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: Avisio river - Italy

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1 Introduction

The Avisio Creek, is an Italian stream draining a basin of about 940 km2 in the central-eastern part of the Alps. The average altitude of the watershed is about 1’663 m a.s.l and the land use is primarily characterized by wild areas and grazing pastures. The main course of the Avisio Creek is about 90 km long and has an average slope of 2.02%, while its watershed feeds four hydroelectric power plants.
The Avisio Creek is as an emissary of Lake Fedaia (2054 m a.s.l.), which receives the melting waters of the Marmolada Glacier. The stream runs through the valleys of Fassa, Fiemme and Cembra, and flows into the Adige River downstream from the town of Lavis (196 m a.s.l.), a few kilometers north of the city of Trento.
Along the Fassa Valley, the stream receives its first tributary, the “Ruf de Contrin” in the village of Penia, and afterwards the waters from several creeks flowing from the Sella and Rosengarten groups. Downstream from the village of Soraga, the stream is regulated by the Pezzé Dam, which has a reservoir capacity of about 460’000 m3.
In the Fiemme Valley, several streams flow into the Avisio Creek, among which the Travignolo Creek is the main tributary. This stream originates from a glacier in the Paneveggio-Pale di S.Martino Regional Park and is dammed about 8 km upstream from the village of Predazzo, where it formed the Forte Buso lake (1450 m a.s.l.). The reservoir has a nominal volume of 32’000’000 m3 and feeds the hydroelectric power station of Caoria, which is located outside the Avisio watershed.
Moving further downstream, close to the village of Molina the main course of the Avisio Creek is regulated by the Stramentizzo dam. The reservoir has a capacity of 11’500’000 m3 and its water is conveyed to the hydroelectric power plant of San Floriano (Province of Bolzano) and then delivered directly to the Adige River upstream from the confluence with the Avisio Creek.
In its lower reach, the Avisio Creek flows through the characteristic porphyry gorges of the Cembra Valley, and finally on a wide (about 1 km wide) alluvial fan deposit before joining the Adige River. The area between the town of Lavis and the Avisio-Adige confluence is a large protected area known as biotope “Foci dell'Avisio”, which is characterized by high ecological and naturalistic value due to the presence of wetlands and natural and semi-natural environments.
From a geological point of view, the Avisio Creek gradually flows from the Dolomite region (characterized by limestone rocks), to the porphyritic Atesina platform (characterized by siliceous rocks), and finally to the Quaternary sedimentary formations of the Adige Valley. The different geological formations and flow regulation pressures existing in the upper and lower parts of the watershed significantly affect the hydrological regime of the Avisio Creek. In particular, the steep slopes combined with outcrops of impermeable rocks typical of the Cembra Valley make the hydrological regime distinctly torrential, with minimal flow rates of about 5 m3/s and flood events up to 1000 m3/s.

Two pilot sites have been identified along the main course of the Avisio Creek, the first in correspondence of the Pezzè reservoir (46°23'2.09"N - 11°39'50.62"E - Fassa Valley) and the second in correspondence of the Stramentizzo reservoir (46°15'50.27"N - 11°22'24.81"E - Fiemme Valley). Both study reaches extend from upstream to downstream of the reservoirs.
From a hydromorphological point of view, the presence of the two dams and of the corresponding upstream reservoirs introduce an interruption on sediment transport. Currently, the management strategy of the two reservoirs does not include any efficient method to ensure sediments continuity from the reach upstream to the reach downstream from the dam. In particular, in the case of the Stramentizzo reservoir all sediment supply from upstream is stored in the reservoir, and sediment flushing operation are typically not performed. Hence, transit of sediment occurs only during flood events with obvious environmental consequences.

The Stramentizzo dam was build between 1954 and 1955, with a reservoir capacity of 11’500’000 m3 (of which 10’000’000 m3 are used for regulation). The reservoir storage is used for hydroelectric power generation by the San Floriano power house located in the Adige Valley (Egna – Province of Bolzano). The average flow rate used for hydroelectric power generation is 13 m3/s, and can increase up to 30 m3/s. Recent studies reported the accumulation of 3,5 million m3 of sediments in the Stramentizzo reservoir, indicating a significant reduction of its regulation capacity and potential technical and water quality issues associated with dam bottom releases.
The Pezzé dam was build in 1952, with a reservoir total capacity of 460’000 m3 (of which 360’000 m3 available for regulation). The reservoir storage is used for hydroelectric power generation by a power station located near the Predazzo village where the diverted water is returned to the Avisio Creek, about 10 km downstream from the reservoir. In terms of flow rate, the hydropower plant utilizes up to 7,7 m3/s. Part of this water (around 1m3/s) comes from the San Pellegrino Creek. From which it is diverted through a 1,2 km long pipe. The reservoir management is currently in charge of the company “Hydro Dolomiti Energia” and includes periodic sediment flushing aimed at ensuring reservoir efficiency.

The main objective of the project with respect to these two pilot sites is to identify and propose efficient strategies to be implemented in the current reservoir management policies in order to preserve and improve existing ES provided by the Avisio Creek. Possible improvements include more efficient and sustainable sediment flushing procedures and the possibility of artificial sediment reintroduction downstream from the Stramentizzo dam.

The monitoring activities and the contents of this report have been produced in collaboration with the University of Trento, participated in the project: G. Zolezzi, W. Bertoldi, L. Fraccarollo, F. Bergamin, E. Fedel, J. Biscola, A. Mittenpergher, T. R. Soto Parra, M. Carolli (IGB Berlin), M. Righetti, G. Stradiotti, G. Pisaturo (Free University of Bozen-Bolzano).

2 Monitoring approach

Due to low availability of topographic data of the state before dams construction, according to the comprehensive classification of restoration monitoring designs presented in Roni et al (2013), the physical and ecological monitoring designs corresponds to a IPT (Intensive Post-Treatment) design.
The physical monitoring of the two reaches of the Avisio chosen as case studies has been carried out using different techniques and approaches, coherently with the different objectives of the river management projects planned at the two sites. Before, also a catchment scale analysis was performed thought numerical approach.

2.1 Physical monitoring

2.1.1 Catchment level

Sediment connectivity modelling at the catchment scale has been performed The MatLab toolbox CASCADE (Schmitt et al. 2016, 2018a,b; Tangi et al. 2019) was used. The river network was extracted from a 4x4 DTM and then the sediment transport was simulated.
Some parameters, required for the network extraction, were set:
• the minimum value of drainage area in order to consider a DTM cell as a river network cell, A_{min} in km^2; this parameter also controls the river network complexity. A_{min}=3 km^2
• the minimum reach slope; in this case the default value (0.0001)
• the way of reach partition; the automatic partition at confluences, defining four breakpoints in correspondence with the dams.
The output of the River Network Extraction are a shapefile (which can be displayed and modified in a GIS software) and a MatLab struct (**ReachData**) which includes the reach features: length (m), slope s (m:m), active width w_{ac} (m), discharge Q (m^3/s), Manning roughness coefficient n ($s/m^{1/3}$), granulometry (d16, d50 and d84 in m) and drainage area A_d (km^2). Length, slope and drainage area are computed bythe model, the others have to be set by the user; so the next step was to compute the parameters to complete the **ReachData**.
About the granulometry, a d50=0.15 m was set for reaches which had a Strahler Order 1 and 2, d50=0.10 m for the reaches which had a Strahler Order 3 and d50=0.05 m for the main river channel (Strahler Order 4). From some studies consulted at the Provincia Autonoma di Trento offices, a relation between diameters were computed (d16=1.02d50-1.77 (R^2 = 0.80) and _d84=0.94d50+1.80 (R^2 = 0.84)). Then d16 and d84 were calculated from d50. The Manning coefficient was computed as $n = d50^{1/6}/21.1$.
The active width of some reaches was measured from the 2015 ortho image; many measures were made and then an average active width was obtained. For some reaches (the ones covered by shadow or vegetation) the active width was computed using an interpolating relation as $w_{ac}=4.6\ A_d^{0.165}\ s^{-0.108}$ (R^2 = 0.5).
To simulate the effects of dams and barries is required a struct called **damdata** which includes the ID of the node where the dam is placed and the trapping coefficient C (0,…,1)for each sediment class (boulders/cobbles, gravel, sand and silt). For dams this coefficient is 1 for all sediment classes.
For the first run, the 2-year RI discharge was used (good to simulate solid transport innon-extreme conditions). To compute this value, were used discharge values recorded by three hydrometers (Soraga, Masi

di Cavalese and Lavis, figure 1). These data are related to the period 01/06/1994 - 30/06/2019 and consist in semi-hourly values that were aggregated to compute the maximum daily discharge.
For every recorded series a threshold discharge was set and about 50_60 peaks were chosen. Then, for different discharges, was computed the probability of exceeding p=n/25 (n is the number of times when the discharge was exceeded in 25 years) and the recurrence interval RI=1/p. Finally, the discharge related to RI=2 years was selected (table 1). Finally, to set a discharge value for the other reaches, Q2 at the hydrometers was interpolated with the drainage area considering the catchment divided into two areas: upstream the Stramentizzo dam, for which the values at Soraga and Masi di Cavalese were used, and downstream the dam, for which were used Q=0m^3/s flowing out from the dam and the value recorded at Lavis.

Tab. 1: value of 2-year RI discharge at the hydrometers.

Hydrometer	**Q2 [m3/s]**
Soraga	30
Masi di Cavalese	104
Lavis	150

2.1.2 Pezzé di Moena

The monitoring program was focused on the evaluation of turbidity and sediment dynamics downstream of the reservoir, in order to provide a framework for defining reasonable turbidity thresholds during the flushing operations of the reservoir.
The monitoring program involved operations carried out before, during, and after the flushing:

- (before the flushing) 1 bathymetry survey of the Pezzè Reservoir;
- (before/after the flushing) granulometric sampling along the study reach downstream of the dam to look for changes in the sediment size distribution after the flushing and to assess the most susceptible areas to sediment clogging phenomena, depending on their morphological characteristics;
- (before/during the flushing) continuous turbidity monitoring upstream and downstream from the dam, to evaluate the effects of the reservoir in altering water turbidity and to compare turbidity values and dynamics during sediment flushing operations and natural floods. The monitoring involved one fixed monitoring station also equipped with pH, conductivity, temperature and oxygen sensors and five turbidimeters and multi-parameter gauges installed in the river reach between Pezzè Reservoir and Stramentizzo Reservoir;
- (during the flushing) periodic multi-purpose water sampling in correspondence of the installed turbidimeters, in order to calibrate the turbidimeters and to perform physical-chemical analyses of the sediment released from the reservoir;
- (during the flushing) painting of gravel plots along the reach downstream of the dam to investigate the mobilization of the surface layer and the bedload initiation. A number of sites were selected as being representative of the different morphological units found the reach of study (i.e. high and low bars,

secondary channels), and for presenting homogeneity. A series of 1m x 1m area gravel plots were painted using fast drying spray paint on top and sides of the bars and side banks before the flush;

- (during the flushing) time lapse of the event via fixed camera traps selected locations;
- (before/during/after the flushing) streamflow measurements (via fixed hydrometers and Surface Velocity Radar to obtain and improve flow-stage rating curves.

Fig. 1: Map with the location of the monitoring sites before, during and after the flushing of the Pezzé Reservoir.

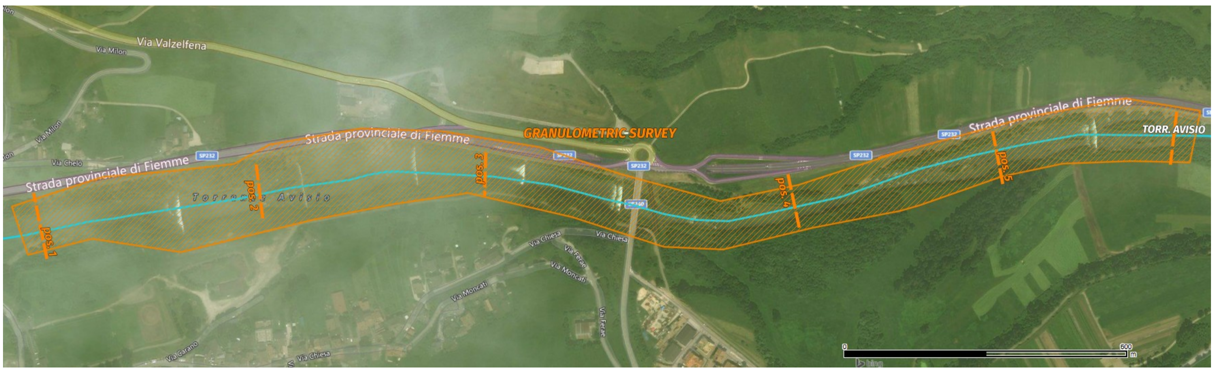

Fig. 2: Close-up of the map in Fig. 1, with the location of the sediment sampling sites.

Fig.3. Sampling of sediments in the same site before (left) and after (right) the flushing.

Fig. 4. Water quality monitoring station installed downstream of the Pezzè Reservoir (February 2018).

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Fig.5. Painted gravel plot to investigate bedload initiation.

2.1.3 Stramentizzo

Concerning the reach downstream from the Stramentizzo reservoir, the monitoring program was aimed at estimating the sediment transport capacity of the river downstream from the dam, hence providing the necessary information for designing optimal sediment reintroduction operations in terms of reintroduction sites, sediment sizing, and sediment volumes. The monitoring program included the following activities:

- cross section topographic survey along a 3.5 km long reach, to produce a detailed topographic map of the study area by combining newly acquired GPS and Total Station data with the existing lidar-derived DTM;
- grain size analysis at several sites along the study reach, to determine sediment size distribution;
- post-event survey of sediment composition, maximum water levels, and morphological changes after the severe flood occurred on October 2018, in order to determine the effect of extreme events on the morphological and sediment dynamics of the study.

Sediment grain size analysis

The classical “Wolman count” method (Wolman, 1954) has been used to determine the bed grain size distribution. The field surveys have been made in 2018 made before and after the October 2018 floods, in the following dates: October 4th, 23rd (before the flood), October 28th - 31st (during the flood) and November 16th, 23rd, 27th (after the flood).

The analysed reach is roughly 20 km long, from the alluvial fan of rio Cadino, just upstream the Stramentizzo artificial reservoir, down to the 1km reach located downstream the provincial road (SP101) bridge “ponte dell’Amicizia” nearby Segonzano. The choice of the sampling sites has mainly been dictated by their relevance for the goals of the analysis, particularly for the feasibility study of the gravel augmentation project but it has also been constrained by the poor accessibility of the river channel downstream of the Stramentizzo reservoir.

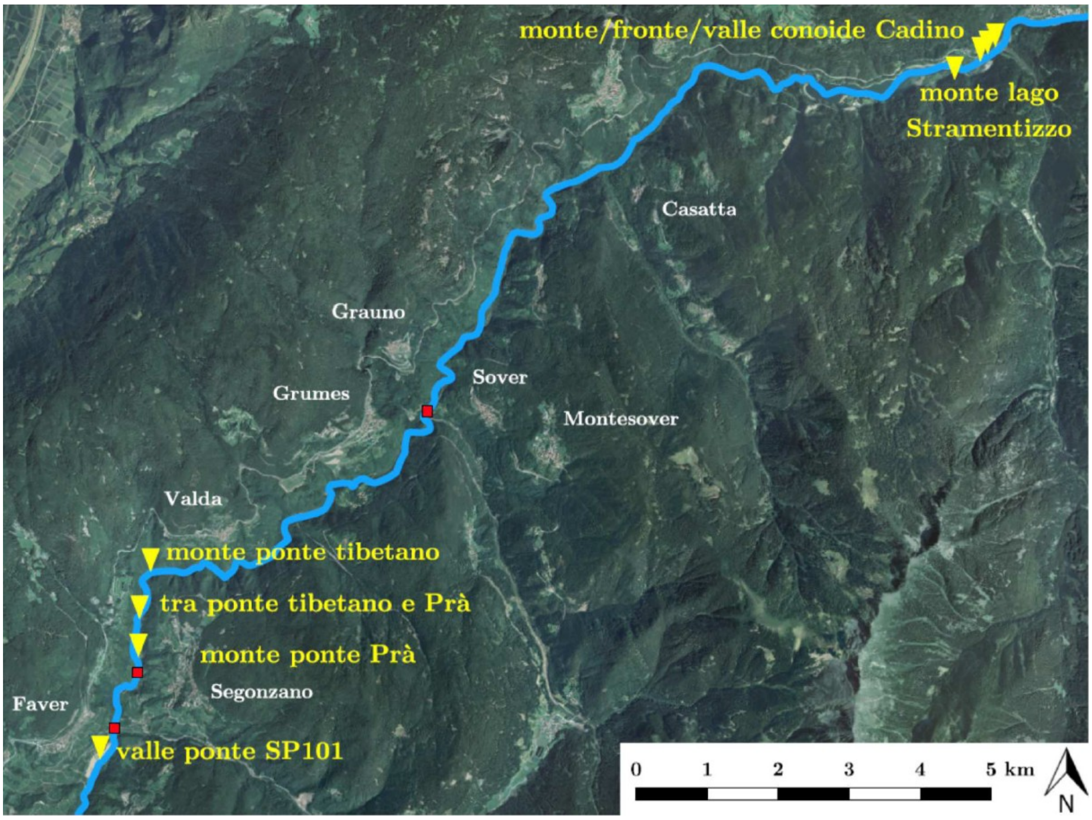

Fig.6.*Location of the sampling sites used for the grain size analysis (yellow symbols). Red symbols denote bridges, from upstream to downstream: pont de la Rio, ponte di Cantilaga (Prà), ponte dell'Amicizia (SP101).*

Analysis of the ecological and morphological effects of sediment continuity interruption

The analysis has been carried out by comparing the outcomes of a manual classification of aerial images of the 31-km investigated reach, between the Stramentizzo reservoir and the bridge connecting the settlements of San Lazzaro with Lavis Aerial images have been acquired in the following dates: 1954 ("Volo GAI", the first photographic aerial survey of the entire Italy, which needed to be georeferenced); 1973 (resolution 1 m, b/w); 2000 (1 m, RGB); 2006, 2008, 2011, 2014 (0.5 m, RGB), all ortophotos surveyed by the Trento Province.

Several images were needed in each date to cover the study area, where seven morphologically homogeneous sub-reaches have been identified, to obtain separate evolutionary trajectories for each of them. Three land cover classes have been detected in every sub-reach: wet channels, bare sediments, and vegetated surfaces (bars and islands). Wet channels and bare sediment surfaces in each image jointly define the "active riverbed", a quantity that can be compared between images of the same sub-reach taken in different dates, because it is not significantly affected by differences in flow conditions among different dates that could not be assessed because of the lack of relevant flow data. One reference active river corridor has been defined as the envelope of all active riverbed surfaces extracted from all images.

The multi-temporal comparison yielding the evolutionary trajectories refers to the percentage area occupied by each land cover class with reference to such active “ensemble” corridor. An error analysis has finally been undertaken to quantify the uncertainty of the classification procedure. The manual classification has therefore been repeated 8 times at 3 weeks intervals on a selected representative subreach, where the images were not affected by shadowing effects. Apart from the 1954 image, where the percentage of vegetated area can be estimated with a 10% error, the error for the same quantity in the most recent images is almost negligible (2%).

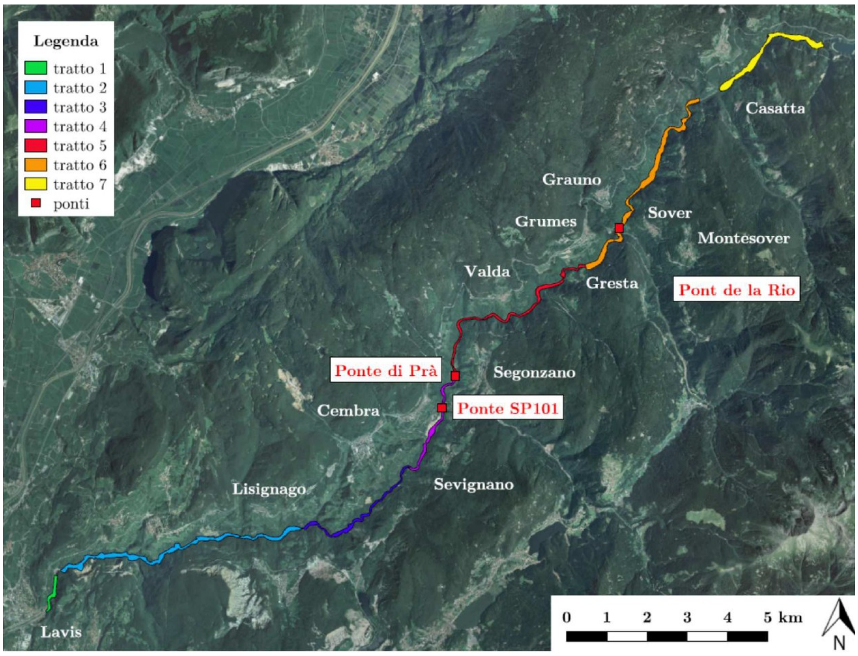

Fig.7. Location of the seven chosen reaches for the analysis of the long-term morphological evolution

2.2 Ecological monitoring

The ecological monitoring program essentially focused on the upper reach, in correspondence of the Pezzè reservoir. The monitoring activity consisted in periodic surveys of hyporheic and fish fauna and relative habitats downstream from the reservoir, before and after the sediment flushing operations. The aim was to assess the ecological response of the aquatic fauna to the reservoir management operations.

The community of running water macroinvertebrates, intimately tied with the substrate, is made up of numerous populations with different levels of sensitivity towards environmental modification, with different ecological roles and with relatively long life cycles.

Macroinvertebrates include numerous taxa with different pollution tolerance, can be easily sampled, identified, classified and are stable and representative of a given tract of a water course: they are useful to formulate a diagnosis of the quality of running waters brought on by pollution or significant alterations in the physical fluvial environment.

The Intercalibration Multimetric STAR Index (ICM-Star, IRSA-CNR 2007) is particularly suited to evaluate the effects of environmental stress factors over a relatively long period of time.
It is able to reveal the quality of a tract of running water integrating over time the effects of various disturbance factors (physical, chemical, biological). Conceptually the method is based on a comparison between an expected community and an observed community in the river tract being examined.
Because of its characteristics this index has shown itself to be very useful as a preliminary diagnostic tool for entire hydrographic networks, for subsequent monitoring of the same networks, for estimating diffuse and point source pollution impact, for evaluating physical changes in riverbeds, for fishery management plans, etc.
Macroinvertebrates community was sampled in 4 separate investigations in Avisio river at Moena and Tesero collected between march and November 2019 in to detect effects of flushing on river ecosystem.
Macroinvertebrates community was collected by kicking up riffle substrateswith subsequent entrapment of debris and organisms in a net held downstream from the investigator. Samples were initially transferred in a mason jar and preserved with 90 percent ethylic alcohol.
In the laboratory, macroinvertebrates were hand sorted from gravel and sand in a shallow white pan. All of them were identified to the family or genus level, in accordance with work protocol for ICM-Star Index.

Fig.8. Ecological monitoring in Avisio river

3 Physical effects

3.1.1 Catchment level

The model simulates the sediment transport as a series of independent cascades from the sources (network nodes) to the downstream reaches; a sediment cascade is interrupted as soon as the entire input is deposited. The sediment supply for each cascade was set equal to the transport capacity for all the reaches upstream the Stramentizzo dam and only for the sources reaches (upstream reaches with Strahler Order 1) downstream the dam; for the other reaches was set a transport limitation to avoid the riverbed erosion (by default the model gives as input to the new cascades a solid discharge equal to the amount eroded from the riverbed).
Sediment deposition depends on the reach transport capacity which is computed using different equations (among which is possible to choose). For this analysis the Wilcock-Crowe equation was used, because it is the only one which calculates the transport capacity for each sediment class. As expected, dams represent discontinuity in sediment transport in fact the sediment deposition is high in reaches upstream the dams. In particular, the total solid discharge deposited upstream Stramentizzo is about 653 kg/s (Fig. 9). In the main channel reaches, sediment transport is in general high, in particular away from dams (Fig. 10).

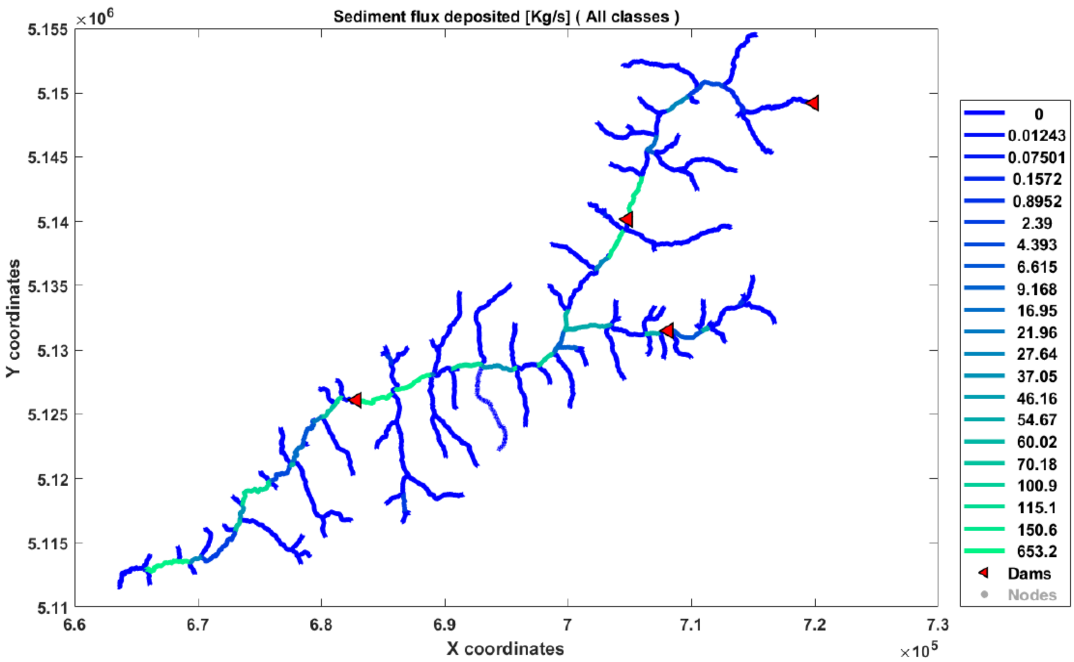

Fig. 9: Total solid discharge deposited in the network reaches; the analysis was carried out using 2-year RI liquid discharge.

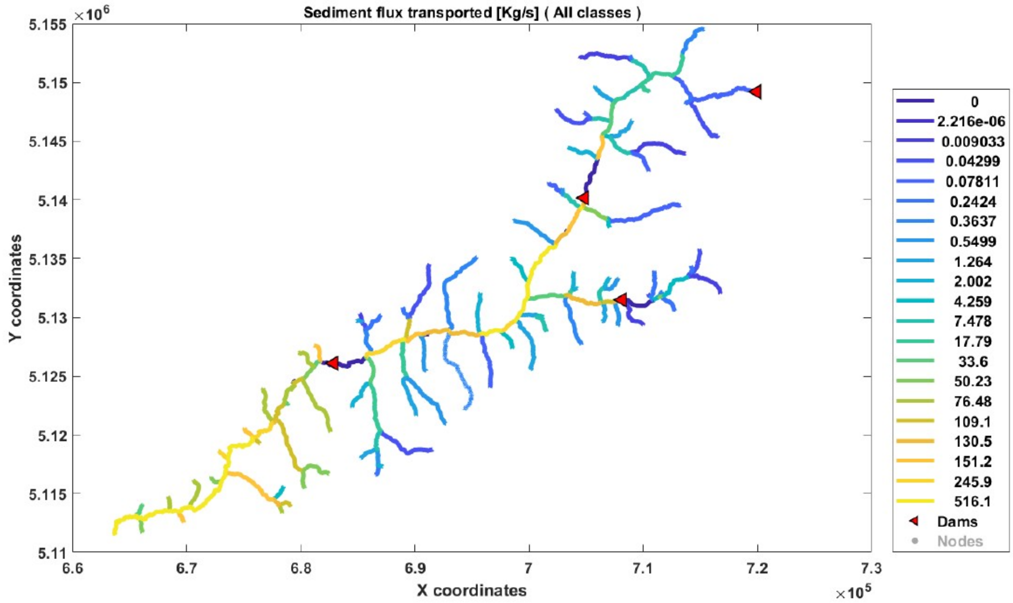

Fig. 10: Total solid discharge transported in the network reaches; the analysis was carried out using 2-year RI liquid discharge.

Simulation of sediment augmentation downstream Stramentizzo dam

This analysis was carried out simulating the reintroduction of the 10% of the solid deposition upstream the Stramentizzo dam (Qs=65 kg/s) downstream the dam, in two different reaches (reach 34 and reach 42, Fig. 14). The sediment were introduced through the struct **extdata**, first in reach 34 and then in reach 42; the solid flux had the same granulometry of the reach upstream the dam (d16=0.014 m, d50=0.005 m and d84=0.209 m). Q2, Q5 and Q10 discharge were used.

If sediment reintroduction occurs in reach 34, using the Q2 discharge about half of sediment are deposited in the reach (33 kg/s); the cascade ends in reach 48 (the outlet of the catchment) but only 5.5 kg/s are transported, the other solid discharge is deposited trough the network between reach 34 and 48. Using Q5 about 26 kg/s are deposited in the reach and the cascade ends in reach 48 where 5.3 kg/s are transported. Using Q10,about 25 kg/s are deposited in the reach and the cascade ends in reach 48 where 5.1 kg/s are transported. If sediment reintroduction occurs in reach 42, using the Q2 discharge 20 kg/s are deposited in the reach; the cascade ends in reach 48 (the outlet of the catchment) and 14.6 kg/s are transported in this reach. Using Q5 about 19.0 kg/s are deposited in the reach and the cascade ends in reach 48 where 15.0 kg/s are transported. The same result is obtained using Q10.

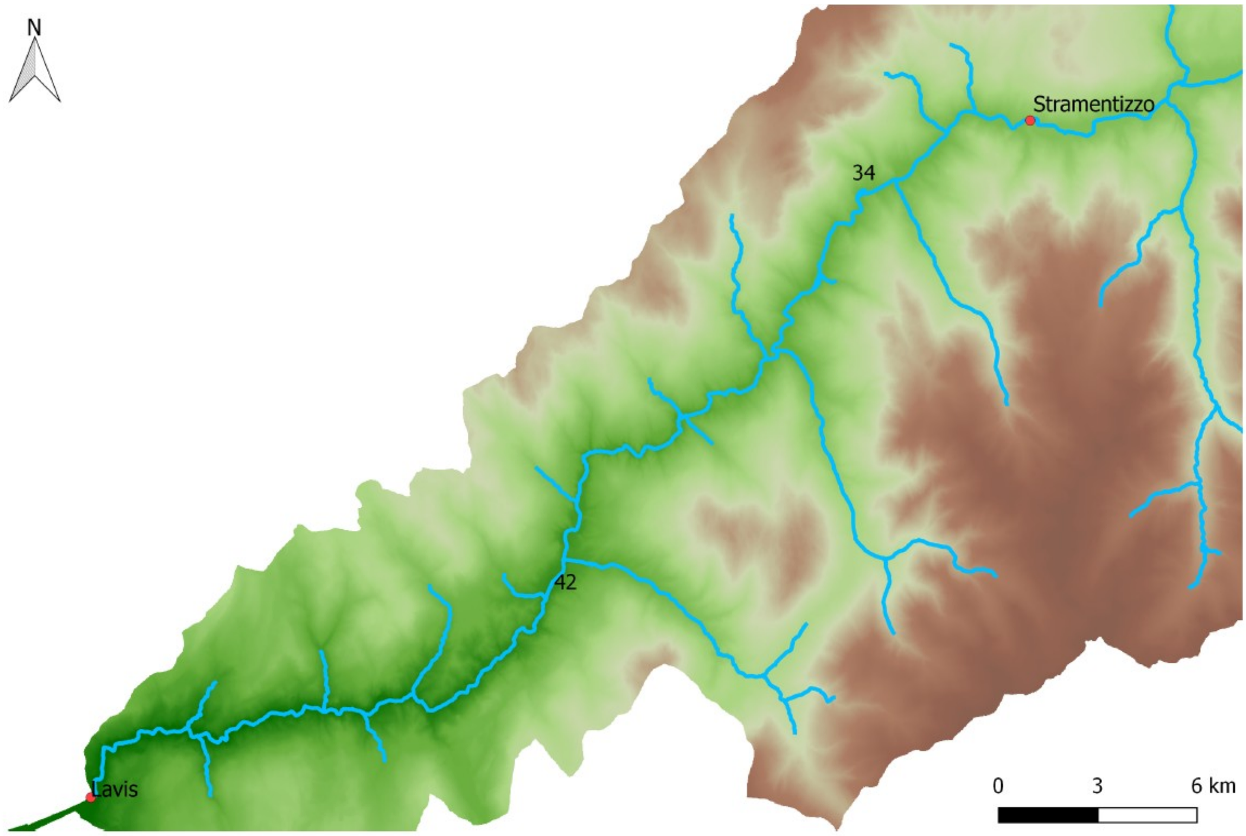

Fig. 11: Location of the reaches where occurs the sediment reintroduction.

3.1.2 Pezzé di Moena

Monitoring of Pezzé reservoir flushing

Here we synthesize the preliminary results of the physico-chemical monitoring, mainly in terms of correlation between turbidity and occurrence of floods and flushing operations, with focus on the observed sediment dynamics.

The flushing operation has shown two markedly distinct phases (Fig. 15), before and after an interruption occurred for the need to display clear water in the river for mainly aesthetic reasons when the famous cycling competition “Giro d’Italia” was passing in the study area. Before the break, snowmelt was unusually limited compared to the season average and the suspended sediments were almost all related to flushing operations. After the break, part of the sediment load at the Masi di Cavalaese gauging station was also attributable to the sudden snowmelt that started because of suddenly rising air temperatures and contemporary thick snowpack in at the highest catchments elevations. In this second part of the operations, separation of the contribution of the natural snowmelt flow pulse from the artificial sediment pulse caused by the flushing is still under investigation.

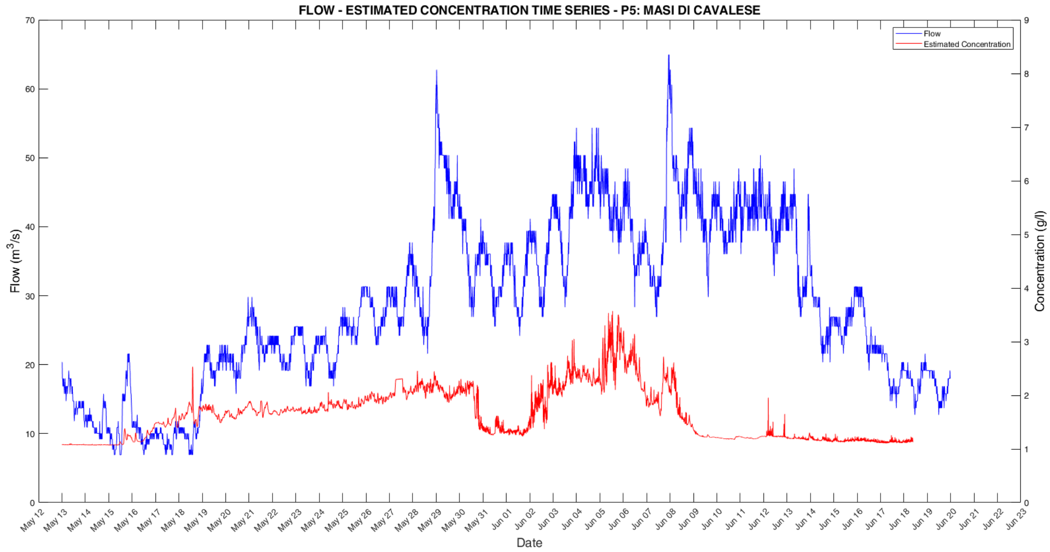

Fig. 12: Concentration and streamflow recorded at Masi di Cavalese gauging station.

In the various location where surface sediment size was sampled before the flushing, a clear fining trend was clearly observed (Fig. 16).

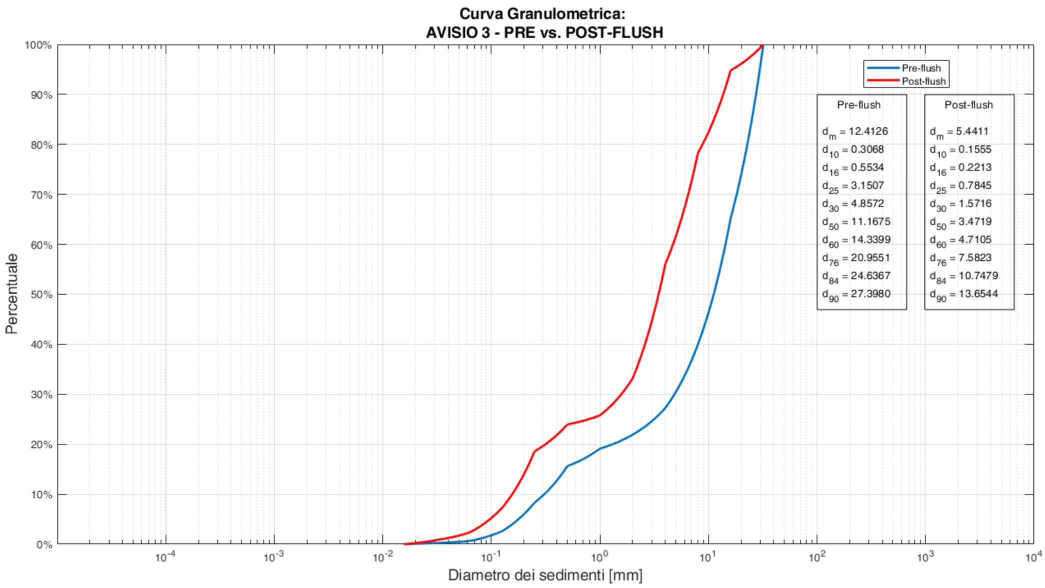

Fig. 13: Comparison of grain size distributions in the study area before and after the flushing.

All painted areas were observed after the flush. Sediment transport was evidenced by presence of heavy scattering of painted sediments in most of the plots, in fact, some particles were found up to 40 m downstream from their respective source points. On the other hand, some plots remained unaffected by the flow or presented only deposition of sand above the colored area, these were mostly located on top of high bars or deep into the side banks, where water could barely reach during the flush.

Fig. 14: Painted gravel plots after the flush.

3.1.3 Stramentizzo

Sediment grain size analysis

The first important outcome is the striking upstream – downstream difference in sediment size, which is much coarser downstream. Upstream d50 ranges between 41 and 55 mm, while d90 ranges between 98 e 162 mm. Instead, downstream d50 ranges between 105 and 230 mm and d90 between 349 e 635 mm. Roughly speaking, average sediment size downstream the Stramentizzo Reservoir is about three times larger than upstream. Besides the average size, a key difference is that the size class 1–10 cm is nearly missing in the downstream samples, while being present in the upstream sites. Apart from the size difference, a clear shape difference can be observed between the upstream and downstream sediment size distributions (Fig. 11). Furthermore, a moderate, progressive average sediment fining can be detected with increasing downstream distance from the dam.

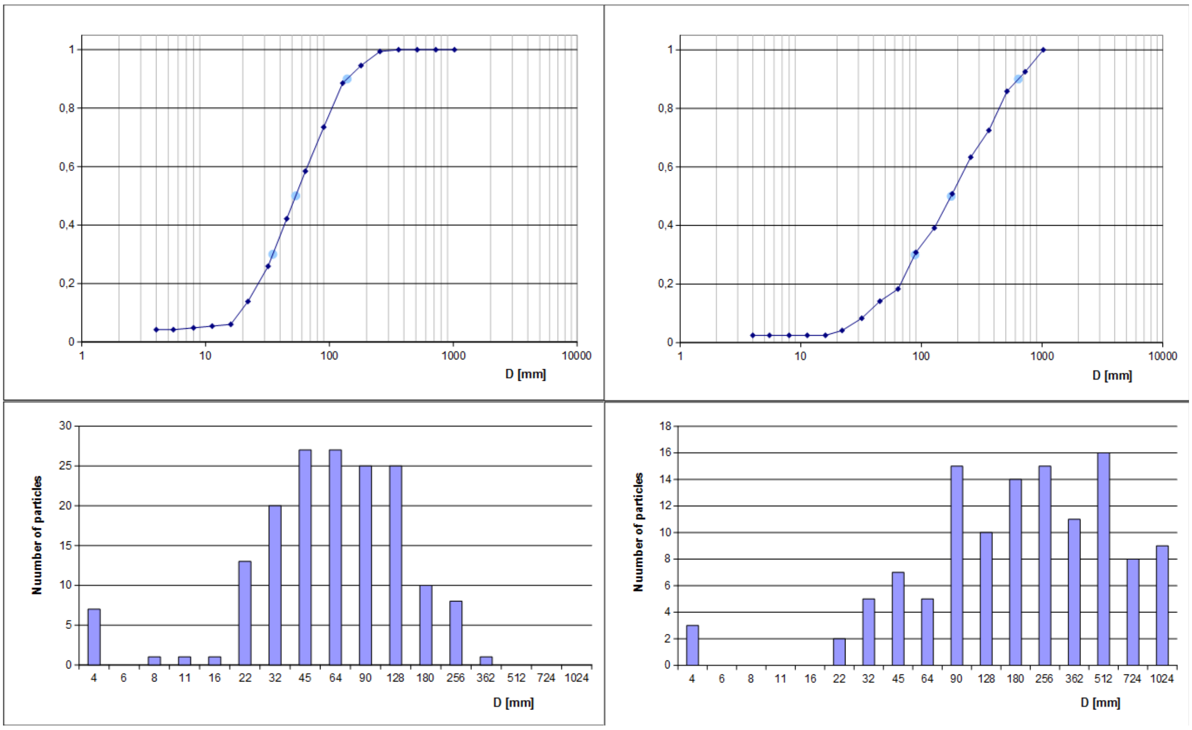

Fig. 15: Example of granulometric curve upstream (left) and downstream (right) Stramentizzo.

The observed downstream reduction of the finer fraction of the coarse bed sediment (1-10 cm) can be associated with the trapping role of the dam, which inhibits the supply of these fractions in the downstream reach. Such fractions are, in turn, the ones that can be transported by the rare small flood and flow pulses that can still occur in the downstream reaches following the heavy flow regime regulation caused by the dam operations. This progressively leads to bed armouring, increased riverbed stability and reduced morphological dynamics.

The progressive sediment fining observed with increasing downstream distance from the dam can be explained by the presence of the relatively small unregulated lateral tributaries, which can still provide supply of finer sediments during their natural floods. The related amount of transport is however limited and cannot compensate the observed sediment deficit caused by the dam.

Analysis of the ecological and morphological effects of sediment continuity interruption

The image analysis highlighted relevant changes of river morphology and related ecological patterns (riparian vegetation) in the last 60 years. Following results shows the trend of the active channel width, computed as the sum of the classes water and gravel, averaged on the whole study reach. Channel width reveals a maximum of 55 m on the aerial image of 1973, just a few years after the major flood of November 1966. After that, the width decreased constantly, reaching 30 m in 2000 and then reducing almost by half in only 6 years. After 2006 the width kept roughly constant around 15 m, that can be considered as a minimum value.

A second relevant parameter is the proportion of the fluvial corridor occupied by riparian vegetation. It shows an opposite behavior, with a minimum value in 1973 (ranging from 20% to 40%, for the different sub reaches), followed by a generalized increasing trend, up to values of 70-90% after 2006. Upstream reaches, closer to the Stramentizzo dam, show higher vegetation proportion and a faster increase after the 1966 flood.

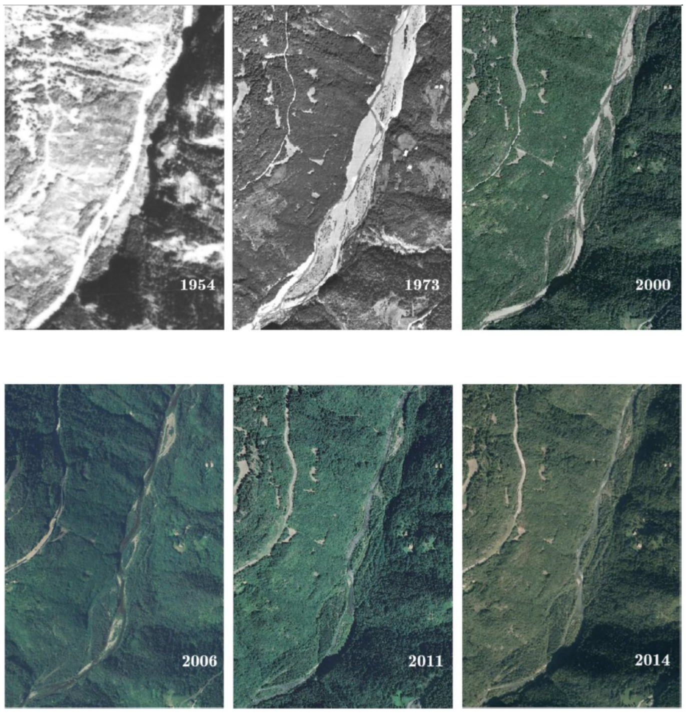

Fig. 16: Illustrative historical evolution of the Avisio river reach nearby the village of Piscine, showing progressive reduction of the morphologically active riverbed and progressive riparian vegetation establishment in the river corridor.

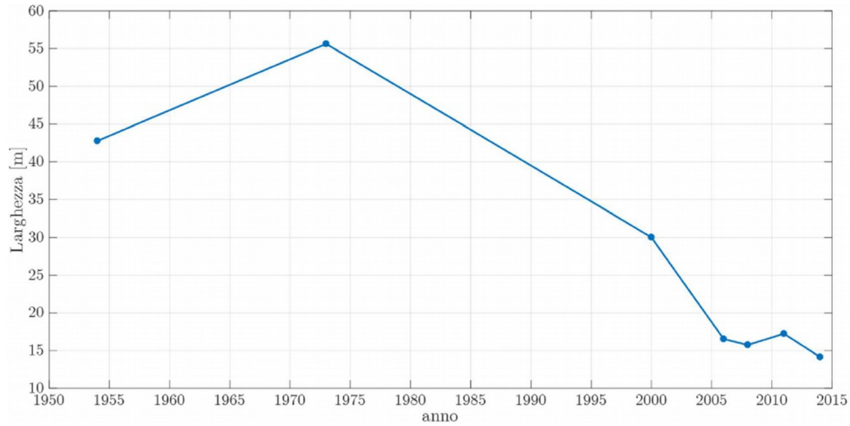

Fig. 17: Temporal evolution of the average channel width of the Avisio from Stramentizzo dam to Lavis.

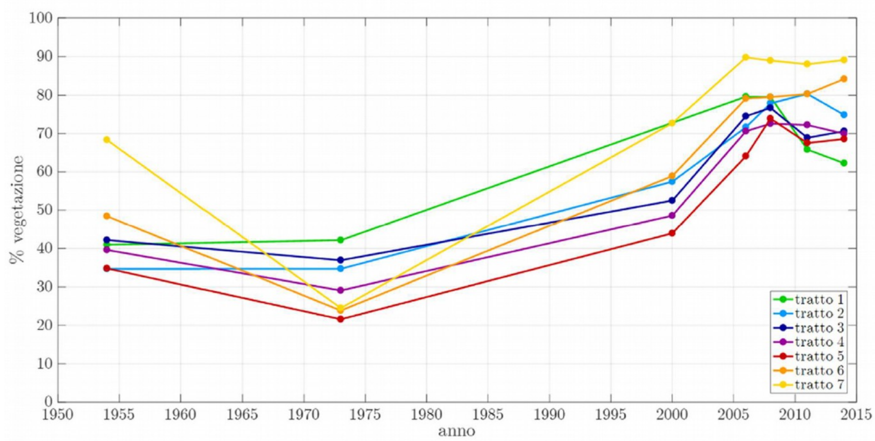

Fig. 18: Temporal evolution of the proportion of vegetated area, for the 7 sub-reaches of the Avisio from Stramentizzo dam (reach 7) to Lavis (reach 1).

The observed trend can be interpreted considering the twofold effect of the dam (regulation of the flow and complete interruption of the sediment continuity), as modulated by the hydrological regime. The dam operations significantly reduced the frequency and magnitude of floods with a return interval in the range 2-10 years, which are considered the most effective to shape the river form. In addition, the sediment deficit caused bed armouring and drastically reduced the riverbed dynamics. The combination of these two effects promoted vegetation establishment and growth. On the last available image in 2014 there were very limited areas of bare gravel, as most of the river corridor was covered by vegetation. The long term trend is modified by particularly strong hydrological events, such as: 1) the 1966 flood, which removed up to 50% of the vegetation; 2) the long dry period from 2002 to 2009, which accelerated the vegetation establishment. The morphological trend of the last 20 years is probably affected also by the release of the minimum flow from the Stramentizzo dam. It has been observed also in other cases that a constant low flow induces vegetation encroachment.

4 Ecological effects

Macroinvertebrate data collection and processing is still in progress. Tab. 3 shows Star-ICM values, which have a range from 0 to 1, where 0 means bad quality and 1 means high quality.

Tab. 3: ICM-Star index values in the two stations.

	08/05/2019	19/06/2019	30/07/2019	11/11/2019
62SD0641 AVISIO - Moena	0.782	0.656	0.840	in progress
62SD0632 AVISIO - Tesero	0.818	0.837	in progress	in progress

From what it has being done until now, we can see that at the Moena station (nearest to Pezzè basin) the ICM-Star Index shows a decline in the sample made two weeks after the flushing period (ecological quality passes from good to moderate), but it recovered in the sample made two months after the flushing period, returning to good quality.
At the Tesero station, about 20 km downstream the Pezzè reservoir, the effect of flushing did not modify ICM-Star Index in the sample made two weeks after its ending: ecological quality remained in a good status. More detailed elaborations will be made on macrobenthos community structure, to evaluate effects of flushing on distribution of functional groups.

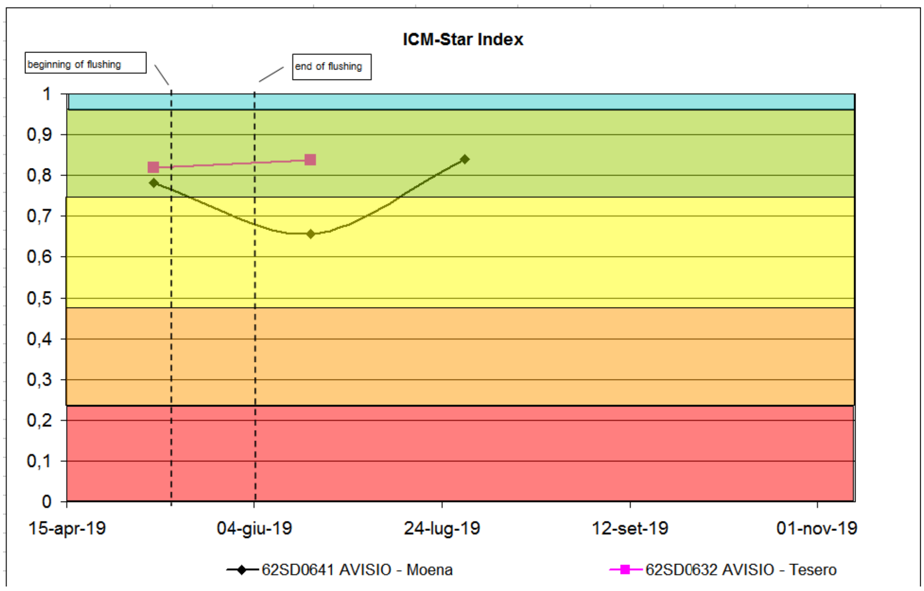

Fig. 19: ICM-Star trend in the different periods of sampling. The colours represent ecological quality of the sample: red means bad, orange scarce, yellow moderate, green good and blue high.

5 Conclusions and perspectives

The main morphological effects of the 2019 flushing event of the Pezzé reservoir on a target subreach nearby Masi di Cavalese have been fining of the surface sediment layer and the transport of the gravel fraction as bedload at some locations. Monitoring results of sediment flushing have to be considered preliminary and further investigation are required for a detail quantification of the sediment dynamics.

About Stramentizzo dam, the interruption of the sediment continuity determines the presence of much coarser sediments downstream (Cembra reach) compared to upstream, as well as much more irregular shapes of the frequency distributions, which are bell-shaped upstream and irregular, with multiple peaks downstream.

The main missing sediment size fraction in the downstream reach is the class 1 – 10 cm, which slightly reappears downstream thanks to the contribution of the small, unregulated natural tributaries. This however cannot compensate the sediment deficit which has important, adverse ecological implications especially for fish (marble trout) spawning habitat.

For such reason, sediment replenishment in the Avisio can only affect the entire reach if smaller size sediment are reintroduced. This creates an opportunity to plan the introduction of sediment size in the gravel range that can also contribute to mitigate the observed armouring process and to increase the spawing habitat for the marble trout, which has been reported to markedly decrease in the last decades. Prediction of the morphological and related ecological evolution of the affected reach under these conditions cannot be achieved by means of state-of-art hydro-morphodynamic models, because of the presence in the riverbed of present large sediments that will be immobile under ordinary floods and of reintroduced smaller gravel that is only partially mobile during the same floods, because of the wake created by the largest, immobile cobbles and boulders, requiring a novel theory of sediment transport able to account for such drag partitioning between the two different classes.

Guidelines on location, tentative volumes and deployment methods have been proposed to develop a possible test of gravel augmentation in the Avisio river downstream the Stramentizzo dam in the near future. To achieve minimum ecological and morphological targets, volumes of replenished sediments shall be much higher than initially foreseen and comparable to estimated mean annual transportable volumes

Since 1973 the Avisio river downstream of the Stramentizzo reservoir reduced its width by almost 4 times from an average of 55 m down to about 15 m. This is reflected by an increase of the proportion of vegetation in the river corridor, which is now up to 70-90% (it was 20-40% in 1973). Flow reduction and interruption of the sediment continuity are the main causes of these changes, due to the reduced bed mobility and the consequently good conditions for vegetation encroachment.

Though no specific habitat-oriented analysis has been undertaken in the present project, it is very likely that both armouring (key point 2) and channel adjustments with extensive riparian vegetation encroachment on the formerly active channel (key point 3) have caused major changes in the spatial and temporal availability of river habitat, and likely reduced to availability of suitable spawning sites for the local trout species (remarkably marble trout).

6 References

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