Eco-investments, mitigations & restoration actions

Proposal of eco-investments, mitigations & restoration actions for the SHARE Pilot Case Studies

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Author(s) Bruno BOZ, Maria BOZZO, Andrea MAMMOLITI MOCHET

Member number and name LP-ARPA Valle d'Aosta

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Summary

SHORT DESCRIPTION
The report gives proposals for the evaluation of measures for mitigation and compensation of HP plants impacts on Alpine rivers. It aims also to describe possible eco-investments and restoration actions for the SHARE National Pilot Case Studies.

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Author	BOZZO – m.bozzo@arpa.vda.it MAMMOLITI MOCHET – a.mammoitimochet@arpa.vda.it

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Table of contents

Introduction and definitions

The installation of an hydropower plant along a river or a channel reach determines various effects on the natural river equilibrium and it may cause environmental impacts, affecting water resources, biological communities and landscape. However, careful designs and rational operations can mitigate these effects and strongly improve the integration of the plant within the natural context in which it is built (WFD and hydromorphological pressures technical report, 2006).

Generally speaking compensations are something given or received as an equivalent for services, loss or suffering: projects that make use of natural resources, as in our case HP production, have in general an impact on the environmental conditions. For this reason **measures for mitigation** (mainly ***in situ***) and **compensation** (mainly ***ex situ***) of the negative impacts on the environment have to be assessed.

This document is not intended to be an exhaustive list of possible measures but a review of main mitigation and compensation actions used and/or proposed for the SHARE Pilot Case Studies.

More in detail, in this document the main compensation actions are intended as specified below:

Mitigation measures: they involve several methods or plans to reduce, offset or eliminate adverse HP project impacts. They include also any action taken to avoid or reduce the severity of an adverse HP impact: so, mitigation actions can include one or more of the following measures:

- avoiding impacts;
- minimizing impacts by limiting the degree or magnitude of an action;
- reducing or eliminating impacts over time.

Restoration measures: they involve different practices of rectifying impacts, restoring or repairing a degraded, damaged, or destroyed environment or a part of it due to HP exploitation, by active human interventions and actions.

Compensation measures: they involve practices of compensating for the adverse HP project impacts by replacing or providing substitute resources or environments to offset the loss.

In situ measures: they involve practices for restoration and/or mitigation directly linked to the river ecosystem affected by adverse project impacts.

Ex situ measures: they involve practices mainly for compensation not linked to the river ecosystem affected by adverse project impacts.

Mitigation measures to reduce the impact due to structures

Fish fauna - Fish passes and bypass channel

DESCRIPTION OF THE POTENTIAL IMPACTS

Dams generally represents an insurmountable physical barrier for the longitudinal movement of fish during the different phases of their life cycle. In particular, their need to move in new sections of the stream is related to the search for appropriate spawning and rearing areas (reproductive migrations), for feeding areas (trophic migration), for refuge areas from strong environmental stress (spates, droughts, point pollution, etc.). The impact induced by the lack of longitudinal movements can affect the fish community upstream (e.g., species once living in the section upstream become confined downstream of the dam) and downstream (e.g., one species can decrease in abundance or disappear because it can not reach the spawning areas which are located upstream). Another possible effect due to the interruption of longitudinal continuity is the genetic isolation between the populations upstream and those downstream.

POSSIBLE MITIGATION MEASURES

Build appropriate fish passes which can allow the longitudinal movements of fish fauna from upstream and downstream and vice versa. A correct construction of these structures requires:

A preliminary assessment at the basin scale to verify the need/possibility to build a fish ladder, taking into account the movements in the upstream and in the downstream directions: this need is not always justified, as for instance if natural discontinuities already exist, if the water body cannot naturally support a fish community; if the river is already too fragmented longitudinally and its continuity should first be restored; if there is a risk for alien species or for new indigenous species with less conservation value to move upstream and replace the existing species. The assessment must take into account the characteristics of the fish community; the autoecology of each species (e.g., presence of migrating diadromous fish) and the effective advantage gained by restoring reaches more easily passable by fish (for instance, by checking if there are other impassable obstacles which could nonetheless be passed with small interventions). The assessment can be achieved by using several evaluation and planning tools, such as the intervention priority indices (an example in Pini Prato, 2007):

1. Once the need/opportunity to build a fishway has been verified, the **fish community** must be investigated in order to identify the one or more target species, and their swimming abilities (to calibrate the streamflow in the pass) and the timing of their migratory and spawning period;
2. Assessment of the **hydrological characteristics** of the stream, mainly for the reach where the fish ladder will be installed. A detailed analysis of the discharge regime and water levels for the migratory period of the target species is particularly relevant; hydraulic characteristics of the stream for the reach where the fish ladder will be installed (direction of the main flow, turbulence, hydraulic jumps, water level, etc.);
3. **choice of the fish ladder** which better fits the biological and environmental conditions. A useful reference scheme for choosing the typology and the related planning standards was defined by the European Commission “EIFAC Working Party for Fish Passage Best Practices” – instituted by the FAO;
4. final **sizing and planning** of the fishway; in this phase it is desirable to run hydraulic simulations to describe different scenarios with and without fishway;
5. definition of an appropriate **management protocol** (related mainly to the variations of water level in the reservoir) to properly maintain the fishway (see Om3);
6. **build the fishway**;
7. **verify the functionality** of the fishway, identify the possible project changes and, if required, plan and carry out the necessary modifications.

The above-described process must be rigorous and the result of a multidisciplinary approach.

In addition to the construction of fish passes, also **direct capture, transport and release of fish** upstream or downstream of the dam can in some cases have a positive effect (in particular when the dam isolates large sections of the hydrographic basin) although such operations are costly, usually do not affect significantly the fish populations and do not permanently solve the problem, i.e., the restoration of longitudinal continuity. The real usefulness of such measures must be carefully evaluated, based on specific data on fish abundance and species composition.

An alternative compensation measure is planning and building artificial spawning areas downstream of the barrier (properly planned and maintained also taking into account the effects of the management operations in the stream reach immediately below the dam). This operation, although it is not equivalent to the restoration of the longitudinal continuity and not always applicable, can reduce the need to move the fish populations along the stream in order to preserve their integrity.

Reference case studies

Even if an official list for the numerous fish passes developed in EU is not available, most of them are not functioning. The most typical and frequent mistake are the following:

- the slope of the fishway is too steep: in fact, the slope must be related to the target fish species, which often are not salmonids, which are good swimmers, but small cyprinids, which are scarce swimmers. As a general rule, a fish ramp for a fish community with mixed species composition (salmonids and cyprinids), should not be steeper than 7-8%.
- planning based on the assumption that, in the pool-type fishway, fish will jump from one pool to the other, when in fact fish swim mainly near the bottom where the roughness reduces the flow, and jump only if they are forced to pass an obstacle. Hence, in the pool-type fishway, the water should not overflow from one pool to the other, but flow through the side slot and the bottom hole, creating a continuous flow;
- wrong planning of the upstream-downstream connection of the pool, with the first pool downstream suspended, or the first upstream fed by only a very thin layer of water with high velocity; the structure of the streambed near the entrance of the fishway is also very important because it must be wide and large enough to allow the fish entering the pass.

Although the badly planned/constructed fish passes are prevailing, some recently-built passes are very well built. Among them, we signal as an interesting case of application of the logical and methodological procedure described above, the work conducted within the LIFE project (Petromyzon And River Continuity) (http://www.lifeparc.eu/index.php/it/partner/22-ente-parco-di-montemarcello-magra) in the Magra-Vara basin. After an accurate costs-benefits analysis, the project to build a fishway near a dam on the Vara river was abandoned, and the river continuity for a 50 km long reach downstream of the dam was restored instead, obtaining more benefits for the fish fauna.

Other examples of good planning/building are those in the Mugello area, described in Pini Prato, 2008 and on the Isarco River in South Tyrol described in Adami, 2002.

A recent and interesting example of sophisticated continuous monitoring of the fishway, is represented by a subterranean room with a system of videocameras connected to a software which counts the animlas which pass through the fishway. This structure is installed near the sluice gate between Lugano Lake and the Tessa River, and is described in Puzzi et al., 2009.

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Fish fauna - Installation of screens and deterrents

Description of the potential impacts

The discharge released by the outlet structures can strongly attract the fish while they are moving along the stream. If the outlet structure has an accessible (with appropriate longitudinal profile, current velocity, etc.) channel, it can turn into a fish trap, limiting or preventing the fish movements upstream. Released water usually has different temperature from the receiving water body and in certain phases of the fish life cycles or in certain seasons, even few tenths of degree can affect the choice of the direction to follow.

If water is not released in the same stream where water was initially abstracted, but in a different stream joined by the abstracted one, the discharge alteration at the confluence, and thus the attracting effect, can influence the water body where the fish preferentially move to.

It must also be taken into account that screens and other deterrents can, in some cases, be passed by fish which can survive the passage through the turbines. If the releases of turbinate water do not provide the hydraulic continuity with the receiving water body, fish can end up stranded near the outlet point.

POSSIBLE MITIGATION MEASURES

A barrier set at the outlet mouth (for instance a screen or, better, an impassable weir 0.50-0.80 m tall) gives good results. If necessary, in order to have a proper difference in height, the streambed at the discharge point can be remodelled, or the discharge point can be moved downstream.

When possible, i.e., only in the case of plant without diversion, it is useful to use the released discharge to increase the attractiveness of the fishway, by joining the two releases (hydropower station and fishway), but preventing the fish to enter the outlet channel by installing the physical barriers listed before.

In order to reduce the impacts on fish fauna, the releases should occur in the same water body from which water is diverted, or at least in a position which would not significantly alter the relative attractive value of the two water bodies at their joining.

Regarding the impacts on the fish which have passed through the turbines, the position of the release point and the management of the released discharge must limit as much as possible the risk of stranding.

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Fish fauna - “Fish friendly” turbines

DESCRIPTION OF THE POTENTIAL IMPACTS

Fish which accidentally enter into intake structures and, when present, the diversion structures (at this purpose, see Bs3) have to pass through the turbines where, due to direct entrainment, or to damages due to the fast changes in pressure, they suffer high mortality.

Mortality (see for instance Larinier and Dartiguelongue, 1989 for a predictive model) is higher for eel than for salmonids, due to their body length, and for cyprinids, which have low tolerance for pressure changes.

POSSIBLE MITIGATION MEASURES

It is possible, for certain ranges of turbinated discharge and hydraulic head, use the so-called “fish friendly” turbines, which are planned to reduce mortality and damages to fish passing through them. These turbines are usually characterized by low peripheral tangential velocity of the rotor, limited velocity gradients, higher minimum pressure and reduced pressure gradients through the rotor, a smaller gap between the moving and stationary parts, wider flow cross-section through the rotor, shorter and less numerous blades in the Kaplan and in the Francis turbines.

Because it is impossible to prevent completely (see description in Bs3) the fish from entering together with water into the intake structures, the fish-friendly turbines could be used for both plant with and without derivation structures. Their use, when technically feasible, must be evaluated taking into account the real environmental benefits which would be achieved, which in turn depend on the type of fish present, the surrounding environment, and the type of intake structure. For instance, it is possible to foresee that the use of such technology would not be suitable at the end of very long high-pressure pipes (km), where the conditions of the fish would already be strongly altered.

Eel deserve particular attention because being a catadrome migrating fish, and because of its particular autoecological characteristics, is particularly sensitive to hydropower-generated impacts. Due to the drastic reduction in eel populations in the last decades, the European Eel has been added to the IUCN Red List and is subject to a particular protection regime in the European Union (Council Regulation EU 1100/2007, establishing measures for the recovery of the stock of European eel). Turbines located along streams used by eel during their migrations downstream, should be planned to limit as much as possible the eel mortality. It is strongly suggested to monitor the reduction of the impacts, particularly on adult eels, obtained with the installation of fish-friendly turbines.

Reference case studies

Some commercial models of Kaplan turbines, Francis turbines, and Archimede screw turbines are already fish-friendly (see for instance www.vlh-turbine.com/FR/html/Ichtyophilie.htm, www.aldenlab.com/index.cfm/Services/Hydroelectric_Turbine_Design, www.spaansbabcock.com, and the interesting review on the "advanced" turbines in http://hydropower.inel.gov/turbines/).

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Mitigation measures to reduce the impact due to release flow alterations

Fish fauna - Flow alterations

Description of the potential impacts

The alteration of the components of the flow regime creates various impacts on fish fauna; to simplify, only the most significant are listed below:

- **Impact of extended periods of artificially-induced low flows**; the main effects on the fish communities are the reduced oxygen availability, temperature alterations (summer warming, excessive cooling ad possible freezing in winter, wider daily excursions) and thermal stratification, increase in pollutants concentration, loss of aquatic habitats necessary for the crucial phases of the life cycle (e.g., drying of the from spawning beds), excessively-low water levels, disconnection of the bank habitats, interruption of the longitudinal and lateral continuity with areas used for spawning, refuge, predation; overall water stagnation and creation of ponds; development of different survival strategies and modification of behavioural patterns (increased competition and predation in the pools). An excessive decrease of the current velocity changes the fish assemblages, with reduction of the rheophilic species such as salmonids, and dominance of opportunistic ones (Bunn & Arthinghton, 2002).
- **Impact of a constant flow regime or with small variations compared with the natural one**; although in several cases short-term effects are not detectable (and instead the stable discharge can locally increase the abundance of individuals for several species), on the medium- and long-

term these conditions alter the fish communities due to a scarce habitat renewal and homogenization, loss of adaptive strategies related to extreme conditions and consequent loss of species able to tolerate the stress imposed by variation in discharge. These species are substituted by species adapted to constant conditions. The increase in discharge frequently results in a large reproductive success with reduction of the fitness of the single individuals and reduced intraspecific competition (particularly in salmonids).

- **Impact of the lack or reduction of the high flows and floods**; also in this case, although floods and high flows represent a strong stress for the fish community, in the short-term the negative effects of their absence might not be detectable. However, on the medium- and long-term the lack of such events can have negative effects, mainly due to the morphological alterations: reduction or loss of spawning and feeding areas (backwaters, lateral channels, etc.), and of nursery areas for fry; lack of accumulation and reshaping of gravel and cobble in the spawning area, reduced transport of coarse wood debris and consequent reduction of riverine mesohabitats; "aging" and clogging of the spawning substrate by silt and/or peryphyton; poor natural selection in the populations, with reduction of the fitness if the individuals.

It must be underlined that the success of invasive alien species, constantly increasing in the Italian water bodies, is promoted by the alteration of the natural flow regime (Bunn & Arthinghton, 2002).

POSSIBLE MITIGATION MEASURES

The possible mitigation measures are generally related to a change in the released discharge management, in order to reduce the alteration of the natural discharge regime.

In particular, in order to reduce the impact on fish fauna, the released discharge should have the following characteristic:

- **minimum releases** adequate to maintain a water level sufficient to ensure a reduced loss of mesohabitats, their hydraulic connection, and prevent the onset of processes which cause a significant variation of the physico-chemical characteristics of water.
- **guarantee a flow regime** which overall follows the natural variations, in order to avoid creating an extremely homogeneous, stable habitat, and instead preserving the occurrence of the geomorphological processes which create and renew the riparian and streambed habitats and the lateral continuity with the floodplain.
- **take into account the specific requirement** of the target species, in particular to the seasonality of certain flow regime characteristics.
- Include the mandatory monitoring of the **hydrological parameters**, and their effects on the biological and physico-chemical indicators.

Based on what described above, none of the methods presently used to define the "minimum vital flow" or the "minimum vital regime" can be labelled as a "good practice". However, there are important differences between the methods based on hydrological parameters without any ecological significance and often characterized by a constant minimum flow, and those based on the quantitative evaluation of the effects on the biota (for instance, the IFIM, available at www.fort.usgs.gov/products/software/ifim/, evaluates the correlation between the released discharge and the habitat availability for certain target species of fish). Even the latter, however, if not based on the achievement of specified quality objectives at a larger scale, cannot be considered coherent with the approach described here.

REFERENCE CASE STUDIES

The website www.nature.org/initiatives/freshwater/conservationtools includes a "Flow Restoration Database" with hundreds of examples (a related literature) of discharge management oriented towards the reduction of the impacts on the different components of the riverine ecosystem,

In Switzerland a protocol programmed experimental floods has been applied from Livigno reservoir into the Spöl River, with continuous monitoring of the water physico-chemical quality and on the biota (peryphyton, macroinvertebrates, and fish). As regards fish fauna, the results are positive especially regarding habitat improvement, particularly spawning habitats (spawning increased 4-fold); this trend was confirmed by the increase in brown trout fingerlings. The total abundance of fish remained constant during the first three years of experimental (Robinson, 2009).

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Benthic invertebrate fauna - Flow alterations

DESCRIPTION OF THE POTENTIAL IMPACTS

The release of reduced discharge for extended periods of time compared to the natural situation can impact the macrobenthic communities due to the reduced oxygen availability, temperature alterations (warming), increase in pollutants concentration, loss of aquatic habitats necessary for the crucial phases of the life cycle (e.g., loss of lateral continuity), overall water stagnation and creation of ponds, drying of the streambed and induced stress on organisms with low vagility.

An excessive decrease of the current velocity can cause the decline of populations of decapods and molluscs. A further consequence of the high summer temperature is the increased development of phytobenthos, resulting in changes in the associated zoobenthic communities.

The progressive reduction in the flood frequency strongly affected the morphological evolution of the streambed (Graf, 2006), with a trend towards colmation of the interstitial space and abnormal development of peryphyton. The vertical continuity between surface- and ground-water can be interrupted by clogging (Anselmetti et al., 2007; Fette et al., 2007), reducing the availability of hyporheic habitat, which is used by benthic fauna as a refuge both during high and low flows (Maiolini et al., 2005; Bruno et al., 2009).

The release of a constant discharge or with small fluctuations, compared to the natural regime, can affect the macrobenthic community due to the reduced renewal of habitats and their homogenization, resulting in an unbalanced community structure, dominated by the most resistant taxa and those which can better adapt to such conditions (filter feeders such as Simuliidae); and to scarce mobilization of coarse detritus and organic matter available for the macrobenthic community. The global effect is the quantitative increase of few macrobenthic taxa and a reduction of the community diversity.

Extended periods of artificially-induced high flows can affect the macrobenthic community due to the loss of mesohabitats (typically occurring in streams with little morphological diversification due to incision or regulation); the community shift towards taxa which are more resistant and adapted to such conditions, or shifts in the longitudinal distribution; drift increases and can involve the entire community.

The discharge regime is critical to allow the transport of solid material, which maintains the substrate conditions suitable for the life a of a large number of benthic invertebrates.

Some of the most dramatic effects on the macrobenthic community are due to extended periods of artificially-induced high flows and low flows. The bed erosion occurring during artificial high flows can cause an extended dispersion and mortality of benthic macroinvertebrates which are crushed by the transported gravel and boulders or abraded by the suspended solids. The organisms which are dislodged from the streambed can die during the transport or later on, if they are deposited in unsuitable habitats in the floodplain such as pools or backwaters.

POSSIBLE MITIGATION MEASURES

The general discussion presented for fish fauna regarding the need of a better adaptation of the discharge regime to the natural patterns, are applicable to macroinvertebrates. Because benthic macroinvertebrates are less mobile than fish, it is particularly important to provide:

- a **discharge regime** which follows as much as possible the seasonal variations, with different current velocities, and which can support a large range of habitats for the macroinvertebrate communities during the entire year. The non-attainment of these conditions can be acceptable only in those sections/reaches which would naturally dry.
- **releases which avoid each artificial isolation of the tributaries**, which would cause segregation of the macrobenthic communities from the mainstem.
- **permanence of a reach** which would remain permanently-wet even during extended low-flows, in order to provide a minimum diversity of functional habitats.

REFERENCE CASE STUDIES

In Switzerland a protocol programmed experimental floods has been applied from Livigno reservoir into the Spöl River, with continuous monitoring of the water physico-chemical quality and on the biota (peryphyton, macroinvertebrates, and fish). As regards macroinvertebrates, the results showed an significant reduction in species richness, biomass and density, with values returning to the expected ones for a typical alpine stream and the substitution of some generalist taxa with other, disturbance-resistant ones (Robinson, 2009).

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Hydrological regime - hydropeaking

Description of the potential impacts

Hydropeaking alters completely the natural hydrograph, which becomes (with the exception of the periods of extended floods or high flows, when the regulation capacity of the upstream reservoir are exceeded) a daily succession of extremely low flow and several hours of high flow. It must be underlined that the usual approaches to hydrological alteration assessment (e.g., The Nature Conservancy, 2009) are based on daily average discharges, and therefore cannot account for the effects of hydropeaking, which have to be analyzed to a shorter time scale.

Possible mitigation measures

Notwithstanding the large number of published works describing the impacts induced by hydropeaking, case studies which combine production and reduction of impacts are few.

The possible mitigation measures obtained by acting on the management of one HPP or, more often, on a network of plants, are aimed to reducing the ratio between hydropeak discharge and minimum flows (an increase of more than 2-fold has strong impacts on fish fauna and biota in general) and increase the transition time between those two conditions. The main mitigation measures can be summarized as follows:

- **reduction of peak discharges** and/or increase a constant production;
- **increase of the time** elapsed between the starting of the turbines and their full operation. i.e., between the minimum and maximum discharge; however, the agreement rules between the producer and the electric network manager can limit the application of this measure;
- **increase of the time** elapsed between peak discharge and switching off of the turbines;
- **releases of discharges into retention reservoirs** (subterranean or surficial) and subsequent gradual release into the stream (see Moog, 1993); it must be underlined that the construction of new structures (which usually require a large size to be effective) can create a significant impact on the riverine ecosystem;
- **expansion of the bypassed reach** to allow other hydropower plants or other users to exploit the peak releases. This specific measure must be evaluated based on the specific features of the stream reach and its biota. The transformation of reaches subject to hydropeaking to reaches with Minimum Vital Flow can often improve the status quo; however, it is not a general rule that the effects of the reduction of the mean discharge are less impacting than those of hydropeaking and of the possible extended downstream releases (nevertheless, the expansion of the bypassed reach is usually associated with a final release into a larger stream, which should guarantee a reduction of hydropeaking ratio): the determinant factors are the characteristics of the possible new discharge regime, the structure of the basin between the intake and the last release point, etc.

Reference case studies

An example of “win-win” approach, based on the integrated management of several interconnected HPPs, regards the Ill River in Tyrol (Austria) (www.ecologic-events.de/hydropower/documents/moser.pdf). The river has great natural value, but was affected by hydropeaking from one hydroelectric power plant. After analyzing several mitigation options, a second HPP was built 20 km downstream of the first, and fed by the turbinated water though a conduit constructed on purpose. As a result, the first HPP was able to releases a higher MVF, because the consequent reduced production was compensated by the second HPP. The project resulted in several positive results: elimination of hydropeaking in the reach previously affected, restoration of a flow regime very similar to the natural one also thanks to the input of some tributaries; reduction of the erosion previously caused by the hydropeaking waves; reinstatement of aquatic flora and fauna similar to those of the regional reference water bodies; production of further 350 GWh/year of hydroelectric power.

LITERATURE REFERENCES

- The Nature Conservancy, 2009. Indicators of Hydrologic Alteration Version 7.1 User's Manual (http://conserveonline.org/workspaces/iha)

Mitigation and compensation measures to reduce the impact due to bed load and fine sediments management

Fish fauna - fine sediments

DESCRIPTION OF THE POTENTIAL IMPACTS

Planned reservoir sluicing and sediment traps cleaning produce a high load of suspended fines. The potential negative effects on fish fauna are due mainly to these processes.

- Asphyxia and direct damages (e.g., abrasions and gill damages), with intensity depending on the fine concentration compared with undisturbed conditions, and to the duration of the turbidity peak;
- stranding, mainly of fry and juvenile stages, strictly related to the discharge fall rate to base conditions;
- prolonged metabolic stress, for instance due to the effort required to swim against the current:
- loss of habitats due to the alteration of the substrate for long reaches, in particular to colmation of the interstices, and to other morphological alterations;
- low food availability due to the impacts on the other biotic components (such as macroinvertebrates, which undergo catastrophic drift or other impacts);
- reduction of growth rates, or resistance to infections, delayed or ceased eggs development;
- only for sluicing, possible alteration of the physico-chemical conditions of the water (temperature, dissolved gas, chemical reductions, release of heavy metals from the sediment due to anoxic conditions).

POSSIBLE MITIGATION MEASURES

Mitigation measures, related to both sluicing and sediment traps cleaning, should produce a sediment transport downstream as similar as possible the one occurring in natural conditions. Possible specific mitigation measures are the following:

- the operations should be conducted with a **proper timing** in order to keep the values of the main physico-chemical parameters (temperature, oxygen, pH, conductivity, etc.) within a range compatible with the natural one. This is attainable for instance following a protocol based on continuous monitoring of such parameters during the operations, which would allow regulating the release timing according to the ability of the stream to absorb the suspended loads;
- plan a **longer closing times of the sluicing gate** to allow fish fauna, especially the juvenile stages, to abandon the riparian areas and avoid stranding;
- plan the **release of appropriate flow** (of clean water) downstream, to flush the sediment from the substrate;
- evaluate the possibility, in particular for medium and small reservoirs, to use **mechanical digging of sediment instead than fluitation**; the removed sediment should be deposited downstream of the dam in areas from which the sediment can be gradually released into the stream with different rates depending on the transport capacity of the stream. The sediment release point must be chosen based not only on geomorphological requirements, but also on ecological ones, because these areas can be severely impacted. Mechanical removal can completely substitute sluicing, or

at least those phases where it is more difficult to avoid that the turbidity values exceed the critical value (typically, towards the end of the operations when the discharge is low compared to the high sediment load);

- adopt **sediment traps** allowing continuous sediment release (when the discharge in the bypassed reach support such operation).
- Adopt techniques allowing the **continuous mobilization and downstream transport of bottom sediment**, for instance by means of hydrosuction (see for instance the floating hydrosuction systems described in www.sedicon.no and www.db-sediments.com).

The cleaning operations must be formalized in an appropriate protocol, and follow these directions:

1. Adopt a **control system working in real time**: the cleaning operations must be conducted following data provided on real time by a data recording and transmission system (to the operative room). The key parameter to be monitored is turbidity, which can be monitored by turbidimeters appropriately set and protected. For a correct monitoring they must be set upstream and downstream of the sediment discharge point.
2. **Respect the maximum values**: a maximum concentration limit of 1% (10 g/L) of suspended solids (and never above the 1.5% threshold) only for time intervals shorter than 10 minutes. At this purpose, see also the thgresholds proposed in : "Quaderno di Ricerca: definizione dell'impatto degli svasi dei bacini artificiali sull'ittiofauna e valutazione di misure di protezione realizzato dalla Regione Lombardia" listed in the table below.

DURATION OF THE SLUICING OPERATION	VALUE OF THE FISH COMMUNITY IN THE DOWNSTREAM REACH			
	NO FISH VALUE		MEDIUM FISH VALUE	HIGH FISH VALUE
Few hours	50	Few hours	20	10
1 – 2 days	30	1 – 2 days	10	5
1 -2 weeks	10	1 -2 weeks	3	1.5

Maximum mean concentration of suspended solids (g/L) allowed during reservoir sluicing operations to safeguard the fish communities

3. In the **final phases of reservoir sluicing**, when due to the very high concentration of sediments it is very difficult to maintain the turbidity above the thresholds, it must be planned to remove the remaining sediment mechanically. The thresholds must not be passed also when emptying the sediment traps. The volume of sediment produced in this case is usually much lower, and it is possible to maintain a low turbidity by diluting with the water released, and by a gradual sediment release from the traps. It must be always avoided to clean the sediment traps with discharge supported only by the ecological flow release.
4. Choose the **appropriate timing**: the optimal time for a planned sluicing must be defined and planned taking into account the hydrological characteristics of the stream, and the life cycle of the target species.
5. **Flush** the sediment from the streambed with a flood characterised **by a discharge 20% higher than the previous one, extended for about 5 hours**. This manoeuvre re-establishes the previous conditions of the streambed, creates substrates fit for spawning, minimizes the turbidity increases during future events (floods, interventions in the riverbed) which can re-mobilize the sediment. After the flush flood, the return to the ecological flow release must be conducted slowly and gradually (1-2 hours), in order to minimize the loss benthic invertebrates and fish (in particular juvenile stages) by stranding.

Once flushing is complete, if the monitoring shows strong losses in the fish community, it is possible to plan actions aimed at repopulating the stream in order to accelerate the recovery.

REFERENCE CASE STUDIES

Some interesting Italian case studies are collected and described in Regione Lombardia, 2008.

LITERATURE REFERENCES

- Regione Lombardia, 2008. Quaderno di Ricerca: definizione dell'impatto degli svasi dei bacini artificiali sull'ittiofauna e valutazione di misure di protezione.

Bedload - Morphological conditions and geomorphological equilibrium

DESCRIPTION OF THE POTENTIAL IMPACTS

One if the most significant downstream impacts of the dam is the alteration of bedload transport, which in turn alters the planoaltimetric evolution of the streambed and its major morphological characteristics.

Typically, sediment trapping in the reservoir alters the granulometric curve (typically, the deposited sediment inside the reservoir decreases in granulometry from upstream to downstream, with coarser material deposited near the reservoir inlet, and gradually finer material deposited towards the dam), because only the fine sediment can move past the reservoir. Depending also on the released discharge, of the streambed in the section closer to the dam can become armoured (i.e., with a surface layer with larger granulometry then the deeper ones).

The accumulation of sediment in the reservoir frequently causes an alteration of the geomorphological equilibrium and sediment deficit downstream, resulting in incision; such alterations can propagate to large distance and to higher order streams, as far as affecting the coastline. When the alteration is significant, it can progressively lead to channelization, with modification of the streambed structure, loss of bedforms, reduction of bed width and even change in channel type (frequently from braided to single-channel). These effects can be self-sustained, for instance a strong channelization further reduced the sediment availability for bank erosion.

Among the coarse material trapped in the reservoir, the Large Woody Debris (LWD) are important for the biota because they represent a habitat; they also affect the streambed morphological dynamic (e.g., favouring the creation and evolution of bars and islands).

It must be underlined that the morphological effects of sediment balance alteration downstream of a dam are strictly related to the co-occurring discharge alterations, in particular the reduction of flood discharge; the two alterations must be analyzed together to detect the past and the present processes and to define appropriate mitigation measures.

POSSIBLE MITIGATION MEASURES

As previously underlined, the mitigation measures for morphological effects should be supported by a comprehensive hydromorphological assessment conducted at the appropriate scale, which would identify the critical issued and the possible management and maintenance measures for the reservoir and the stream.

Mitigation measures should be aimed at restoring the bedload transport downstream of the dam and can be divided into two main types: sluicing through the controlled opening of channels at the bottom of the reservoir to be conducted during flood events; mechanical dredging, transport and download of the sediment downstream. In general, it is better to use systems (removal from upstream the reservoir, aspiration or mobile dredging from the shores or from the surface, etc.) which based on the environmental requirements, remove the amounts and types of sediment as directed by the above-mentioned assessment. This sediment should be distributed downstream of the dam, with modality and techniques depending on the conditions of the stream, for instance by stocking the sediment in areas from were it can be easily mobilized and transported into the stream by formative floods.

A specific category of measures is the release of LWD to compensate for their reduction due to trapping in the reservoir.

Compensation measures, with effects on the impacted reach comparable to those of above described mitigation measures, involve the increase of sediment input from the slopes or from tributaries through the removal of bank protections, reactivation of landslides, selective removal of vegetation (in the latter case causing a local sediment production higher than the natural one, to compensate for the sediment trapped in the reservoir). These measures have to be conducted avoiding the increase of downstream flood risk

REFERENCE CASE STUDIES

A list of interesting experiences, involving both release of sediments from reservoirs and compensation through other means, are summarized in Piégay and Rinaldi, 2006.

In 1997, a master management plan was developed by the State services and the regional water authorities of the Rhône catchment. The plan indicated bedload as a key element for stream ecosystems which must be managed in a sustainable manner. The options in sediment management at the local scale depended on the conditions observed at the catchment scale. In clearing their installations, the private managers of weirs, who traditionally removed the gravel from their reservoir to maintain water abstraction, have now to transfer the gravel immediately downstream of the weirs to preserve sediment transfer. In mountain areas, where the RTM services had created numerous artificial areas for trapping and then systematically clearing gravel; the gravel is now pushed downstream of these structures back into the river, particularly in reaches with a recognised sediment deficit which created impacts.

In a reservoir on the upper Rhône River (Seyssel), which is silted by coarse sediment released from the Les Usses River, gravel is captured by a pump and conveyed downRiver of the dam by a pipe to maintain e sediment continuity.

The Drôme catchment suffers of a general sediment deficit, with local aggradation. Rather than removing the gravel from these areas, the active channel was remodelled to create a temporary geometry (narrower channel with gravel levees) which can transport more gravel (higher frequency and magnitude of shear stress), locally reducing the flood risk. Such work as repeated along the sensitive reaches, allowing the sediment to migrate into the deficit reaches.

Where incision resulted from reduced bedload sediment supply (e.g., downstream dams, gravel mining), the supply of bedload can be increased, thus sustaining processes causing incision rather than simply limiting the effects. On the Rhine River below the barrage of Iffezheim, an annual average of 170,000 ton of sand and gravel are dumped on the river bed from barges to compensate for the bedload trapped upstream dams. Similar approaches have been tested in the Danube River after the building of the hydropower plant Freudenau on the Austrian Danube downstream of Vienna (about 300 000 m^3 of gravel per year), although aiming to reduce this amount by improving the bed granulometry (increase in sediment size).

On the Rhône River near Chautagne, sand and gravel deposited upstream of a dam is mechanically moved to the incised reach downRiver of Motz Dam, at an annual cost of 170 000 Euros.

In the U.S.A., pioneer works of this kind were those of Kondolf and Matthews (1993) along the Sacramento River in California downRiver from Shasta dam.

Scientists and managers in France are now gaining preliminary experience in gravel reintroduction in the Ain and Drôme Rivers, within projects funded by the European Community (LIFE program). The Ain River, in its valley stretch, underwent progressive erosion following a chain of dams built between 1933 and 1968. The sediment deficit downstream extends at an estimated average of 500 m per year, based on bar disappearance observed from historical aerial photos (Rollet et al., 2004). This is a major problem in terms of ecological conservation, because the most valuable areas will be affected by this alteration within the next decade. In order to reduce this process and to restore the already disrupted reach, sediment is being re-introduced. The potential bedload transport has been estimated based on hydraulic calculations and field bedload surveys, and the amount of gravel sediment stored in the floodplain has been estimated from sediment cores and GIS calculations. From these estimations, artificial reintroduction from floodplain storage has been considered a feasible strategy for several decades. Such an approach is efficient because it will restore the river bedload (half of the potential annual bedload transport); it will also restore the riverine habitats by coupling the sediment release with floodplain habitat restoration: floodplain habitats with will be created at a lower topographical level, which therefore will be flooded more frequently and reconnected to the groundwater table. The first sediment release took place in August 2005 and the bedload was excavated from a former channel which was deepened and widened. Bedload supply may also be increased by permitting the river to erode its banks upstream.

An erodible corridor has been planned or adopted along several French piedmont tributaries to the Rhône River, to provide sand and gravel input from the former floodplain.

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- Kondolf G.M. and Piégay H. (editors) , 2003. Tools in Fluvial Geomorphology. John Wiley & Sons Ltd.

Assessment of the different types of measures

Mitigation through HP infrastructure management

This category comprises **management measures** that are more or less **linked to electricity production**, either concerning the operation or the design and the building of the necessary HP infrastructure.

Appropriate management measures could be:

CODE	MITIGATION MEASURES THROUGH HP INFRASTRUCTURE MANAGEMENT
A1	Minimum flow: qualitative & quantitative improvement (i.e. upstream regulation level strategy)
A2	Hydropeaking reduction (i.e. minor reservoir and second turbine insertion)
A3	Reservoir management optimization (i.e. seasonal variation of reservoir according to natural solid transport scheme)
A4	Power plant design (i.e. insertion of fish ladder, different geometry of brook intakes, change of tailrace outlet location, Fish friendly turbines, Mini/micro hydropower plants in artificial structures,…)
A5	Cross basin water transfer restriction
A6	Refurbishment of older water management facilities

Mitigation through environmental measures

Environmental measures are supposed **to improve the environmental quality** of the concerned river ecosystem. They are not limited to the HP infrastructure.

Appropriate environmental mitigation measures could be:

CODE	ENVIRONMENTAL MITIGATION MEASURES
B1	Improvement of the hydrological character of river
B2	Restoration of the connectivity of river systems
B3	Restoration of the solid material transport and deposition equilibrium
B4	Landscape & biotopes conservation (i.e. water impoundment, sediment impoundment, shoreline erosion, …)
B5	Biocoenoses conservation (i.e. Natura 2000 or Habitat species)
B6	Pollutants dilution (i.e. physical . chemical condition enhance) in withdrawn stretch /n in reservoir
B7	Restoration measures focused on biocoenoses (i.e. fish stocking, riparian vegetation restocking, etc. …)

Compensation through "*ex situ*" measures

Compensation actions (***ex situ***) are measures not linked to the affected river ecosystem.

Different degrees of compensation have to be distinguished: the compensation actions included between D1 – D7 measures listed in the table below, presents different categories covering a large range of possible measures and the functional coherence with the impact of the HP installation is generally in decline from D1 to D7.

Appropriate compensation measures could be:

CODE	COMPENSATION (DE-LOCATED MITIGATION / RESTORATION / ECO-INVESTMENT MEASURES)
D1	Complete re-naturalization and decommissioning of a river stretch inside the same catchment area
D2	Complete re-naturalization and decommissioning of a river stretch outside the catchment area
D3	Partial restoration of a river stretch inside the catchment area
D4	Partial restoration of a river stretch outside the catchment area
D5	Eco-investment in local/regional nature conservation or water management projects
D6	Eco investment in a different type of local/regional sustainable development projects:
a	Energy efficiency
b	Transport
c	Waste Management
D7	Direct Payments for mitigation to local/regional bodies

Compensation through Impact on Regional Economy

The compensation of HP impacts can be reflected **on regional economy** and can it be an **additional criterion** to distinguish alternative HP exploitation solutions. Proposals of how to assess this impact are basically the same as the **regional economy indicators** to be taken into account for the discussion of different HP alternatives.

CODE	REGIONAL ECONOMY (INDICATORS BASED ON EUROSTAT, ADAPTED TO REGIONAL ECONOMY)
C1	Total of long term jobs created by HP facilities
C2	Impact on local/regional employment rate created by HP facilities
C3	Impact on local/ regional gross domestic product created by HP facilities
C4	Impact on regional gross domestic product/inhabitant created by HP facilities
C5	Impact on regional primary income of private households/ inhabitant created by HP facilities
C6	Contribution to regional economic diversification created by HP facilities
C7	Positive or negative cross impact with:
a	science/technology
b	education
c	tourism
d	transport infrastructure
e	health
f	agriculture
g	cultural heritage

Processing for the SHARE project

Based on the principle that the environmental impact of HP has to be mitigated or compensated, the **costs** and the **functional coherence** of the mitigation and compensation actions have to be considered.

The cost analysis

The **cost analysis** refers to the economic impact of the compensation and mitigation. The cost effect on water HP use can be generically evaluated as:

- **Low**
- **Medium**
- **High**

The functional coherence

The **functional coherence** gives priority to the "*in situ*" mitigation by management and environmental measures. Only if the incurred degradation cannot be fully mitigated or if these measures are inefficient (see below), additional compensation measures should be considered as described into the SHARE "**Guidelines to integrate MCA procedures in local normative**".

This principle is integrated into the **efficiency evaluation**.

The efficiency evaluation

As **priority** has to be given **to "*in situ*" mitigation measures** (management, environmental), their efficiency has to be formally assessed comparing these measures with the "*ex situ*" compensation actions.

As shown in the table below, for categories can be distinguished **four different efficiency assessments** and only for the efficiency category number 1 "*ex situ*" compensation actions are not necessaries.

CODE	EFFICIENCY DESCRIPTION
1	The negative impact caused by HP construction can be mitigated completely, or almost completely "*in situ*"; compensation "*ex situ*" is not necessary or much less efficient
2	The negative impact caused by the HP construction, can be partially mitigated; an additional compensation "*ex situ*" has to be integrated
3	Only a very small part of the negative HP impact can be mitigated; compensation has to be planned exclusively "*ex situ*"
4	"*In situ*" HP negative impact could be mitigated, but the mitigation is less efficient than "*ex situ*" mitigation

Proposal of eco-investments, mitigations & restoration actions for the SHARE Pilot Case Studies

SHARE PCS	PP INVOLVED	LOCAL COMPENSATION / MITIGATION / RESTORATION / ECO-INVESTMENT (*MAINLY IN SITU*)						REMOTE COMPENSATION / MITIGATION / RESTORATION / ECO-INVESTMENT (*MAINLY EX SITU*)			
		Mitigation measures through HP infrastructure management			Environmental mitigation measures			Compensation (de-located mitigation / restoration / eco-investment measures)			
		CODE	Negative impact on water HP use	Efficiency	CODE	Negative impact on water HP use	Efficiency	CODE	Negative impact on water HP use	Efficiency	Impact on local/regional economy
		A1 – A5	HIGH MEDIUM LOW	1-4	B1 – B7 D1, D3, D5, D6	HIGH MEDIUM LOW	1-4	C1 – C6 D2, D4, D7	HIGH MEDIUM LOW	1-4	SIGNIFICANT LOW IRRELEVANT NEGATIVE
Dora Baltea	**LP**	A1	HIGH	2	B1	HIGH	2	C4	LOW	3	SIGNIFICANT
		A3	LOW	1	B2	LOW	2				
		A4	LOW	4	B3	LOW	4				
					B4	MEDIUM	2				
					B5	MEDIUM	2				
					B6	MEDIUM	1				
					B7	LOW	2				

					D3	LOW	2				
					D5	LOW	3				
					D6 –c	LOW	3				
Chalamy	**LP**	A1	HIGH	1	B1	MEDIUM	1				
					B4	LOW	1				
					B5	LOW	1				
					B7	LOW	1				
Astico	**PP2**	A1	LOW	2	B1	MEDIUM	2				
		A3	MEDIUM	2	B2	MEDIUM	2				
		A4	LOW	2	B3	MEDIUM	2				
					B6	MEDIUM	2				
					B7	MEDIUM	3				
					D3	LOW	2				
Cordon	**PP2**	A4	HIGH	2	B1	MEDIUM	2				
		A6	HIGH	2	B2	MEDIUM	2				
					B3	MEDIUM	2				
					B4	MEDIUM	2				
					B6	MEDIUM	3				
					B7	MEDIUM	3				
Chisone	**PP1**	A1	LOW	2	B1	MEDIUM	2	C4	LOW	3	SIGNIFICANT
		A2	MEDIUM	2	B2	MEDIUM	2				
		A3	MEDIUM	3	B3	MEDIUM	2				
		A4	LOW	2	B4	LOW	2				
					B6	MEDIUM	2				
					B7	LOW	2				
Mur	**PP6**	A3	MEDIUM	2	B3	MEDIUM	2				
					B4	MEDIUM	2				
Inn	**PP7**	A1	MEDIUM	2	B1	MEDIUM	2				

		A3	MEDIUM	3	B4	MEDIUM	2				
		A4	LOW	3	B2	HIGH	2				
Kokra	**PP4 + PP5**	A1	MEDIUM	2							
		A4	LOW	2							
Lech	**PP11**	A1	LOW	3	B3	MEDIUM	2	D3	MEDIUM	3	LOW
		A2	MEDIUM	2	B4	MEDIUM	2				
		A4	MEDIUM	2							
Var	**PP10** (for the Alternative 1)	A4	LOW	3	B1	LOW	3	C1			LOW
					B2	LOW	3	C6			SIGNIFICANT
					B3	HIGH	3	C7b			LOW
					B4	LOW	4				
					B5	LOW	4				
	PP10 (for the Alternative 2)	A4	HIGH	1	B1	HIGH	1				
					B2	HIGH	1				
					B3	HIGH	1				
					B4	HIGH	1				
					B5	HIGH	1				
	PP10 (for the Alternative 3 and 4)	A4	MEDIUM	2	B1	MEDIUM	2	C1			LOW
					B2	MEDIUM	2	C6			SIGNIFICANT
					B3	MEDIUM	2	C7a			LOW
					B4	MEDIUM	2	C7b			LOW
					B5	MEDIUM	2				
Arc-Isère	**PP9**	A1	LOW	2							
		A3	MEDIUM	2							
		A5	MEDIUM	2							