear differences depending on the life stage). If longitudinal connectivity was the obstacle preventing upstream colonization of *Thymallus thymallus*, in the next years it is expected an increase of the population.

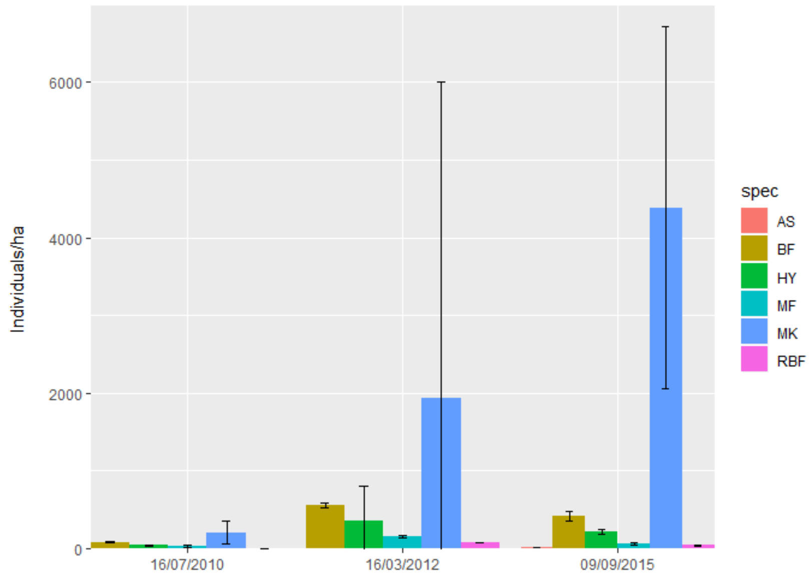


Figure 47: *Density of fish in three sampling dates in the monitoring station. Thymallus thymallus (AS = Äsche = temolo = grayling), Salmo trutta fario (BF = Bachforelle = trota fario = river trout), Salmo trutta marmoratus (MF = Marmorierte Forelle = trota marmorata = marble trout), hybrid (BF-MF), Oncorhynchus mykiss (RBF = Regenbogenforelle = trota iridea = rainbow trout), and Cottus gobio (MK = Mühlkoppe = scazzone = European bullhead)*

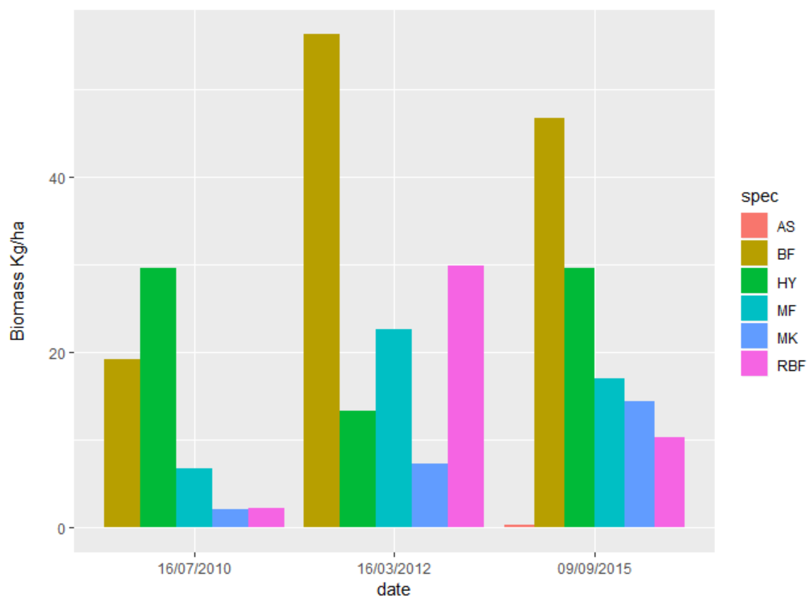


Figure 48: *Biomass of fish in three sampling dates in the monitoring station. Thymallus thymallus (AS = Äsche = temolo), Salmo trutta trutta (BF = Bachforelle = trota fario), hybrid (HY = BF-MF), Salmo trutta marmoratus (MF = Marmorierte Forelle = trota marmorata), Cottus gobio (MK = Mühlkoppe = scazzone), Oncorhynchus mykiss (RBF = Reg)*

A previous study carried out between 2011 and 2013 (Festi and Adami, 2013) investigates the fish habitat along the Talvera; in particular the authors found that the biomass was much lower in the downstream reach (T1-T2 Figure 17, 25 kg/ha), whereas it attained higher values in the middle and upper reaches (T3-T4-T5 Figure 17, 80-120 kg/ha). The electrofishing carried out by Festi and Adami (2013) (23-27.03.2012) was nearly simultaneous to the one performed by the Office for Hunting and Fishery (16.03.2012); they show comparable results when the same location is considered (the sampling reach of the Office for Hunting and Fishery falls between reaches T1 and T2 of Festi and Adami (2013) study, see Figures 17 and 24).

6.1 Habitat assessment by the MesoHABSIM methodology

Since the S. Antonio power station is regulated by a reservoir which provides daily storage, it can be assumed that on a daily base the discharge released at the power station is a proxy of the reference discharge. Discharge data are available dowstream the power plant with a record rate of 10 minutes. In 2015 the management of S. Antonio power station changed, therefore the current situation is better captured. Within the HyMoCARES project, data collection took place on August, 9^{th} and 19^{th} 2019. In order to simulate different hydrological scenarios, the tested discharges have been previously agreed with the S. Antonio hydropower plan managers and correspond to 1.1 m^3/s, 1.6 m^3/ s, 3.5 m^3/s and 6.4 m^3/s. The application consists of the following steps::

1. identification of a sub-reach,representative of the study area, in which the analysis has to be carried out: a length of ca. 200 m has been selected downstream the gauging station as shown in Figure 49; this is representative of the entire reach extending from the fish ladder to the confluence to the Isarco;
2. identification of the most suited places where to set the total station (TS);
3. preliminary analysis of the study area to identify the Hydro-Morphological Units (HMUs);
4. mapping of the HMU perimeter through the TS (Figure 51-b);
5. substrate classification and measurements of flow velocity and flow depth for each HMU. According to the extension of each HMU, a different number of measures was taken to grant a homogeneous distributions. The current meter OTT C2 was used to estimate the flow velocity based on the revolutions per second of the installed propeller (Figure 51-a).

The limited available time, agreed with the manager of the power plant to carry out the measurement campaign, did not allow to collect data along the optimal length (which should be 10 times the active channel width according to ISPRA, 2017), however, given the homogeneity of the reach, the analysed sub-reach is adequate to achieve reliable results.

Figure 49: *Identification of the sub-reach where the MesoHABSIM survey took place*

According to the discharge, different Hydromorphological Units have been identified. Figure 50 shows the HMUs associated to a discharge of 1.6 m^3/s, while Table 12 reports the total number of HMU and the type of HMU detected per each discharge.

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Discharge	N. HMU	Step	Pool	Glide	Riffle	Rapid	Cascade
1.1 m^3/s	12	1	6	1	3	1	-
1.6 m^3/s	12	1	4	3	2	2	-
3.5 m^3/s	10	1	3	1	2	2	1
6.4 m^3/s	9	1	1	1	1	4	1

Table 12: *Total number of HMU and type of HMU detected for each discharge*

Figure 50: *HMUs associated to a discharge of 1.6 m^3/s*

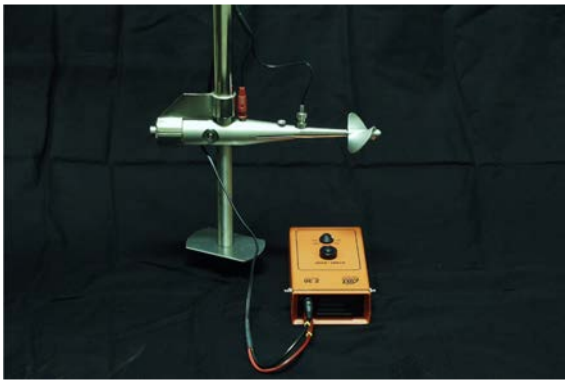
The inputs necessary to run the model are:

- a shape file describing the HMUs identified during the survey and containing information regarding maximum and minimum bed elevations associated to each HMU and characteristics such as the presence of connectivity, of boulder, of vegetation, etc.;
- a text file illustrating the physical features measured inside each HUM, such as flow velocity, flow depth and substrate characterization. The number of measurements carried on per each HUM depends on its extension;
- a text file including the estimated reference discharge, i.e. not altered by the power plant. The reference discharge was calculated as the mean daily discharge over the last 4 years, from 2015 to 2018, since from 2015 the management of the S. Antonio power plant has changed. The reference discharge values are then calculated as the average of the mean daily discharge of these years (i.e the reference value of the 1^{st} of January is obtained by averaging the values of all discharges (expressed as daily means) of the 1^{st} of January of the years 2015, 2016, 2017 and 2018).

The main outputs of the model show the habitat spatial availability for different species, by considering the input parameters measured in the field (discharge, substrate, flow depth and velocity) and empirical curves describing the presence of the fish species in similar conditions.In particular the species for which the habitat availability was checked are *Salmo trutta fario*, textitSalmo marmoratus, trout juveniles, *Cottus gobio* and *Thymallus thymallus* (both adults and juveniles). Mesohabitats, classified as suitable and optimal wetted areas, must be aggregated for the construction of the habitat-flow relationship (see Figure 58), which relates the discharge to the available habitat (expressed in m^2 on the right y-axis or as a % of the wetted area on the left y-axis) for each of the species present (or theoretically present) in the Talvera. According to ISPRA (2017) the total available habitat (H_d) within the analysed stretch is obtained through the equation:

$$H_d = H_I * 0.25 + H_O * 0.75 \tag{4}$$

where H_I and H_O indicate respectively the available suitable and optimal habitat. Figures 52, 53, 54, 55, 56 and 57 show the habitat availability for the different species depending on the simulated discharge,



(a) *The OTT C2 small current meter for discharge measurements*

(b) *TS used for collecting topographic data*

(c) *Ovewview of the sub-reach*

(d) *Flow depth and velocity measurements*

(e) *Measurements taken during a discharge of 1.1 m^3/s*

(f) *Measurements taken during a discharge of 6.4 m^3/s*

Figure 51: *Pictures showing the field survey along the Talvera*

species and its stage of life (adult or juvenile).

The available habitat quantity is expressed as percentage % (see Figure 58) and refers to the total wetted area corresponding to the maximum discharge measured in the field (i.e. 6.4 m^3/s).

The results suggest that for the:

- *Salmo trutta fario* (Adult brown trout): the available habitat increases until 1.6 m^3/s, it stays constant until 3.7 m^3/s and then decreases;
- *Salmo marmoratus* (Adult marble trout): two peaks of high habitat availability are visible in the graph (Figure 58), the first at 1.1 m^3/s and the second at 3.7 m^3/s; afterwards the available habitat decreases;
- Juvenile trouts: the suitable condition occurs at a discharge of 1.1 m^3/s and then the available habitat decreases monotonically with the discharge;
- *Cottus gobio* (Adult grayling): for discharges higher than 1 m^3/s, the conditions in the Talvera are always suitable for this species;
- *Thymallus thymallus* (Adult and juvenile grayling): for both adult and juvenile individuals of grayling, the habitat suitability tends to be very low; in fact, this species prefers river with lower flow velocity such as the Isarco or Adige river.

Figure 52: *Maps of habitat suitability for the brown trour species depending on different simulated discharges*

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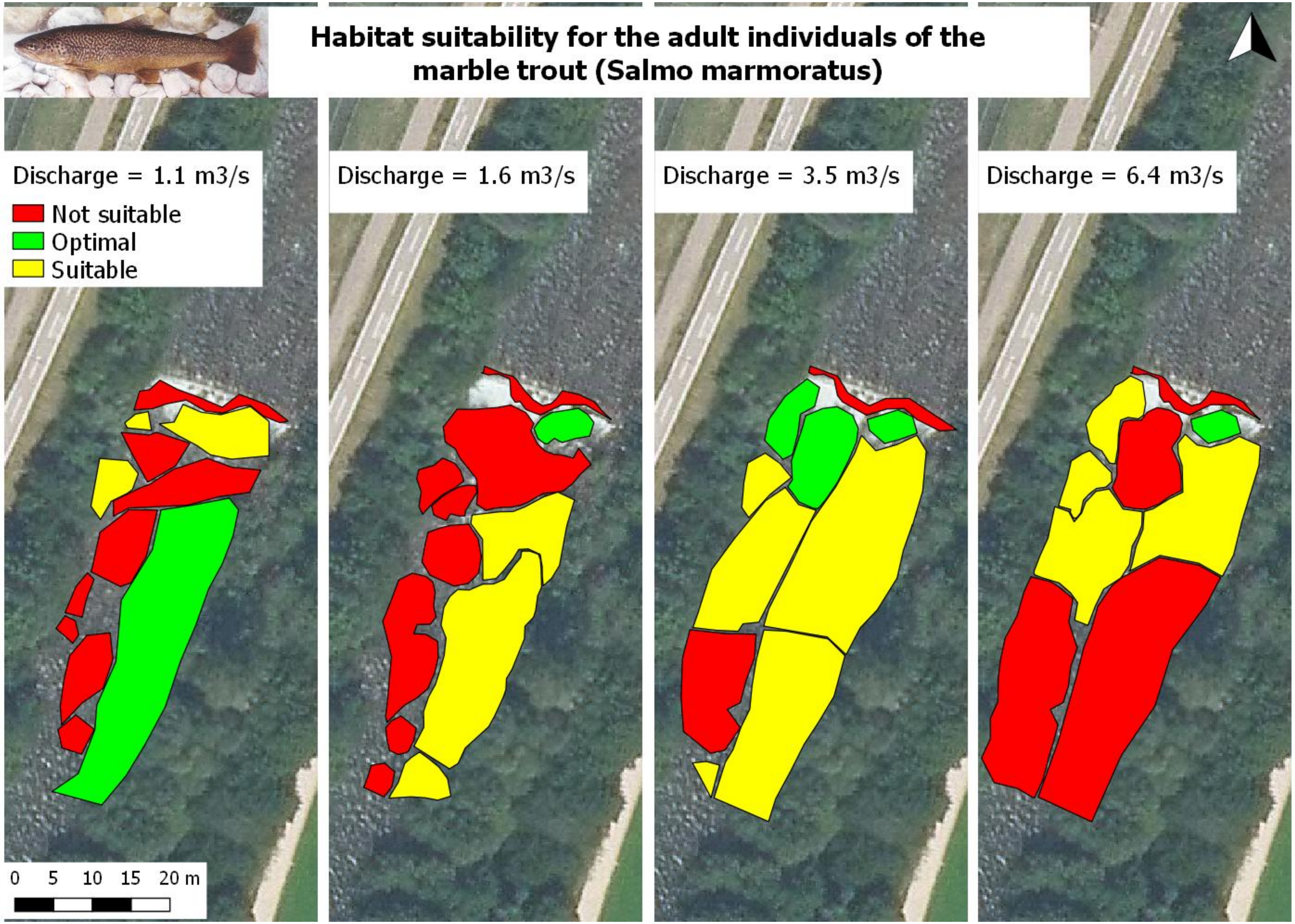

Figure 53: *Maps of habitat suitability for the marble trout species depending on different simulated discharges*

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Figure 54: *Maps of habitat suitability for the juvenile trout species depending on different simulated discharges*

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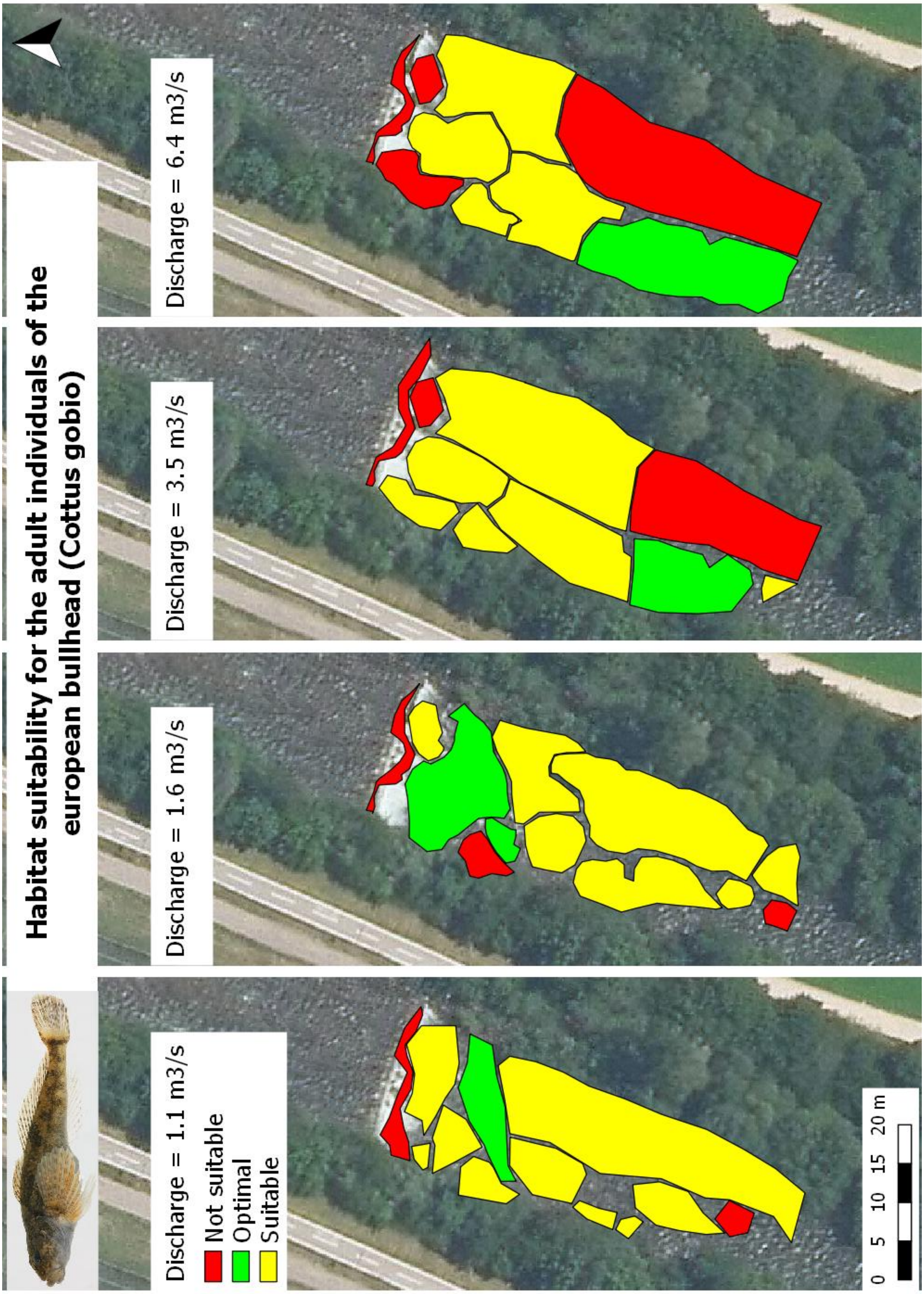

Figure 55: *Maps of habitat suitability for the european bullhead species depending on different simulated discharges*

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Figure 56: *Maps of habitat suitability for the grayling species depending on different simulated discharges*

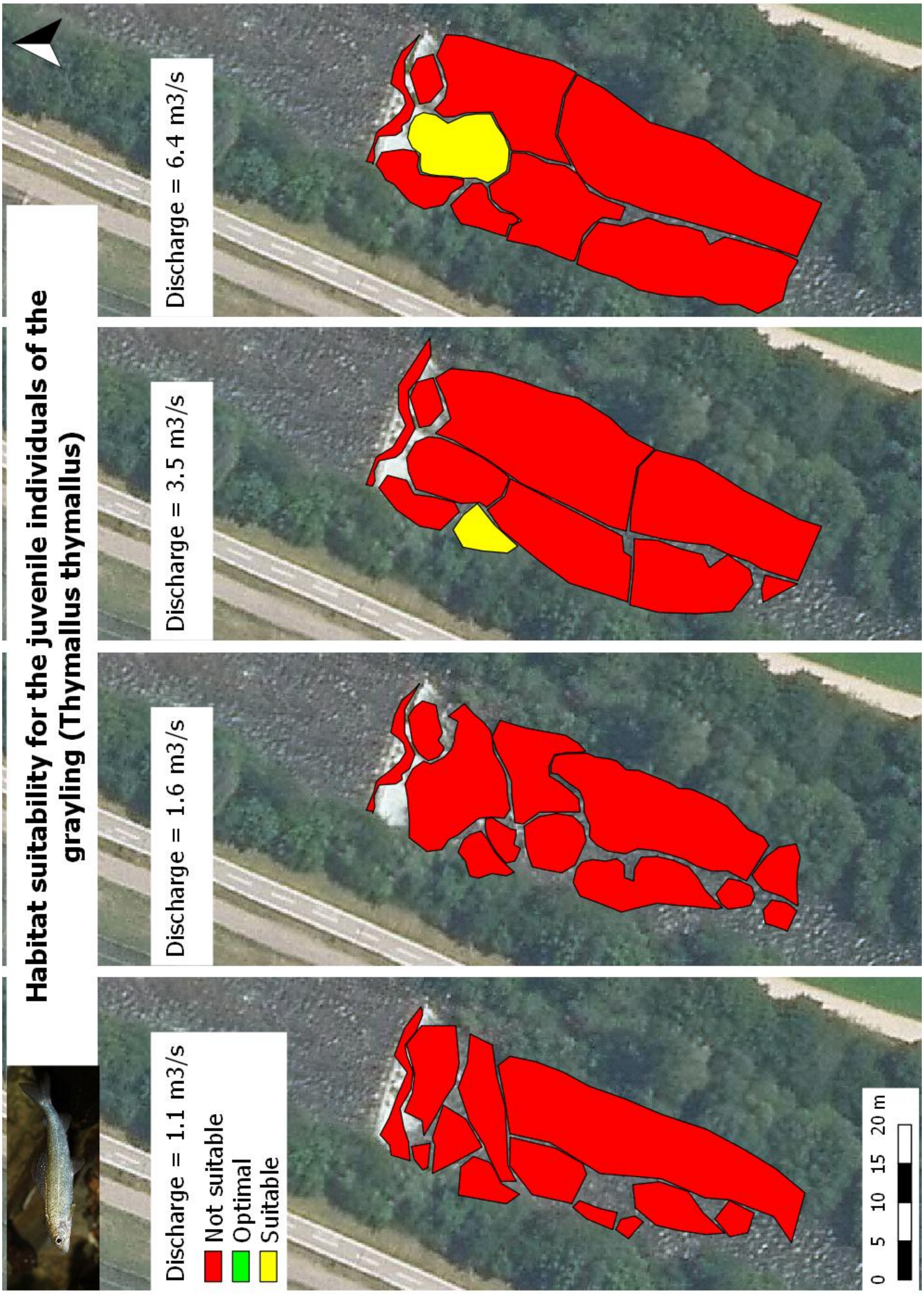

Figure 57: *Maps of habitat suitability for the juvenile grayling species depending on different simulated discharges*

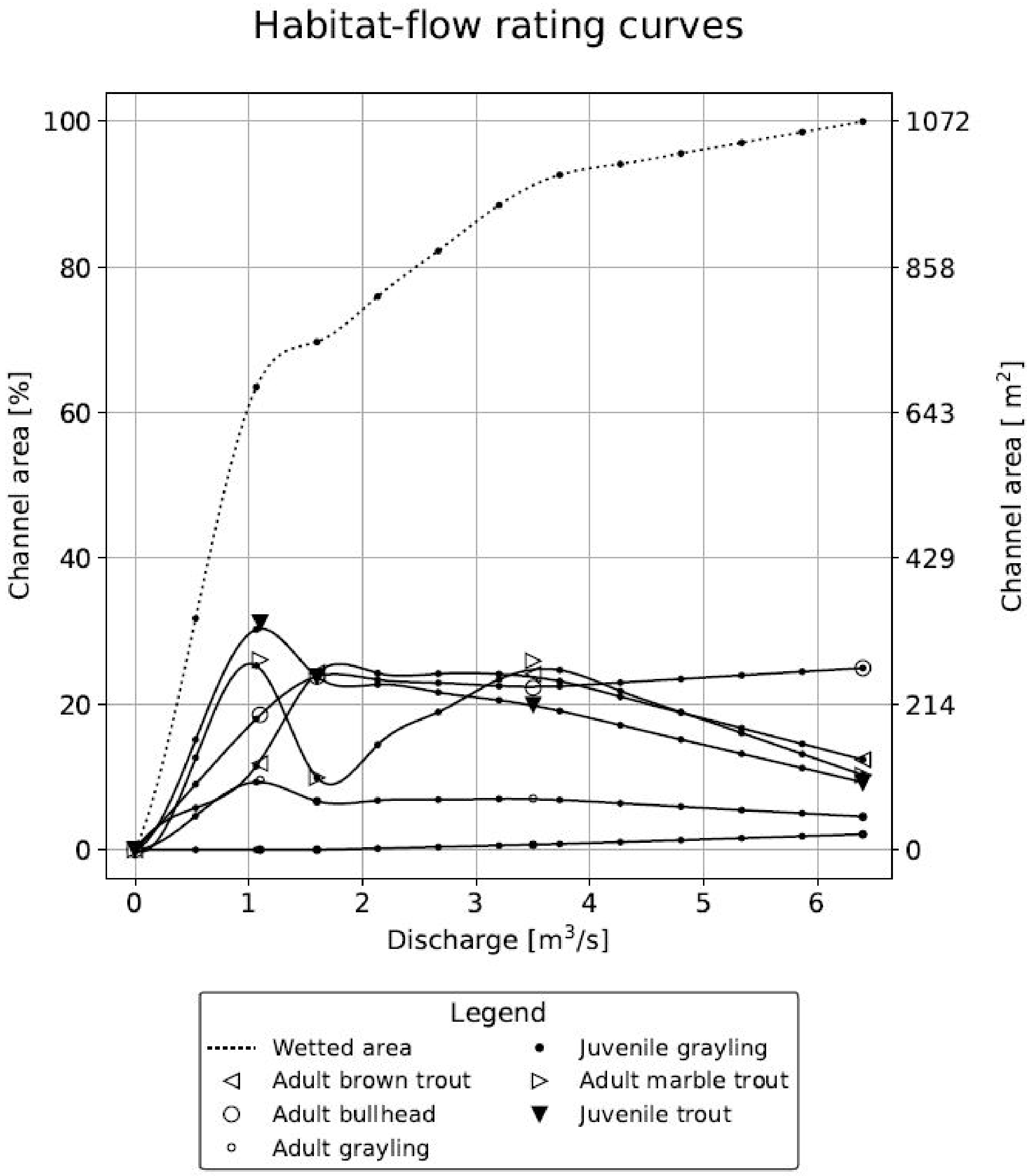

Figure 58: *Habitat-discharge relationship for the different fish species and their life stage for the Talvera River*

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7 Conclusions and perspectives

Within the HyMoCARES project the WPT3 aims at evaluating the effects of stream restoration works in physical and ecological terms.

The monitoring design applied by the Autonomous Province of Bolzano, based on a **B**efore **A**fter approach, allowed data collection and elaboration for assessing the restoration efficiency.

From a physical point of view, the main findings are the following:

1. **DoD**: the analysis reveals an enhanced sediment dynamics, which causes a preferential pattern followed by the stream after the restoration works. An overall change in the morphology can be observed in terms of macroforms, which give the stream a sinuous shape. In addition, the triggering of sediment dynamics takes time to show its effectiveness, whereas flood events such as the October 2018 one can mobilize a great amount of sediment, which is an unusual supply. Such an event in a renaturalized environment can cause important changes to the river morphology.

2. **IARI**: the restoration was not conceived to address the hydrological regime alteration, therefore significant variations are not expected to be observed. The hydropeaking strongly alters the natural regime, negatively influencing the stream morphology and ecology. However, the construction of the 95000 m^3-buried reservoir within the S.Antonio power plant is expected to improve the actual situation. A more constant discharge will be released in the water body so that the negative impacts of fluctuations on the aquatic life can be minimised (4 to 5 times lower).

3. **MQI**: the Morphological Quality Index showed an improvement on the river morphology after the restoration works. The improved longitudinal connectivity and the channel widening brought benefits to the watercourse; this will hopefully also positively affect its biota. However, along the downstream part of the study reach, a strong anthropization still persists, which limits the natural morphology of the Talvera.

4. **Grain size analysis**: the results on the coarse portion analysis show a difference on grain diameters pre- and post-restoration. The recent removal of the Sill retention check dam has triggered the mobilzation of diameters which used to be stable, so that after restoration new diameters have been observed along the study reach. In addition, the results for the fine portion of sediments show how fine sediments segregate along the study reach, being coarser upstream and finer downstream.

Regarding to the ecological effects of the restoration, the main findings are the following:

1. **Chemical analysis**: no major differences were detected when analysing water chemistry pre- and post-restoration. A slight increase in the BOD_5 has been found after restoration; however, it is highly improbable that this difference could be directly due to the restoration activities, conversely it can rather be related to external factors. In addition, the difference is not high in absolute value and the ecological effect probably is negligible.

2. **Diatoms and Macroinvertebrates**: both groups show significant differences comparing the pre- and post-restoration situation. The differences are in terms of species abundance and species composition, as the multivariate analysis suggested. However, with the available data it is not possible to determine whether these differences were actually caused by the restoration or by external factors. Lacking both a control and a reference sites, concluding with some confidence that the observed changes are imputable to restoration is so far premature. In other terms, it is not possible to separate external factors from the actual effect of restoration. It is suggested to perform targeted samples at least on macroinvertebrate to assess the real effects of restoration. The monitoring approach used so far, and based on data collected by the Environmental Protection Agency (for classification purpouse) it is not suited to assess the restoration effects.

3. **Fish**: data regarding fish species, either considering abundance or biomass do not show a clear trend. The only exception is given by the *Cottus gobio*, which showed an increase in the number of individuals. However, as highlighted in the results, this increase started before the restoration works: therefore this trend probably does not depend on the restoration itself but rather on external factors. In addition, the available dataset is too scanty (only 3 sampling sets) to determine a clear trend for fish species and further data are needed to achieve more confident results. Carrying on the fish monitoring would be particularly helpful in understanding the restoration effects. In fact, the restoration effects often are not immediately evident, as some time is needed for the fish to explore and colonize new suited portions of the river. Moreover, it is suggested to perform targeted samples on fish to assess the real effects of restoration. The monitoring approach used so far, and based on data collected by the Hunting and Fish Department, it is not suited to assess the restoration effects since it should be more focused on sampling the area object of restoration.

4. **Habitat**: the results obtained by applying the MesoHABSIM methodology to the Talvera provide

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information on the spatial (not temporal) habitat availability for four different species: *Salmo trutta fario*, *Salmo marmoratus*, *Cottus gobio* and *Thymallus thymallus*. In particular, due to the physical characteristics of the river, the habitat is mainly suitable for the *Cottus gobio* and secondarily for the trout species. Instead, the Talvera appears not suitable for the species of *Thymallus thymallus*, which prefer calm water. This analysis can also be confirmed by the collected fish data: the *Cottus gobio* is the dominant species (highest number of individuals per ha), followed by the trout species, while the *Thymallus thymallus* is almost undetected.

In general, the effect due to the restoration works is positive, since it brings improvements to the river habitat, both in physical and ecological terms. The considerations that have been done on this study rely 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. Without a proper sampling design it is hard to confidently attribute changes to a treatment or to a cause. To reduce the possibility of misinterpreting the restoration effect with natural variability, it is suggested to include at least one control site (portion of the river not restored), and one or more reference sites (the target condition) in future monitoring designs. The minimum essential sampling design is the Before-After Control-Impact (BACI), where both a control and treatment sites (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 represents the success of the restoration. Control and reference sites must be selected with care, 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 the followings (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. 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 and conclusive 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. Collection and elaboration of data regarding wrong parameters are time and cost consuming.

7.1 Future monitoring and good practices

A long term monitoring of the river morphology and ecology will allow to understand whether the perfomed restoration works had the expected results or rather ephemeral ones. If the morphological changes carried out along the watercourse are destroied with the first flood event and the stream goes back to its original (pre-restoration) 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 Talvera Torrent, the outcomes of this study suggest the following monitoring actions to check the effectiveness and the evolution in time of the restoration works.

- Morphological monitoring. The morphological evolution of the Talvera should be kept under control to be aware of the tendency of the torrent with respect to aggradation, degradation and formation of macroforms. DoD analyses are an effective tool to perform this assessment at the scale of interest (i.e. reach of the Talvera in Bolzano). In a shortage of funds a discrete number of reference cross sections can be established to perform topographical surveys.

- MQIm. 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. For this reason, the MQIm is more appropriate than the MQI to detect the changes in time of the effects brought about by a local change in morphology and sediment supply. It should be performed once every two-three years.

- Grain size distribution. The monitoring of the bed load in fordable conditions (Wolman count from Bunte and Abt, 2011) would complete the grain size distribution analysis performed in this study and provide information on which particle sizes are missing. Annual grain size monitoring will contribute to understand the effects of retention check dam removal and weir opening and to quantify the benefits brought from this measures. In addition, it should be carried out after flood events.

- MesoHABSIM. The application of the MesoHABSIM methodology lists and describes hydromorphological units suitable for fish along the Talvera Torrent. River restoration projects aim at enhancing the number and diversity of habitat, therefore the application of this method would define the state of the art (in 2019) and allow for future evaluations and comparisons on the quality of the river system. If possible, the MesoHABSIM application should be performed in the same period of the fish monitoring, so that the fish preferences for the different hydromorphological units can be effectively studied.

- Hydropeaking mitigation. Future monitoring should assess the effects of the S. Antonio buried reservoir on the hydropeaking. The reservoir aims at decreasing discharge fluctuations which have negative impacts on the aquatic system. In particular, a comparison of the macroinvertebrate populations upstream and downstream the outflow could assess the effects of a reduced hydropeaking.

- Fish monitoring. Since one of the most important measures carried out on the Talvera Torrent was the restoration of the longitudinal connectivity, the monitoring approach should assess the fish community structure in at least three points, see Figure (59). A better connection between Talvera and Isarco enhances the fish passability and promotes new communities to populate the Talvera. The relative assessment should be carried out as far as possible from the fish introductions operated by the Fishermen's Association.

Figure 59: *Future monitoring points for fish surveys*

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References

Abenis-Alpinexpert, GmbH/srl (2013). *Studie Fischlebensraum der Talfer bei Bozen für das Projekt: Studie des Geschiebehaushaltes zurVerbesserung des Fischlebensraumes am Fallbeispiel Talfer bei Bozen*.

Bunte, K. and S.R. Abt (2011). "Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring." In: URL: `https://books.google.it/books?id=I9WZ54gwYMEC`.

Elzinga, Caryl et al. (Jan. 2001). "Monitoring Plant and Animal Populations". In: *A handbook for field biologists*.

Festi, A. and V. Adami (2013). *Il torrente Talvera a Bolzano: effetti delle modificazioni morfologiche ed idrologiche sull'ittiofauna*.

IRSA/CNR, APAT (2003). *Metodi Analitici per le Acque. Manuali e linee guida 29/2003*.

ISPRA (2011). *Implementazione della Direttiva 2000/60/CE. Analisi e valutazione degli aspetti idromorfologici.*

— (2014). *Metodi biologici per le acque interne italiane. Manuali e Linee Guida, 111/2014.*

— (2016). *SUM - Sistema di rilevamento e classificazione delle Unità morfologiche dei corsi d'acqua. Manuali e Linee Guida 132/2016.*

— (2017). *Manuale tecnico-operativo per la modellazione e la valutazione dell'integrità dell'habitat fluviale. Manuali e Linee Guida 154/2017.*

— (2018). *Il campionamento delle acque interne finalizzato alla determinazione dei parametric chimici e misura in campo dei parametri chimico fisici di base per la Direttiva Quadro delle Acque. Manuali e Linee Guida 181/2018.*

Ogle, D. H. (2016). *Introductory fisheries analyses with R.* Chapman and Hall/CRC.

Parasiewicz, P. (2007). *The MesoHABSIM model revisited*. DOI: `10.1002/rra.1045`.

Parasiewicz, P. et al. (2013). *Applications of MesoHABSIM simulation model*. DOI: `10.1002/9781118526576.ch6`.

Patscheider-Partner (2015). *Monitoraggio dello stato morfologico, analisi dei deficit e proposta di misure di miglioramento della funzionalità fluviale di corsi d'acqua in Provincia di Bolzano*.

R-Development-Core-Team (2018). "R: A language and environment for statistical computing." In: URL: `http://www.R-project.org.`.

Roni, P. and T. Beechie (2013). *Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats*. John Wiley & Sons.

Underwood, A. J. (1997). *Experiments in ecology: their logical design and interpretation using analysis of variance.*

Valorzi, Christian (2012). *Ökomorphologische und zoozönotische Erfolgskontrolle der Renaturierung der Talfer in Bozen*.

Vezza, P. (2014). *Habitat Indices for Rivers: Quantifying the Impact of Hydro-Morphological Alterations on the Fish Community*. ISBN: 978-3-319-09053-5. DOI: 10.1007/978-3-319-09054-2_75.

WFD Annex V, Section 1.2 (2003). URL: https://circabc.europa.eu/sd/a/06480e87-27a6-41e6-b165-0581c2b046ad/Guidance.

www.basement.ethz.ch (2015). URL: http://www.basement.ethz.ch/download/tools/basegrain.html.

www.cen.eu (2003). URL: https://www.cen.eu/Pages/default.aspx.

www.isprambiente.gov.it (2015). URL: http://www.isprambiente.gov.it/it/pubblicazioni/manuali-e-linee-guida/idraim-sistema-di-valutazione-idromorfologica-analisi-e-monitoraggio-dei-corsi-dacqua.

Zancan, W. (2016). *OPTIMIERUNG WASSERKRAFTWERK "St.ANTON" | OTTIMIZZAZIONE IMPIANTO IDROELETTRICO "S.ANTONIO" - Progetto definitivo opere civili (edizione Maggio 2016 - rev04)*. GEOINGEGNERIA.