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ENVIRONMENTAL IMPACT OF RESERVOIR DESILTING OPERATION

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The reservoir Cancano (Italian Alps) had problems of silting; the deposit amounted to about 0.2 million m^3 and had completely occluded the bottom outlet of the dam, beginning to threaten the intake of hydroelectric power plant. This deposit has been partially removed by controlled flushing operations lasting 40-50 days each. Particular attention has been paid to the regulation of the amount of sediment discharged according to the limits of concentration of suspended solids (SSC) fixed in the river downstream of the dam in order to reduce the environmental impact of operations.

Keywords: Flushing, reservoir silting, suspended solids, macroinvertebrate, fish

1. Introduction

The need to manage the resevoirs in order to preserve the capacity in the medium-long term (ie, well beyond the life of the work specified when planning) has emerged since the 90s [1,2]. To date, however, despite the increasing exploitation of water resources and the increasing demand for renewable energy sources, in particular from waste biomass [3,4,5,6,7] and virgins [8,9,10], it is not yet clear what is the best strategy to cope with this need.

In fact, the solutions implemented to face the silting of reservoirs can also significantly impacting the affected aquatic ecosystems [11,12]. Among them, the flushing done in condition of empty reservoir, may be an effective alternative

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technique [1]. Among the major practical problems that arise in implementing such an intervention [13,14] should consider the need to:

- set limits to the duration of the operations and concentration of suspended solids (SSC) and manage the operations in compliance with those limits;
- assess the effects on aquatic ecosystems.

In particular, these effects should be such as not to impair the ecological quality of water bodies concerned in accordance with the latest environmental laws.

In this paper for the Cancano reservoir (Valtellina, Northern Italy), limit values of average SSC were set by referring to the results of previous flushing activities carried out in the same environment contest (Central Eastern Alps) [13,14]. The operations have had a relatively long duration (40-50 days) as were made between late winter and early spring (i.e. at the end of the low-flow period) and not as usual for this type of activity [15] towards the end of the period of soft (which in the study area is between August and October). The choice of the period was influenced by the low capacity of the discharge and the need for management of the site in a safe condition.

The management of operations within the constraints of SSC was made by considering the activity of earth-moving machines and diluting the flow exiting along the downstream reach based on the raw values of SSC continuously measured with optical turbidimeters. The monitoring of the SSC has been extended to about 65 km downstream of the reservoir. To quantify the biological impact of these transactions was monitored benthic macroinvertebrate communities and the fish communities during the period 2009-2011.

2. Materials and methods

The Cancano dam was built during the years 1954-1956 in the high basin of the Adda, near the border with Switzerland (in the province of Sondrio, Italy, Figure 1) just downstream of the existing dam of St. James. The share of the top of the dam is 1,902 m above sea level and the capacity of the reservoir is 123 million m^3. The bottom outlet (altitude 1,806 m) is constituted by a branch of the tunnel junction in the right bank, the discharge (altitude 1,781.5 m) is constituted by a metal pipe of 1.2 m diameter present in the body of the dam.

The reservoir of San Giacomo has a basin of 18.7 km^2 and a connected basin of 254.4 km^2 for a total of 273.1 km^2. The Cancano reservoir has a catchment of 17.3 km^2, a basin connected to the right orographic through the derivation of T. Viola of 74.9 km^2, a small basin connected to the left orographic by the derivation of Inferior Forcola and the basin of San Giacomo reservoir for a total of about 369 km^2 (Fig. 2).

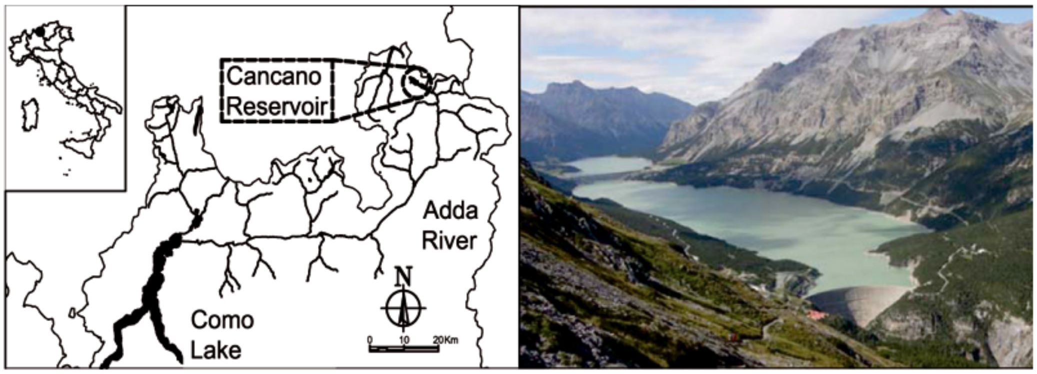

Fig. 1. Location (left) and picture of Cancano reservoir (right)

The altitude of the basin connected to the Cancano dam ranging from 1,900 m above sea level up to a maximum of 3,769 m s.l.m. Monte Alps. The hydrographic characteristics of the high basin of the Adda can be summed up in winter low-flow and summer high-flow due to rainfall inputs is in addition to the glacial runoff. The average annual rainfall is approx. 900 mm.

The two reservoirs allow a seasonal adjustment of the flow turbinate in the Premadio hydroelectric power plant (installed capacity of 226 MW and useful jump of 646.7 m). Upstream of this power station there are secondary hydroelectric plants, related to the use of the withdrawals and the difference between the two reservoirs, with a total capacity of 31.9 MW. The flow discharged from the Premadio hydroelectric power plant is diverted to the reservoir that feeds the Valgrosina Grosio hydroelectric plant (430 MW), the most important in the area of study. Along the Adda, items of the present study are also the Grosotto central (10 MW), the Lovero central (49 MW) and the Stazzona plant (30 MW).

The monitored reach of Adda river is about 60 km long; the main monitoring activities were carried out in the following sections:

- Premadio (6.7 km downstream of the Cancano dam, section (sec. I);
- Cepina (14.2 km downstream of the dam, sec. II);
- Valpola upstream of the back-water flow created by the damming (16.4 km downstream of the dam, sec. III);
- Valpola downstream of the dam (17 km, sec. IV);
- Le Prese (22.9 km, sec. V);
- Boscaccia (28.2 km, sec. VI);
- Sernio (42.7 km, sec. VII);
- Tirano (46.7 km, sec. VIII);
- Baghetto (64 km downstream, sec. IX).

Figure 2 shows the plan with the withdrawals and sections of interest.

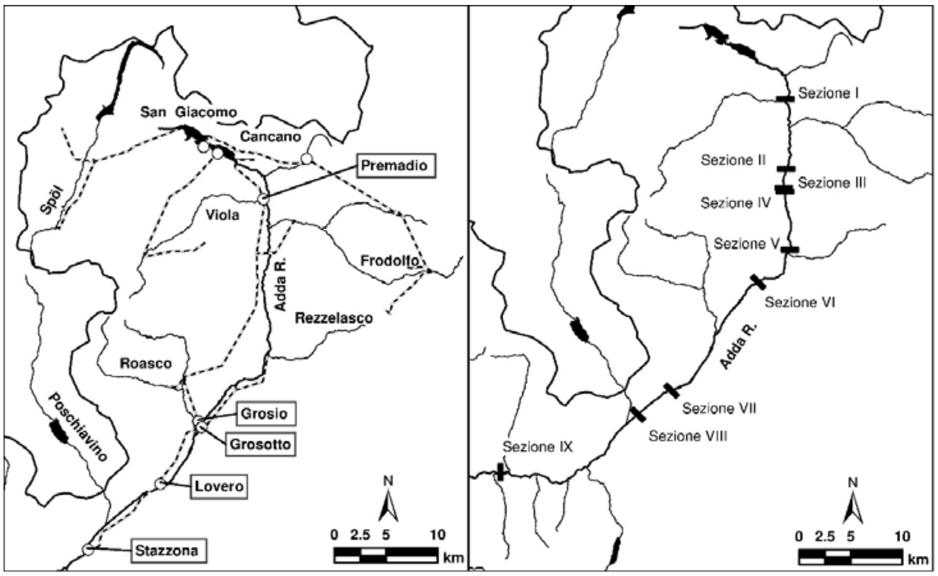

Fig. 2. Withdrawals system in high Valtellina (left) e plan with monitoring sections (right)

The average slope of the sections between the sections described above are the following:

- stretch between the Cancano dam-section I: 8.5%;
- sec I-III: approximately constant and equal to 1 .3%, between the sec. I and II are entered T. Viola (average annual natural flow of 4 m^3/s) and the T. Frodolfo (average annual natural flow 5.8 m^3/s);
- section III-IV: short section of length 600 m and slope of 0.6%, in the context of the reorganization of the hydraulic works of the Val Pola following the landslide of 1987, was created a barrier height of about 2 m with inert material, large to cause a upstream backwater flow that favored the sedimentation of silt and therefore the reduction of the SSC during the floatation of Cancano reservoir;
- section IV-VI: approximately constant and equal to 2.3% until the sec. VI;
- section VI-VII: average slope of 2.3%, just upstream of the sec. VI, T. Roasco junction (average annual flow 2.2 m^3/s).

The average flow of natural $Q_{AVE,N}$ in sec. I is 2.5 m^3/s. The MF (Minimum Flow) trial today (instream flow) guarantees to the sec I the release of 0.2 m^3/s (6% of the average annual flow) increased to 0.25 m^3/s (10% of the average annual flow) during the months between May and October. The $Q_{AVE,N}$ in sec. V stood at 15.0 m^3/s, the MF has issued an average of 1.2 m^3/s (8% of the average annual flow). The $Q_{AVE,N}$ in sec. VII is equal to 25.0 m^3/s, the MF issued to 2 m^3/s.

The flushing operations were planned to remove the deposit of silt behind the bottom outlet (1,781 m) deposited in 50 years of operation, such deposit, amounting to over 0.2 million m^3, extending to a height of more than 15 m above the altitude of the drainage and started to create problems to the intake work (1,806 m). Since all diversion works with sand treatment and there being upstream of San Giacomo reservoir, the deposit in the Cancano reservoir consisted mainly of glacial silt as demonstrated by particle size of the deposited material in the artificial lake. In fact, with reference to the known classification Udden-Wentworth, 80% of the sample analyzed results to be silt while the remaining 20% clay.

Removal activities have been scheduled in late winter (February-April) in order to have the temperature conditions that would allow the conduct of activities and complete the work before the snow melt and thus the increase of inflow to reservoir.

The flushing operations were carried out in three consecutive years:

- from 9 March 2010 to 24 March 2010 (duration: 16 days);
- from 18 February to 11 April 2011 (duration: 53 days);
- from 13 February to 23 March 2012 (duration: 40 days).

The operation carried out in the first year is described in detail in Espa et al. 2013 [14]. In summary, the reservoir has been emptied and was made a small barrage to convey the inflow (due to the contribution of the residual basin) to the reservoir intake. The removal of the deposit was achieved by pumping and mechanical removal with excavators. At the end of the operation, the washing out of the intake tunnel was performed.

The flushing of the first year has allowed the removal of the sediment up to the bottom outlet level that, during the second year of flushing, was put in safety. A few days before the end of the second year of operations (6 April 2011) it was possible to discharge the flow outside of the reservoir through the bottom outlet. The high SSC recorded between 6 and 7 April in the monitoring section I made it necessary to divert the flow to the Valgrosina reservoir.

In the third year the operation was conducted from the beginning through the flushing of the flow from the bottom outlet. The initial opening of the discharge, as expected, caused a transient increase and can not be controlled by SSC. Following the complete emptying of the reservoir began operations mechanical removal managed in a controlled manner on the basis of the SSC values recorded by the probes turbidimetric as described in the next section.

The regulatory framework governing the operations of flushing is still evolving, the limit values of the SSC average over the entire duration of the transaction were set by referring to the results of previous flushing activities carried out in the same environment contest (Central-Eastern Alps) [13,14]. The limit values, depending on the quality of the fish in the considered section of the river and the duration of the operations, are as follows: 3 g L^{-1} for the reach between the sec. V and VII and 1.5 g L^{-1} downstream of the sec. VII. There are no fixed criteria to SSS upstream of the section IV. The activities have been managed on the basis of the raw values (i.e., not calibrated) of SSC in real time measured by turbidimetric probes. A posteriori, was carried out a verification that the limits of CSS were met.

The used SSC continuous monitoring stations for real-time management of the removal activities, have been provided for in Sections I, V and VII. In such stations a probe Large SC100 (full scale at 50 g L^{-1}) was located. In the first two years of flushing the SSC was monitored for a few days and during the working hours, even with the help of portable turbidimeters (Partech 740 - full scale at 20 g L^{-1}) and Insite 3150 (full scale at 30 g L^{-1}) at stations II, III and IV, with the main purpose of estimating the deposition of sediment between sections I and III and the efficiency of sedimentation of small reservoir created in Valpola. turbidimeters have been calibrated using the laboratory analysis [16]. The values of flow rate Q, obtained indirectly from the continuous measurement of water levels, are available at the stations I , II, V and VII. Here below we refer to the SSC and Q monitored in sections I and V.

The bottom material was characterized by means of the technique of the Pebble Count [17] (Table 1).

To determine the particle size of the sediment transported in suspension, in some stations and within certain days of flushing, samples were taken containing turbid water (1 L every 5 min) and left to decant. The sediment collected was then analyzed in the laboratory (by dry sieving and gravitational settling of the fraction with a size less than 62.5 µm).

Table 1

Mc Neil monitoring stations: progressive altitude and average slope

Mc Neil stations	Altitude [m a.s.l.]	Progressive distance from Cancano dam [km]	Average slope [%]
S0-S1	1,208	7.0	2.28
S2	1,172	9.0	0.83
S3	1,118	14.2	0.66
S4	1,114	14.8	0.66
S5	930	24.0	3.28
S6	831	28.1	2.91

To estimate the amount of fine interstitial material a McNeil sampler with an internal diameter of 135 mm [18] was used and the samples were analyzed in the laboratory. For each section were collected from three to five samples (two to a distance of about one meter from the river bank, one about the middle of the riverbed wet during DMV and possibly two others at a distance about a quarter of the width of the riverbed) in sections shown in Table 1. The survey was gradually expanded over the years to include more monitoring sections. The sampling post - flushing was carried out as far as possible in the same sampled points before flushing.

The bio-monitoring campaigns were conducted for three years (2009-2011). The macroinvertebrates were sampled seasonally in sections I (except for 2009 and autumn 2010), II, V, VI and VIII using a quantitative multi- habitat approach [19], developed as a result of the transposition of the Framework Directive the Water. The macroinvertebrates were then preserved in formalin (4 %), identified at family level and counted in order to determine the total density, the number of families, the Shannon-Wiener diversity index and the Italian official index STAR_ICMi (STAR_Intercalibration Common Metric index), developed for the purpose of determining the quality of watercourses in accordance with the requirements of the water Framework Directive [20]. Considering the Italian official index, the values are grouped into 5 different quality classes whose limits are 0.95 for the classes high/good, 0.71 good/sufficient enough, 0.48 sufficient/poor, 0.24 poor/very poor.

The fish community was sampled twice a year (spring and fall) in sections II, V, VI (except for spring 2010) and VIII by electrofishing. Individuals captured were identified to species level and counted in order to determine the density (no. ha^{-1}) of each of the sampled population, taking into account (0.14 in sec. II; 0.12 in sec. V and VI; 0.34 in sec. VIII).

3. Results

The coefficients of the calibration curves, having expression $SSC_{LAB}=a\times SSC_{TUR}$ were obtained with the method of least squares. The following have been reported in the calibration curves of sections I and V

- Sec. I (2010): $SSC_{LAB}=0.91\times SSC_{TUR}$ ($R^2=0.93$) (96 samples);
- Sec. I (2011): $SSC_{LAB}=1.38\times SSC_{TUR}$ ($R^2=0.89$) (145 samples);
- Sec. I (2012): $SSC_{LAB}=1.21\times SSC_{TUR}$ ($R^2=0.85$) (using samples 2010 e 2011);
- Sec. V (2010): $SSC_{LAB}= 0.78\times SSC_{TUR}$ ($R^2=0.90$) (99 samples);
- Sec. V (2011): $SSC_{LAB}=0.84\times SSC_{TUR}$ ($R^2=0.92$) (100 samples);
- Sec. V (2012): $SSC_{LAB}=0.83\times SSC_{TUR}$ ($R^2=0.93$) (using samples 2010 e 2011).

Figure 3-4-5 show the trends of SSC hourly average (SSC_{mh}) and Q hourly average hourly (Q_{MH}) on the flushing of 2010-2011-2012. The first fifteen days flushing in 2010 are characterized by fairly constant fluctuations of SSC in section I, ranging between 1-2 g L^{-1} during night time, up to 25-30 g L^{-1} during the daytime hours; in sec. V between the minimum values below 0.1 g L^{-1} and a maximum of 2-3 g L^{-1}. In the remaining days, the oscillations recorded were lower than previous days, in the order of 5-7 g L^{-1} in sec. V and lower than 1 g L^{-1} in sec. I.

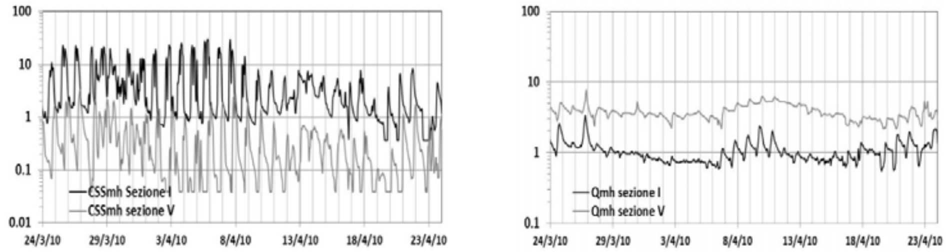

Fig. 3. SSC and QMH trends in sections I and V, flushing 2010

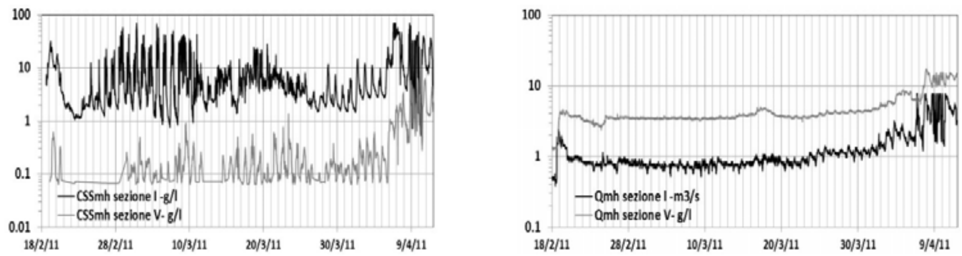

Fig. 4. SSC and QMH trends in sections I and V, flushing 2012

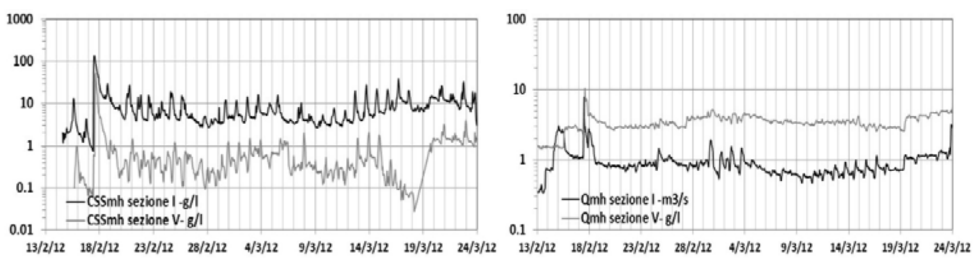

Fig. 5. SSC and QMH trends in sections I and V, flushing

In 2011, it appears a first phase with a reduced removal activity and a malfunction of the probe in sec. V; after this period, for about 10 days it is possible to notice fluctuations with daily peaks of 40-50 g L^{-1} in sec. I and values less than 1 g L^{-1} in sec. V. The last days of flushing, due to both the commissioning of the discharge and the increase of the flow inlet (due to rising temperatures) SSC peak values were recorded: 50-60 g L^{-1} in sec. I and 5 g L^{-1} in sec. V.

In 2012, as mentioned earlier, complete emptying of the reservoir through the bottom outlet caused a not controllable high peak of SSC around 140 g L^{-1} in sec. I and about 50 g L^{-1} in sec. V. About 40% of the mass transited in sec. I and

V are due to the first phase. Once finished emptying the reservoir, the SSC are back under control with diurnal peaks recorded in sec. I and V around 15-30 g L^{-1} and 1-2 g L^{-1}. In the last four days in the sec. V is a noticeable increase in the SSC with values above 1.5 g L^{-1}. In Table 2 we report the values of the main hydraulic quantities of interest. The mass transiting from the sec. I in 2010 is about 15,000 tons, in 2011 about 72,000 t, in 2012 approximately 36,000 tones. The mass deposited up to section IV is about the 65-70% of the mass transited from the sec. I in 2010 and 2012, while in 2011 is around 80%. The SSC average recorded during the entire duration of the sec. V is 0.3 g L^{-1} in 2010 and 2011 while in 2012 is 0.8 g L^{-1}. Values significantly lower than the limit value of 3 g L^{-1}.

Table 2

Average flow (Q_{AVE}), SSC (SSC_{AVE}) and daily mass (M_{AVE}) at sections I and V. Total mass (M_{TOT}) and sedimented mass percetage (M_{SED}) between two stations (* calculated excluding the transited mass during emptying of the reservoir)

	duration	$Q_{AVE, I}$	$Q_{AVE, V}$	$SSC_{AVE, I}$	$SSC_{AVE, V}$	$SSC_{max, I}$	$SSC_{max, V}$	$M_{AVE, I}$	$M_{AVE, V}$	$M_{tot, I}$	$M_{tot, V}$	M_{sed}
	day	m^3/s	m^3/s	g/l	g/l	g/l	g/l	t/day	t/day	t	t	%
2010	46	1.0	3.4	3.5	0.3	30.2	3.3	320	100	14’660	4’590	69
2011	53	1.3	4.8	7.9	0.3	68.9	6.2	1360	250	72’123	13’340	82
2012	40	0.9	3.4	8.2	0.8	137.2	51.4	610*	210*	36’370	12’210	66*

In Table 3 are shown the duration of the SSC as a percentage of the whole duration of the flushing. In sec. I, the durations for 2011 are comparable with those of 2012 and in 2010 are significantly lower. In sec. V, SSC greater than 1 g L^{-1} were recorded in 2010 and 2011 for comparable durations (about 7%) and significantly lower than the relative duration to 2012 (about 19%). Values greater than 5 g L^{-1} were recorded in sec. V only occasionally in the last year of flushing.

Table 3

SSC duration as percentage of the whole duration of operations in sections I and V

CSS-g/l	40	20	10	5	2	1	0.5	0.2	0.1	0.05	0.02	0.01
Duration sec. I-2010		1.9	8.9	19.3	39.6	74.8	90.8	100				
Duration sec. V-2010					1.1	7.2	17.6	34.2	51	68	100	
Duration sec. I-2011	2.1	9.4	23.2	45.1	82.0	97.9	98.8					
Duration sec. V-2011				0.6	3.2	7.2	11.3	24.3	46.6	60.0	62.2	64.2
Duration sec. I-2012	1.2	4.0	24.2	57.5	92.5	95.6						
Duration sec. V-2012	0.1	0.3	0.6	1.1	3.5	18.6	39.0	73.6	85.5	88.9	89.5	

Figure 6 (left) shows the curves obtained with the Pebble Count technique. The curves are quite similar with d_{50} variable between 20 and 30 mm. A greater variability is known for d_{90} between about 60 and 250 mm.

Again figure 6 (center and right) shows the distribution curves of the suspended sediment collected during the day on 8 and 11 April 2011 in different sections. The curves related to the sec. I are very similar to that obtained from the sediment sample collected just downstream of the dam during the operations of 2011, with the values of the characteristic diameter d_{50} of around 0.02 mm and d_{90} of about 0.06 mm. The distribution curves of the sediment collected on April 8, in downstream sections (II and III) present slightly higher particle size (d_{90} around 0.1 mm). The distribution curves of the sediment collected on April 11 in sec. I and III are almost similar, while there is an evident reduction of the grain size of the sediment in sec. V (d_{90}=0.3 mm). This reduction is presumably due to deposition occurred in the reach III- IV due to the presence of the dam realized in Val Pola.

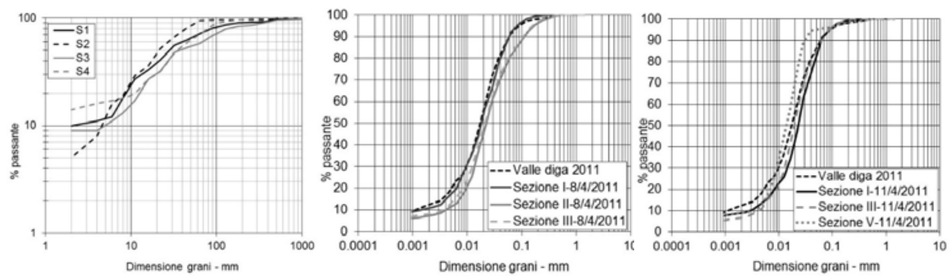

Fig. 6. Sediment size charts

In Table 4 (right) shows the content in kg m^{-2} of interstitial fine sediment (SS) on the average section. The sampling was carried out as in correspondence of multiple sections. It should be noted that in 2010 and 2011 samplings were performed after flushing in May, while in 2012 in October. The average value of SS measured in sections is equal to approximately 1.7 kg m^{-2}, the maximum value detected is about 7.2 kg m^{-2}. Considering the measurement campaign carried out before flushing the average content of SS is around 1.1-1.2 kg m^{-2} in both 2011 and in 2012; this value is around 2.5 kg m^{-2} after the flushing in 2011 and about 2 kg m^{-2} approximately 7 months after the end of the flushing in 2012.

All the samples indicate that in the riverbed characterized by the MF, there is an increase of interstitial sediment on the bottom, due to the flushing and a return to values pre-flushing before the start of the following year. It is a clear upward trend in the years of progressive interstitial content of SS.

Table 4 (left) shows the contents of SS on the single particle size fraction smaller than 0.063 mm (silt and clay). On average in the samples collected the content of silt and clay represents about 45% of the total. The average value of this fraction on the bottom is 0.7 kg m^{-2}; the maximum value detected is about 1.8 kg m^{-2}. The tendency to change is similar to that described above relative to the total SS.

Table 4

Average fine interstitial sediment content SS in section (left) and fraction lower than 0.063 mm (right)

	SS average - total kg/m^2					
	03/03/2010	03/05/2010	17/01/2011	05/05/2011	26/01/2012	10/10/2012
S0						1.44
S1			1.22	2.75	0.26	1.22
S2-1			1.67	2.7	0.33	0.91
S2-2			0.93	1.46	0.78	0.27
S2-3			0.59	1.44	1.05	1.28
S3	1.51	6.46	1.03	4.73	2.96	2.56
S4			1.67	2.61	2.83	1.72
S5-1					0.33	2.21
S5-2					0.99	1.34
S6					0.5	7.16
average			1.18	2.61	1.11	2.01

	SS average <0.063 mm kg/m^2			
	17/01/2011	05/05/2011	26/01/2012	10/10/2012
S0				0.55
S1	0.57	1.38	0.13	0.82
S2-1	0.6	1.18	0.14	0.51
S2-2	0.28	1.08	0.06	0.09
S2-3	0.4	0.97	0.33	0.43
S3	0.74	1.64	1.79	1.36
S4	0.8	1.25	1.31	0.8
S5-1			0.05	0.94
S5-2			0.55	0.39
S6			0.17	0.93
average	0.57	1.25	0.5	0.68

In all monitoring stations, the macrobenthic community detected in samples pre-flushing is characterized by the dominance of ubiquitous and tolerant taxa such as *Leuctra, Baetis, Limnephilidae, Rhyacophilidae, Chironomidae, Simuliidae and Limoniidae*. Furthermore, the data show high variability (Fig. 7) in part linked to the life cycles of different taxa and in part probably due to hydrological changes (regulation of outflows related to the activity of the hydroelectric plants) and morphological (e.g., whether directed), characterizing the river reaches investigated. Monitored events have not resulted in a significant deterioration in the structure of the benthic community existing and recovery times observed proved to be relatively short. In most stations the flushing operations have led to a reduction in the density (Fig. 7), generally do not taxa-specific and short-term (a few months). The peaks of density (> 3.000 no. m^{-2}, Figure 7) recorded in winter are due to the boom in the populations of specific taxa, as *Limnephilidae, Simuliidae and Chironomidae*. The number of families has reached its lowest value after the flushing of 2011 in the station closest to the Cancano reservoir (section I) (Figure 7), indicating how this intervention may have had a greater impact than that of 2010. This seems to be also confirmed by the index STAR_ICMi showing a lowering of the quality class, from the winter of 2011 in good enough in the spring of 2011 (Fig. 7). Both of these metrics have returned to levels close to those pre-flushing in the autumn of the following year (Fig. 7).

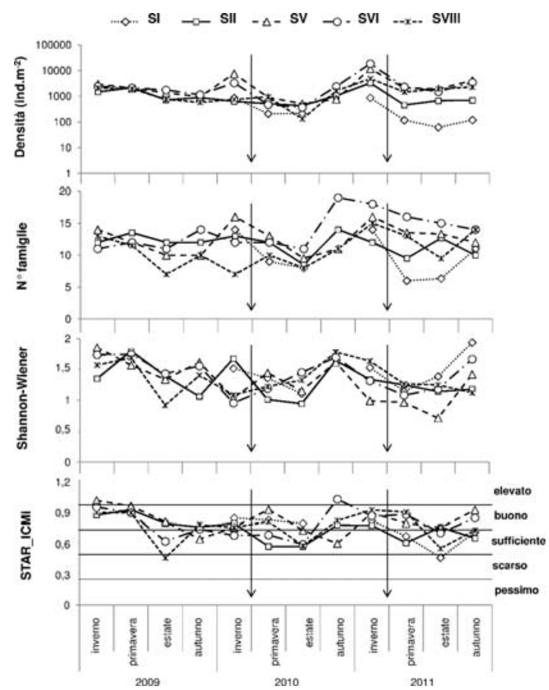

Fig. 7. Seasonal trend from 2009 to 2011 of four metrics (density, number of families, Shannon-Wiener and STAR_ICMi) concerning the structure of benthic macroinvertebrate communities sampled at sections I (missing data for 2009 and autumn 2010), II, V, VI and VIII. The arrows indicate the events of flushing

Considering the fish, all the investigated reaches are characterized by the dominance of populations of brown trout (*Salmo trutta trutta*) (Fig. 8), with the exception of the section VIII where the most representative species is the bullhead (*Cottus gobio*), small benthic species of high conservation value (Habitats Directive 92/43/EEC). Sometimes it was also detected the grayling (*Thymallus Thymallus*), rainbow trout (*Oncorhynchus mykiss*) and hybrid trout (*Salmo trutta trutta x marmoratus*). The populations of brown trout are strongly influenced by withdrawals and entries related to sport fishing. In section VIII, the pre-flushing situation is characterized by relatively low density (Fig. 8), likely attributable to the scarcity of suitable habitats. The most obvious effects of flushing operations are found in the stations closest to the Cancano reservoir (sec. II and V), where the density decreases were recorded after the flushing activity of both the 2010 and 2011 (Fig. 8). However, considering the overall results of the monitoring, there were no impacts of particular importance: in fact, the density values recorded in spring 2010 and 2011 in the sec. are similar to that of spring 2009 (Fig. 8). Even the natural population of bullhead recorded in sec. VIII maintains density similar or even higher than those pre-flushing.

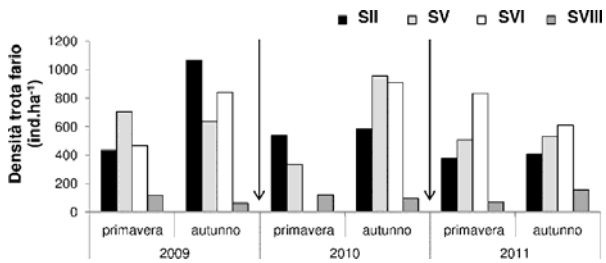

Fig. 8. Time trend from 2009 to 2011 of the density of brown trout in the stations II, V, VI (missing data relative to spring 2010) and VIII. The arrows indicate the events of flushing

4. Conclusions

The operations of controlled flushing of Cancano reservoir, made in the next three years and a total duration of 139 days, allowed to remove about 123.000 tons of mainly silty sediment, by securing the discharge of the dam. As a result of the calibration of turbidimeters, operations have been managed within the limits of SSC average over the entire duration of the operation. As expected, at the beginning of the flushing of 2012, when emptying the reservoir is completely carried out through the bottom outlet, SSC high and uncontrollable were detected.

The grain size of the sediment collected in suspension remains roughly unchanged proceeding downstream, although a modest reduction in particle size is found in section V, downstream of the Val Pola, where there was a short backwater flow reach (600 m) allowing upstream sedimentation. The presence of interstitial fine sediment undergoes an increase due to the transaction flushing; that content, in the analyzed samples, returns to its pre-flushing values, detected before the start of the operation related to the following year. It is not evident an increasing trend of fine interstitial SS content.

Both the results of the monitoring of benthic macroinvertebrate communities that those related to fish fauna, indicate that the flushing operations cause temporary reductions in density, especially at the stations closest to the reservoir object of intervention. These effects were, however, of marginal importance compared to seasonal variations of the different metrics investigated, due to both natural causes (biological cycles of taxa) and anthropogenic (hydromorphological alterations and management of fish fauna).

R E F E R E N C E S

[1]. *G.L. Morris and J. Fan*, Reservoir Sedimentation Handbook. McGraw-Hill, New York, 1997.
[2]. *W.R. White*, World water: resources, usage and the role of man-made reservoirs. Foundation for Water Research, Marlow, UK, 2010.

[3]. *R.D. Ionescu, M. Ragazzi, L. Battisti, E.C. Rada, G. Ionescu* Potential of electricity generation from renewable energy sources in standard domestic houses, WIT Transactions on Ecology and the Environment, **vol. 176**, 245-253, 2013.
[4]. *V. Torretta, E.C. Rada, I.A., Istrate, M. Ragazzi,* Poultry manure gasification and its energy yield, UPB Scientific Bulletin, series D, **vol. 75,** no. 1, 231-238, 2013.
[5]. *E.C. Rada, M. Ragazzi, V. Torretta* Laboratory-scale anaerobic sequencing batch reactor for treatment of stillage from fruit distillation, Water Science and Technology, **vol. 67,** no. 5, 1068-1074, 2013.
[6]. *S.L. Martinez, V. Torretta, J.V. Minguela, F. Sineriz, M. Raboni, S. Copelli, E.C. Rada, M. Ragazzi*, Treatment of slaughterhouse wastewaters using anaerobic filters, Environmental Technology, **vol. 35**, no. 3, 322-332, 2014.
[7]. *E.C. Rada, M. Ragazzi, L. Fiori, D. Antolini*, Bio-drying of grape marc and other biomass: A comparison, Water Science and Technology, **vol. 60,** no. 4, 1065-1070, 2009.
[8]. E.C. Rada, M. Ragazzi, E. Malloci, Role of levoglucosan as a tracer of wood combustion in an alpine region, Environmental Technology, **vol.33**, no. 9, 989-994
[9]. *E. Girelli, M. Ragazzi, E. Malloci, E.C. Rada, L. Paternoster,* Agricultural biomass availability for energy conversion in Italy, UPB Scientific Bulletin, series C, **vol. 74,** no. 1, 11-18, 2012.
[10]. *R. Patrascu, E. Minciuc, D. Tutica, M. Norisor, G. Ionecsu, P. Stefani,* Reducing environmental impact through efficient utilisation of biomass in a cogeneration plant case study - energy supply of an industrial company through biomass utilisation in a cogeneration plant with internal combustion engines, Quality - Access to Success, **vol. 15**, no. 138, 84-88, 2014.
[11]. *K.J.Collier*, Effects of flow regulation and sediment flushing on instream habitat and benthic invertebrates in a New Zealand river influenced by a volcanic eruption. River Research and Applications, **vol. 18**, no. 3, 2002, pp. 213-226.
[12]. *T. Gomi, S. Kobayashi, J.N. Negishi and F. Imaizumi*, Short-term responses of macroinvertebrate drift following experimental sediment flushing in a Japanese headwater channel. Landscape and Ecological Engineering, **vol. 6**, 2010, pp. 257-270.
[13]. *G. Crosa, E. Castelli, G. Gentili and P. Espa*. Effects of suspended sediments from reservoir flushing on fish and macroinvertebrates in an alpine stream. Aquatic Sciences, **vol. 72**, 2010, pp. 85-95.
[14]. *P. Espa, E. Castelli, G. Crosa and G. Gentili*, Environmental effects of storage preservation practices: controlled flushing of fine sediment from a small hydropower reservoir. Environmental Management, **vol. 52**, no. 1, 2013, pp. 261-276.
[15]. *W.R. White*, Evacuation of sediments from reservoirs. Thomas Telford Publishing, London, 2001.
[16]. *APHA, AWWA, WEF*, Standard methods for the examination of water and wastewater, 21st edn. American Public Health Association, Washington, USA, 2005.
[17]. *M.G. Wolman*. A method of sampling coarse river-bed material. Transactions American Geophysical Union, vol. 35, no. 6, 1954, pp. 951-956.
[18]. *W.J. McNeil and W.H. Ahnell*, Success of pink spawning relative to size of spawning bed material. U.S. Fish and Wildlife Service, Special Scientific Report-Fisheries No. 469. Washington, USA, 1964.
[19]. *A. Buffagni and S. Erba*, Macroinvertebrati acquatici e Direttiva 2000/60/EC (WFD) – Parte A. Metodo di campionamento per i fiumi guadabili. IRSA-CNR Notiziario dei metodi analitici 1: 2-27, Rome, Italy, 2007.
[20]. *A. Buffagni and S. Erba*, Intercalibrazione e classificazione di qualità ecologica dei fiumi per la 2000/60/EC (WFD): l'indice STAR-ICMi. IRSA-CNR Notiziario dei metodi analitici 1: 94-100, Rome, Italy, 2007.