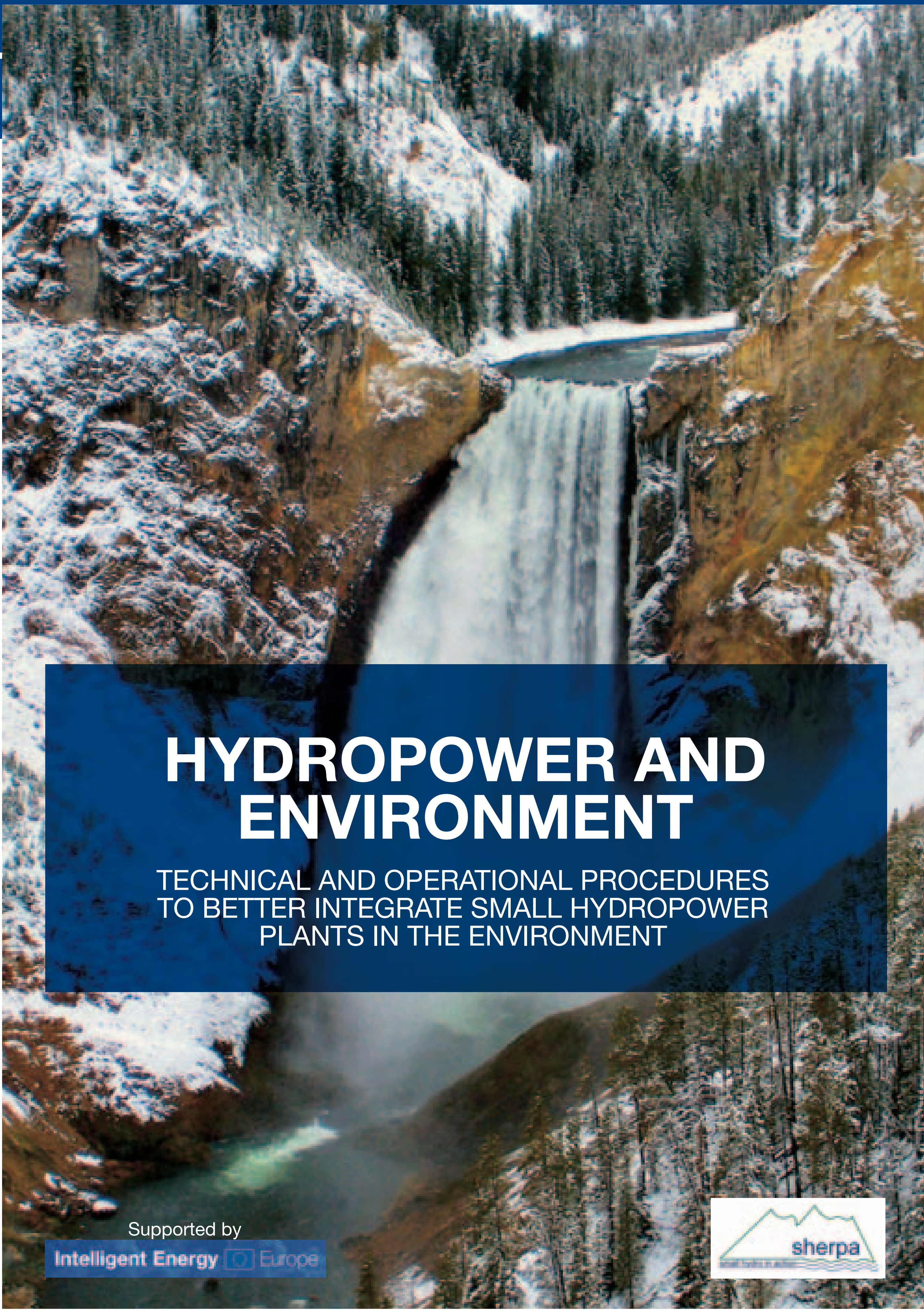

HYDROPOWER AND ENVIRONMENT

TECHNICAL AND OPERATIONAL PROCEDURES TO BETTER INTEGRATE SMALL HYDROPOWER PLANTS IN THE ENVIRONMENT

Supported by

Intelligent Energy Europe

sherpa

This brochure has been developed under SHERPA project – Small Hydro Energy Efficient Promotion Campaign Action.
SHERPA is a European Funded Project in the framework of the Intelligent Energy for Europe Programme (IEE).
SHERPA aims to make a significant contribution in reducing the barriers that are currently hindering the development of SHP, addressing the challenges and contributing to the uptake of SHP in the new enlarged European Union.
The result of SHERPA will not only increase the awareness of politicians and decision makers on SHP as a key renewable energy source, but will also create favourable framework conditions for the further uptake of SHP within the European Union.
The project specifically addresses the issue of environmental performance of SHP plants, as well as a comprehensive territorial planning approach at the level of water bodies.
ESHA, the European Small Hydropower Association, is the European co-ordinator of this project, which includes eight additional partners: SSHA (Slovenia), LHA (Lithuania), APER (Italy), SERO (Sweden), IED (France), IWHW (Austria), EC BREC/CLN (Poland), ADEME (France).

This brochure has been coordinated by Sara Gollessi and Giulia Valerio from APER (Italy).

We wish to thank ESHA staff for the revision and other SHERPA partners for their contributions.

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INTRODUCTION

Hydropower is a key source for renewable electricity generation and has an important potential to be marketed as green power. While offering ecological advantages from a global perspective, such as climate change mitigation, emergency management and reduction of flooding risk, the construction and operation of hydropower plants may cause some environmental impacts on the local and regional level. These include harm to fish populations, a loss of aquatic habitat, a significant change in natural flow regimes and deterioration of the landscape. The following table lists the main positive and negative impacts of hydropower. As a result, a contrast between two different but well-grounded environmental goals seems apparently insoluble: green-house effect reduction, on the one hand, and water habitat protection, on the other. This is a very weak point that has important consequences from a regulative point of view, as reflected in the contradictions between the objectives and targets set by two key European Directives: WFD (Water Framework Directive) and RES-e (Renewable Energy Sources electricity Directive). Nevertheless, there are different solutions that can reduce these contrasts and promote, as a consequence, the achievement of a higher environmental quality.

First of all, the choice of **Small Hydropower**, i.e. plants with a capacity of less than 10 MW: they are often run-of-river hydro plants and, thanks to the absence of a storage basin, have a minor impact on the hydrological regime of the river, one of the most important sources of environmental impact.

THE ENVIRONMENTAL PROBLEM: A BALANCE

Secondly, the application of a careful and modern design based on the application of **mitigation and compensation measures** that can ameliorate integration of Small Hydro Plants (SHP) in the environment.

The aim of this report is to describe a new concept of hydropower design, more environmentally-friendly than the traditional one. Nowadays, when climate change and water resource management have been defined as the major international problems faced by the International Community, this sort of approach seems to be the only rational way to continue using a reliable source of renewable energy while at the same time maintaining a healthy environment and a sustainable ecosystem.

1 GWh produced by a SHP plant avoids on average the emissions of about 480 tons of CO_2

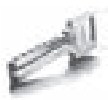
ACTIONS DURING OPERATION	IMPACTS		PERSONS OR OBJECTS AFFECTED
Renewable energy production	☺	Avoid green-house gas emissions	General public
Presence of a trash rack cleaning machine	☺	Removal of anthropogenic waste from the water for free	General public
Raising of river banks near to the diversion works Presence of a storage basin	☺	Flood protection	General public
Water diversion	☹	Habitat modification due to the interruption of spatial and temporal continuity of rivers	Aquatic ecosystem and environment in general
Water diversion	☹	Creation of a barrier for fish passage Death of a certain percentage of fish passing through the turbine	Aquatic ecosystem and environment in general
Presence of anthropogenic structures (powerhouse, electric lines, penstocks, ripraps)	☹	Visual intrusion Possible movement barriers for animals	General public, animals and environment in general
Impoundment generated by weirs in backwater areas	☹	Alteration of natural habitat conditions (reduction of flow velocity and consequent sedimentation)	Aquatic ecosystem
Operation of hydroelectric unit, speed increasers, trash rack cleaner, trash conveyor	☹	Noise emission	General public and environment in general

Main impacts of a hydro plant on the environment

1 LOW IMPACT HYDRO PLANNING

Before an in depth analysis of the technical procedures that can mitigate the negative effects of SHP on the environment, it is crucial to underline the existence of planning solutions intrinsically presenting a very low environmental impact. Here we are talking about the hydroelectric production realized on existing structures, that itself exploits water diversion, and also about those that develop marginal potential present on an anthropical area. In this way, the impacts connected to the use of a vital and limited resource and to the location in a natural place are strongly reduced, while at the same time the environmental benefit is maximized due to renewable energy production, i.e. the reduction of greenhouse emissions. This sort of planning can be considered as an effort to rationalize water resource exploitation and to optimize human actions on the environment, which is a strategy, shared at an international level, to achieve the goal of a sustainable way of life that would not threaten future generations. In order to promote this way of planning, it is essential to develop an integrated and multidisciplinary approach in water-resource management; also these hydro-schemes have a future only if they are supported by economic incentives and simplified administrative procedures.

1.1 MULTIPURPOSE SCHEMES



INTEGRATION

Water is an essential need in a wide range of human activities, such as hydroelectric power generation, irrigation, water supply and domestic life. Year after year, this requirement is becoming more and more intense, in contrast with the limited nature of the resource and the problems connected with the compromise of the quality of available freshwater. Accordingly, this situation intensifies the resource exploitation and creates a strong competition between different water uses. A sustainable development therefore demands a sustainable management of the world's limited resources of water, in order to meet the needs of society, to permit mitigation of water-related hazards, and to maintain or enhance the condition of the global environment. In an integrated water resource management perspective, the **multipurpose hydro plants** find a more suited position. A multipurpose scheme is one that combines different water uses in a single diversion. In these schemes, energy production is not the only and often not the main goal of water exploitation and, for this reason,

"Water is necessary in all aspects of life. […] Its multi-sectorial nature must be recognized in the context of socio-economic development and, as a consequence, the essential role that it carries out in a whole series of indispensable operations: from the supplying of drinking water to hygiene-sanitary conditions, from agricultural to industrial production, from urban expansion to the production of hydroelectric energy, from transport to recreation and tourism and numerous other activities".
-From: Agenda 21, Rio de Janeiro, 1992-

it can be seen as an example of rational exploitation of the resource and an effort towards environmental sustainability. This results in the best compromise between different public interests while reducing environmental impacts. In particular, when a plant is built in order to use an existing discharge, it has the only benefit of reducing green house gas emissions with no extra negative impacts on the environment. Hereafter, some examples of multipurpose hydro plants are shown.

1.1.1 SHP along irrigation channels

(➡ CASE STUDY N.1)

Some small hydro plants, especially low-heads plants, have been realized along existing irrigation channels to use part of the water that has just been diverted to irrigate fields.

1.1.2 SHP along drinking water supply system

(➡ CASE STUDY N.2)

Many drinking water systems, especially in mountainous areas, are characterized by high water heads, that can be exploited for energy production, instead of being dissipated in relief valves. In fact, when there is a significant difference in height between the intake and the final point of distribution, it is necessary to install some relief valves to reduce water pressure and avoid problems in the downstream equipment and pipes. The same effect can be obtained by installing a turbine. In this way the surplus water pressure can be exploited for energy production and the aqueduct manager has a supplementary economical benefit thanks to the energy sale.

1.1.3 SHP along waste water system

Some waste water treatment systems are characterized by significant water heads above or below the plants. These can be exploited through a hydro plant, that needs, only in the first case, a pre-treatment.

1.2 RESTORATION OF ANCIENT WATER MILLS

REUTILIZATION

The first hydraulic machine capable of exploiting water power was the wheel, a simple and ingenious machine that could provide mechanical energy taking advantage of the natural slopes of the waterways or falls artificially created with simple derivations. Romans were the first to use them, but it is above all in the Middle Ages that wheels became much more widely used, enough to become year after year a primary energy source.

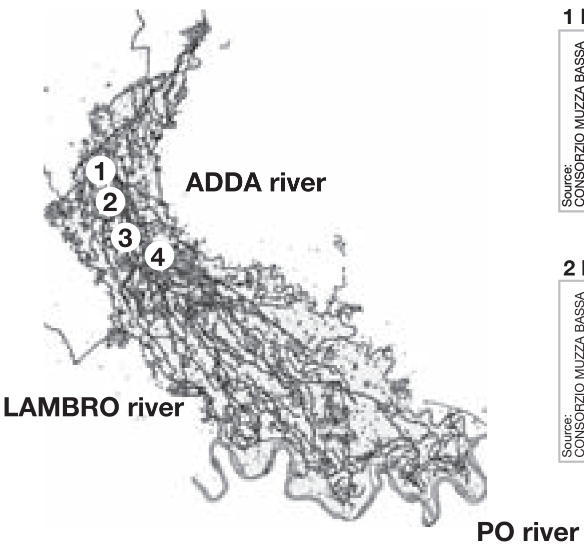
A WATER-MILL IN DENMARK

Nowadays, in the European countries it is still possible to see many abandoned water-mills near to old farmsteads that could be upgraded and reutilized. In this way, an existent energetic potential would be appreciated, and hydroelectricity could become an opportunity to safeguard our cultural and historical heritage.

CASE STUDY N°1:
Hydro plants on Muzza channel, Lodi, Italy

Muzza is the oldest diversion channel realized on the natural watercourse Adda, which is an important tributary of the Po river located in northern Italy. Beginning from Muzza, a network of artificial channels have been developed: they run for about 6000 km and irrigate 735,1 km2 of fields. Along Muzza, 4 run-of-river hydro plants are operational: in this way, agriculture has been well integrated with hydroelectric production, through an optimisation of water resource exploitation.

	PAULLO	BOLENZANA	BELGIARDINO	QUARTIANO
Turbines	Kaplan (2)	Kaplan (2)	Kaplan (2)	Kaplan (1)
Net head [m]	3,79	3,52	9,69	3,5
Average discharge [m^3/s]	59,80	52,50	14,00	48,02
Installed capacity [kW]	2.600	1.800	2.200	1.400
Average generation [kWh/year]	14.000.000	13.500.000	9.500.000	13.000.000



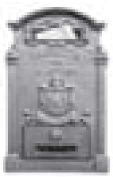
1 PAULLO

3 QUARTIANO D'ADDA

2 BOLENZANA

4 BELGIARDINO

Small hydro plants on the irrigation channel Muzza, Italy.



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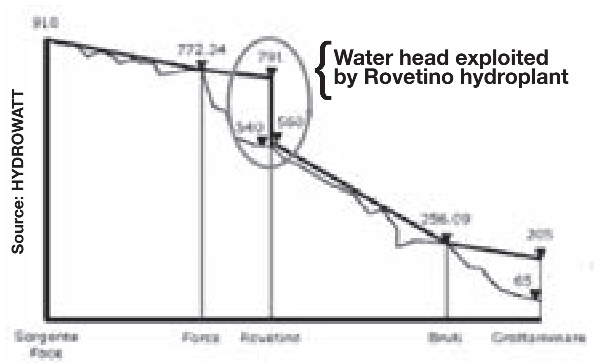
Environmental benefits:

- Multiple water use: rational exploitation of the resource
- Location in a still anthropogenic place and use of the local architectural style: small impact on the landscape
- Electrical production as a secondary scope of water use: hydro plants with low environmental impact

CASE STUDY

CASE STUDY N°2:
An hydro plant on a drinking water supply system, Ascoli Piceno, Italy

Rovetino is a SHP that exploits a water head present along a mountain supply system located in Italy, that otherwise should be dissipated by pressure regulation valves to avoid problems in the downstream pipes and equipment. To assure a compatible coexistence of energy and water supply use, the adoption of proper technology is needed in this sort of hydro planning:
- installation of turbines without lubricated organs in contact with water and choice of proper materials (stainless steel for runner and guide-vanes, cast iron for turbine box). In this way, every kind of drinking water pollution is avoided;
- installation of reaction turbines, which give back water with a proper pressure, to assure the efficiency of the water supply system;
- creation of an automatic by-pass to assure a continuous water flow even in presence of an interruption of the hydro plant operation;
- management of the hydro plant with a remote control system: by monitoring and modifying the operation conditions, a good service of the aqueduct is guaranteed.

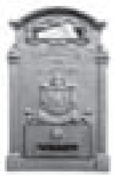


Hydraulic grade line in the aqueduct of Monti Sibillini, Ascoli Piceno, Italy.

	ROVETINO
Turbines	Francis (3)
Net head [m]	180 + 40
Average discharge [m^3/s]	0,27 + 0,25
Installed capacity [kW]	760
Average generation [kWh/year]	4.000.000

Environmental benefits:

- Multiple water use: rational exploitation of the resource
- Location in a still anthropogenic place: minor impact on the landscape
- Electrical production as a secondary scope of water use: hydro plants with low environmental impact
- Optimisation of the aqueduct costs, thanks to the use of energy produced for the pumping systems
- On-site generation: reduction of energy losses due to long distance electricity transport



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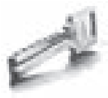
1.3 UPGRADING AND REPOWERING OF EXISTING SHP



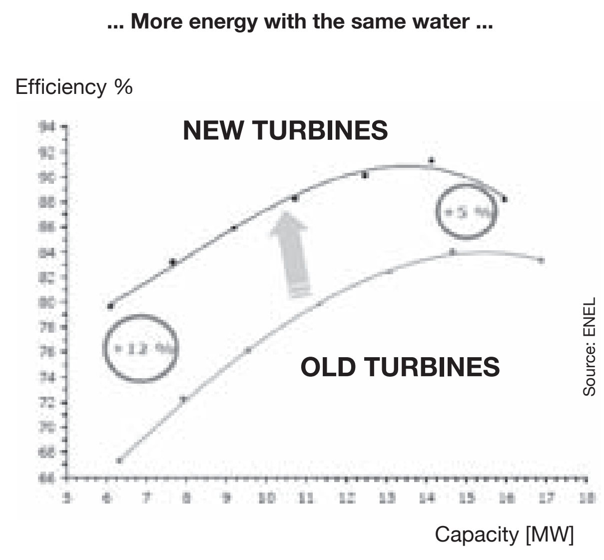
EFFICIENCY

It is quite intuitive to understand that the upgrading and extension of existing facilities generate impacts that are quite different from an entirely new scheme. In these cases, in fact, some of the anthropical structures are maintained, such as the powerhouse and penstocks, without any consequent visual impact of the action. Even better, the pre-existent structures can be modernized by adopting new techniques that can mitigate this sort of impact.
In this context some particularly well accepted projects are the ones directed towards the increase of machine efficiency and reduction of water head losses, i.e. towards an upgrading of the whole yield of the transformation. As the following formula shows, the effect is an increase of the plant capacity and production, under the same discharge conditions.

$$P = \eta\gamma QH$$

where:
- Q is the volumetric discharge;
- H is the gross head, calculated as the difference between the geodetic head and the water head losses;
- γ is the water specific weight;
- η is the plant efficiency, calculated by the product of the efficiencies of turbine, generator, speed increaser and transformer.

In other words, these projects turn the hydro capacity increase to the advantage of the producer, that can sell more energy, and to the environment too, because of the percentage growth of renewable energy production.
In Europe, where the sector started to develop 150 years ago, there is a consistent potential in repowering old hydro plants.



Effect of repowering on turbine efficiency

The European Project "Blue Age for a green Europe" (2002) is focused on the study of the potential of SHP in Europe. The estimation of the residual potential only under technical constraints is 2080 MW (8100 GWh/year) by upgrading existing plants.
http://www.esha.be/fileadmin/esha_files/documents/publications/publications/BlueAGE.pdf

2 MITIGATION MEASURES

As previously mentioned, the construction and operation of SHP may cause quite severe environmental impacts on the local and regional level, affecting water resources, some biological communities and landscape. Nevertheless, a careful design and rational operation can mitigate these effects and strongly improve the integration of the plant within the natural context in which it is built. Hereafter, some of the most effective mitigation measures are shown.

2.1 RESERVED FLOW

FLEXIBILITY

Water diversion, which deprives a reach of a part of its natural flow, is the key-problem concerning the environmental impact of small hydro plants. So, in order to make hydropower production more compatible with the natural life of rivers, a minimum flow must be released so as to assure the preservation of the hydrological continuity of the river and the consequent conservation of natural habitat and ecological life.
Most of reserved flow definitions underline the will to achieve biocenosis protection and a good aquatic ecosystem quality. Nevertheless, it is quite difficult to express these biological aspects in a mathematical formula: nowadays there isn't yet a universally valid solution to calculate reserved flow.
As the following table shows, the most diffused calculation methods are based on empirical formulae that express reserved flow as a function of different variables (morphological, statistical and hydrological). They are very easy to apply, but also simplified and often unrelated to the biological factors. On the contrary, methods based on multi-objective and experimental planning, taking into consideration ecological parameters too, are very expensive and complex in data collection and mathematical computing, but also much more efficient. In fact a common belief, shared by ecologist associations too, is that it is almost impossible to extrapolate the optimum reserved flow to a vast area. For this reason up to now the only way of assuring the goal of efficient environmental protection, without any useless loss of renewable energy, is through experimentation, based on specific morphological, hydrological and ecological conditions.

In the future, a desirable outlook is the diffusion of experimental methods, where one can measure the real effects of a discharge release on fluvial environments. Future evaluations of environmental flow are encouraged to take into account the principles of this sort of approach:

- field activities and modelling;
- site-specific approach;
- integrated vision of the ecosystem;
- variability of reserved flow;
- multi-criteria evaluation;
- collaboration between competences.

Source: APER

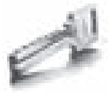
COOPERATION BETWEEN ECOLOGISTS AND ENGINEERS IN A FIELD ACTIVITY

... THE PRESENT:

COUNTRY	NOT REGULATED	REGULATED	WATER USE AUTHORIZATION CONSTRAINT	RESPONSIBLE AUTHORITY	FORMULA
AUSTRIA		X	X	An official expert	There is no standard method: RF is fixed before granting a licence, with reference to the case under examination. Often, the reference is the range between annual mean minimum flow and annual minimum flow.
FRANCE		X			General rule: RF >1/10 of inter-annual mean flow For flow rates higher than 80 m3/s: RF > 1/20 of inter-annual mean flow.
GERMANY		X		Länder	Different regulation among Länder. A very common approach is to fix the RF between 1/3 and 1/6 of mean minimum flow.
GREECE		X			RF > 1/3 of average summer mean flow.
ITALY		outgoing	X	Regions	Different regulation among regions. A very common approach is to use parametric formulae, where the reserved flow is imposed as a fraction of the mean river flow. This fraction takes count of hydrological, morphological and environmental aspects.
LITHUANIA		X		Ministry of Environment	Differentiation among two different hydrological regions: 1): RF = low flow warm reason of 30 days duration and 5 years return period. 2): RF = low flow warm reason of 30 days duration and 20 years return period.
NORWAY		X			RF > Q350 (flow rate that is equalled or exceeded on average 350 days in/year).
PORTUGAL		X			RF >= 1/10 of inter-annual mean flow.
SCOTLAND		X			RF >= 45/100 of inter-annual mean flow.
SWEDEN		X			There is no standard method: RF is fixed to the specific case under examination.
SWITZERLAND		X		State	RF is a growing function of Q347 (flow rate that is equalled or exceeded on average 347 days in/year).
SPAIN		outgoing		River basin authority	Before 2001, RF was established at 10% of inter-annual mean flow; after 2001 different formulae have been developed for each basin. According to the new Water Act each river authority should develop a system to evaluate RF for each river. A majority tend to follow the IFIM method, but up to now only the Basque region has elaborated a computer programme to do it.
UK		X	X	Environment Agency	There is no standard method: RF is fixed before granting a licence, with reference to the case under examination. The starting point of negotiation is Q95 (flow rate that is equalled or exceeded on average for more than 95% of the year).

Some of the current European regulations relating to reserved flow.

2.2 AESTHETICAL IMPROVEMENT



HARMONY

Each component of an hydro scheme - powerhouse, weir, spillway, penstock, intake, tailrace, substation and transmission line - has the potential to create a change in the visual impact of the site which is important to the public, who is increasingly reluctant to accept any changes to their visual environment. Most of these components may be screened from view on the base of a well-chosen design, i.e. by incorporating mitigation strategies that, usually, can facilitate permit issue without generating too many extra costs.

2.2.1 Powerhouse

Especially in mountainous areas, the designer has to integrate the powerhouse in the environment to the best of her/his abilities. In order to minimize visual impacts, the most effective powerhouse is the interred one, but its cost can make a SHP investment unprofitable. A good but cheaper solution is the use of natural features - local stones, ground, vegetation - to shroud the building and, if not applicable, painting it with non-contrasting colours and textures to reduce contrast with the background. It is very important to include specific elements that ensure the recognition of a SHP identity, allowing people to associate the concepts of beauty and peculiarity with these buildings, just as mills throughout the centuries had been conceived. In this way, aesthetics could become an opportunity to make the community aware of the highly positive value of such a plant.

2.2.2 Penstocks

The penstock is usually the main cause of visual intrusion of a SHP, and it also forms a barrier to the movement of wild-life. From this point of view, an excellent solution is penstock interment, although this carries disadvantages in terms of control and geological risks connected with the stability of steep slopes. Nowadays, the pipe and coatings have strongly improved at the technological level, to ensure that an interred penstock requires practically no maintenance for several decades. In particular, the choice of glass reinforced plastic pipes is strategic to control corrosion and consequently reduces maintenance. Where a penstock cannot be interred, other mitigation measures available are the adoption of anchoring blocks and the elimination of expansion joints.

2.3 NOISE REDUCTION

Noises and vibrations within a small hydroelectric plant come from the trash rack cleaner, the trash conveyor, the generator, the gearbox, the turbine, the transformer, the hydroelectric unit and the speed increaser. This sort of impact can be unacceptable when houses are located near to the powerhouse or when the plant is located in a protected natural site. In these cases, a careful design can allow the achievement of excellent levels of noise reduction and thus strongly mitigate the acoustic impact of the plant.

Some of the most diffuse techniques are the following:

- small tolerances in gear manufacturing;
- sound insulating blankets over the turbine casing;
- water cooling instead of air cooling of the generator;
- acoustic insulation of the building.

CASE STUDY N°3:
Cordiñanes hydro plant, Picos de Europa, Spain

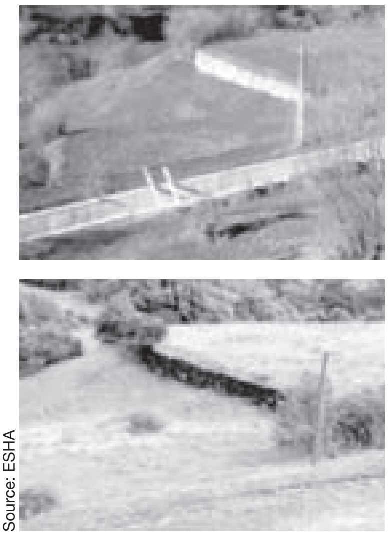
Cordiñanes, a small hydro plant located in eastern Spain, is an emblematical example demonstrating the efficiency of the actions directed to mitigate the visual impact on landscape of hydro scheme components. Although the weir is quite high (14 m), the water level in the reservoir cannot vary by more than two metres, which confers to the pond the character of a picturesque lake. The powerhouse is a typical mountain house, characterized by limestone walls, old roof tiles and heavy wooden windows, which veil its industrial purpose. Additionally, two thirds of its height are buried to improve its appearance. With regard to the infrastructures, the channel that transports water from the intake to the forebay is entirely buried and covered by a layer of soil and vegetation. From the forebay a steel penstock brings the water to the turbines, with a first trench excavated in the rock and filled with coloured concrete, a second excavated in the soil and the last one covered by vegetation. The power cables are buried when the line passes through the habitat of a very rare bird species - the “Tetrao Urogallus”.

Turbines	Francis (2)
Net head [m]	3,79
Installed capacity [kW]	1.000

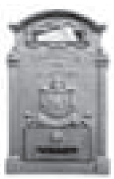
Source: ESHA

CORDIÑANES PLANT; IMAGES OF THE POWERHOUSE

Source: ESHA



CORDIÑANES PLANT; IMAGES OF THE CHANNEL BEFORE (LEFT) AND AFTER COVERING (RIGHT)



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Environmental benefits:

- Well screened anthropogenic elements
- Plant integration in a mountainous area
- Defence of natural habitats

2.4 FISH PASSES

NATURE-LIKE

Going from the spring to the mouth of a river, it is possible to recognize a succession of different ecosystems, each characterized by specific morphological, hydrodynamic, climatic, physical and chemical parameters and, as a consequence, by specific biological communities. Nevertheless, the transition from an ecosystem to another is always gradual, both in time and space, and this sort of continuity is a peculiar element of fluvial habitats. The ichthyofauna is strongly influenced by the characteristics of the environment where it lives, and in particular the migratory communities need a high level of habitat diversification during their life cycle. The characteristics of these migrations strongly change from one species to another, and this is often due to different needs, such as reproduction, search of food and holds; in any case, these movements are always vital as they ensure the best conditions for fish survival. An emblematic example is the migration of Salmons that, after growing in the sea, go upstream the river for hundreds of kilometres in order to reproduce.
From this point of view, it is not difficult to understand the criticism coming from ecologists with respect to weirs and dams, as they constitute barriers that interrupt the continuity of rivers and therewith may delay, hinder or block fish migrations. So, only by adopting mitigation actions finalized to restore river continuum, called fish passes, it is possible to guarantee the diversity and abundance of fish fauna and, as a consequence, achieve an ecological acceptability of SHP concerning fish and benthonic organisms. There is a great variety of manufactures and designs of fish pass systems, realized both along the weir and nearby through a by-pass. Instead of the most conventional ones, SHP are in particular suitable for the application of natural-like fish passes, recently developed with the aim to simulate some natural features of fluvial systems, such as pool-riffle, step-pool, rapids and plane bed formations. Predominantly made by natural materials, such as boulders, cobbles and finer sediments, and protected by using bioengineering techniques, these fish passes reproduce the variable hydraulic conditions, typical of mountain torrents. Thanks to the succession of areas with low and high flow velocities, fish are able to overcome the obstacle and migrate upstream.

The design philosophy of nature-like fish passes is ecologically minded, aiming to achieve compatibility with the specific fluvial environment as well as the landscape they are built in; as a result, they are welcomed by local authorities. Also, they are often more efficient than the classical ones, thanks to the natural maintenance, assured by the natural variability of flow velocities and, as a consequence, by the alternating periods of deposition and transport.
The construction of a fish pass implies an additional cost for the SHP constructor: to avoid spending money in vain, it is important to take care of both the design and the operation. In particular, the design of a fish bypass is a very specific and singular exercise requiring the consideration of a wide range of parameters and restrictions, which cannot be reduced to copying a standard type.
Three prerequisites are decisive for the effectiveness and efficiency of fish passes:

- **Traceability:** migrating fish must be able to effortlessly find the entrance independently of the flow conditions. So, the location must be identified with special care and the flow must therefore be strong enough to attract fish away from spillways and tailraces.
- **Passability:** all fish species, present in the specific site in exam, must be able to pass into the structure in every discharge condition. So, the design of the passage geometry has to take into account the local fish characteristics and guarantee proper hydraulic conditions (i.e. flow velocities and water depths).
- **Duration:** planned maintenance is necessary to ensure fish pass efficiency in time, because of the sedimentation of gravel and other materials that can modify the original structure.

In synthesis, an effective fish passage design for a specific site requires good communication between engineers and biologists, and thorough understanding of site characteristics. Site and species-specific criteria and economics determine which solution is the most appropriate.

CASE STUDY N°4: Restoration of migration path on the Sava river, Tacen, Slovenia

In the Sava river (Slovenia), the interruption of hydraulic continuum by the presence of a dam justified, years ago, the creation of a fish pass. However, it was unsuitably constructed and not properly functioning, as demonstrated by the interrupted migration path of freshwater fish species, like Nase and Barbel, between the Tace hydropower water reservoir and downstream river. So a restoration was recently planned, providing the reconstruction of the old dam and the removing of the existing fish-way, to be replaced by rocky glide. An activity of two months fish migration monitoring proved that the restoration achieved the biological goals by allowing fish migration, while having no impacts on the existing hydropower production.

Source: INSTITUTE FOR WATER OF THE REPUBLIC OF SLOVENIA

Source: INSTITUTE FOR WATER OF THE REPUBLIC OF SLOVENIA

FISH PASSES BEFORE (1982) AND AFTER RESTORATION (2006)

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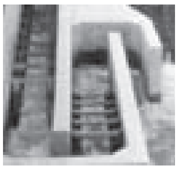
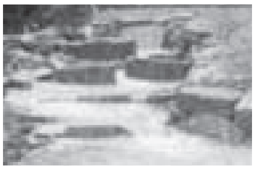
Environmental benefits:

- Possibility of fish migration
- Biological approach at the base of the design
- River habitat naturalisation

SYSTEM	WORKING	IMAGE
	CONVENTIONAL TYPES	
Weir and pool fish passes	The whole head is divided in a succession of smaller heads, in communication to each other through different kinds of openings, like slots and bottom orifices. Fish can go upstream thanks to the energy dissipation and the presence of rest sites.	Source: ESHA 
Denil fish pass	Narrow chutes with vanes, set in the bottom and/or on the banks, dissipate the energy providing a low-velocity flow through which the fish can easily ascend.	Source: Provincia di Bergamo 
Borland lock	Through periodical operations of opening and closing of the regulation systems, the water level inside the sluice is changed so as to guarantee the passage of fish from the down-stream chamber to the upstream one.	Source: Provincia di Bergamo 
Lift	Mechanical system that periodically picks up fish in a tank filled with enough water and then lifts and empties it upstream.	Source: Provincia di Bergamo 
	NATURAL-LIKE TYPES	
Rock-ramp	Large-scale roughness of the bottom of the ramp ensures enough turbulence for energy dissipation, which in this way takes place on the ramp surface and at the ramp's toe. So, the hydraulic conditions ensure the passage of the fish.	Source: Provincia di Bergamo 
Pool and boulders pass	Rock boulders are placed across the channel, more or less regularly over its entire length in order to create a series of pools in which water energy is dissipated. Fish can go upstream by passing through the empty space that divides two boulders and can then have a rest in the pool.	Source: Provincia di Bergamo 
By-pass channels	Artificial shallow sloping channel which links the weir or the whole impoundment. The velocity in the channel is quite slow due to the considerable length and the consequent reduced slope; often it is also reduced by a series of constrictions and expansions of the flow, created by perturbation boulders placed on the bottom.	Source: BOKU 

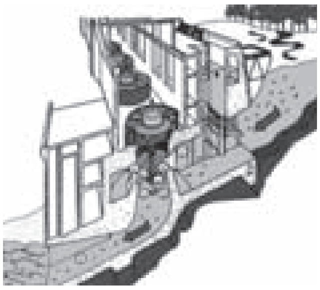
Types of fish passes.

2.5 FISH-FRIENDLY TURBINES

PAST LEARNING

When fish are going downstream in a river, they may get into the headrace channel and risk dying when passing through the turbine. The survival of a turbine-passed fish is highly dependent on the path the fish takes; usually the main damaging zones are the ones shown later in the figure, which correspond to specific injury mechanisms: increasing pressure (1), rapidly decreasing pressure (2), cavitation (3), strike (4), grinding (5), shear (6) and turbulence (7).
Different types of equipment like strobe lights for repelling fish, mercury lights for attracting fish, sound generating devices and electrical guidance systems

Source: U.S. Department of Energy



FISH DAMAGING ZONES

can keep fish away from passing the trash rack, but it has not yet been demonstrated that these measures can be directed reliably. So, many studies are now developing new hydropower turbine designs that would minimize fish injury and mortality, by simulating turbine hydraulics in the laboratory coupled with using fish species of interest for testing and by reefing the conceptual design with the use of the Computational Fluid Dynamics (CFD) simulations.
Otherwise, in the SHP field, there are a lot of applications, such as low head and extreme low head, where the installation of conventional turbines may be economically unsuitable. Instead of them, the widespread choices are the classical water wheels, built traditionally from wood or recently from steel, or the "inverted" Archimedean screw. They do not need a fine trash rack, are robust in operation and, above all, are fish-friendly, thanks to their much slower rotation velocity. So, by learning from the past it could be possible to improve the future.

EXAMPLE: THE ARCHIMEDEAN SCREW

Source: RITZ-ATRO

The Archimedean screw is over 2000 years old, and has traditionally been used for pumping. Only recently it has been used in applications for generating electricity at low-head hydro sites too: this special turbine consists of an Archimedean screw operating in reverse, so that the falling water turns the screw, which itself in turn drives a generator.

ADVANTAGES:

- high efficiency maintained over a wide range of flows;
- no fine screening required;
- very good fish compatibility.

The EPRI study (1992) findings showed that estimated mortality averaged 20% for Francis turbines, 12% for Kaplan turbines, and 9% for bulb turbines

"The hydraulic screw shows a high level of compatibility with fish and it is well suited to facilitating fish descent". (Fishery Biological Opinion on the Fish Compatibility of the Patented Hydrodynamic Screw by Dr Späh

CASE STUDY N°5:
Feasibility study regarding the establishment of ecological turbines on Cèze river

This project is applied to the reach of Cèze river, located in the south of France, between the Municipalities of Montclus and Sailt-Gervais, and regards the development of micro-power stations equipped with ecological turbines, called Aqualinnes. These are hydraulic wheels, with a fixed barrage inside of them; their ecological peculiarity is due to the rotation velocity of the vanes, about 10 times slower than the classical ones. Fish can therefore go through the turbines without being damaged by them. This sort of technology is suitable for hydraulic heads lower than 5 meters, and so ideal for SHP applications with installed capacity included from 10 to 2000 KW.
The project advisability is evaluated on the base of a multi-criterion analysis. The pilot-sites are two ancient mills, named Combe Soulouze and Martel, which will be restored and returned to operation.

Source: H3E

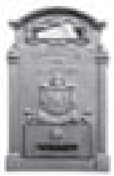
SCHEME OF AN HYDRAULIC WHEEL

	COMBE AND MARTEL MILLS
Turbines	wheels (4)
Net head [m]	< 5m
Installed capacity [kW]	400 KW

Source: IED

Source: H3E


MARTEL MILL (LEFT) AND AN INSTALLATION OF AQUALINNES TURBINE (RIGHT)



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Environmental benefits:

- No fish damage due to the passage through the turbine
- Safeguard of cultural and historical heritage
- Employment of a just existent hydropower potential

3 ADDITIONAL BENEFITS

OPPORTUNITY

Although SHP undoubtedly have some impacts on the environment, we want to point out that the presence of these plants can also have positive effects on the territory, representing a great opportunity from a naturalistic point of view. A hydro plant, in fact, becoming part of a natural environment gives people an opportunity to operate in this context, by promoting an eco-friendly tourist use of the territory and through fluvial habitat consolidation and restructuring.

3.1 TRASH RACK MATERIAL MANAGEMENT

Almost all modern small hydroelectric plants have a trash rack cleaning machine, necessary to avoid any material carried by water to enter the plant waterways and damage electro-mechanical equipment or reduce hydraulic performance. Each year tonnes of anthropogenic material are removed from the river for free by SHP operators. This benefit to the river is often unacknowledged but clearly represents a positive impact generated by the small hydroelectric plants and it should be truly taken into account.

Source: APER

A TRASHRACK CLEANING MACHINE

3.2 INTEGRATION OF OTHER ENVIRONMENTAL PURPOSES

It is possible to plan an additional volume of the basin in order to store a part of flood volumes: in this way, the hydro plant has an additional positive effect on territorial hydraulic protection. Another positive result can be achieved by keeping the poundage level higher, in order to allow some recreation activities such as angling and tourist recreation. Similarly, territorial requalification actions, such as cycle-lane construction, can promote an eco-friendly way to live in the environment.

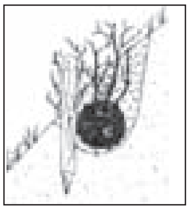
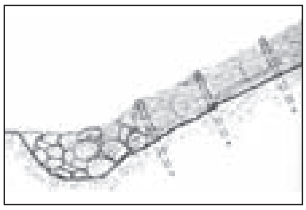
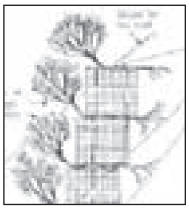
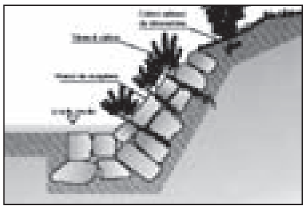
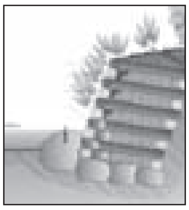
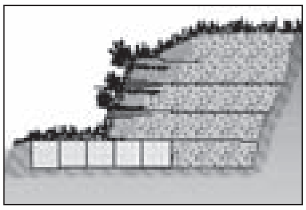
Source: APER

CYCLE-LANES ALONG A SHP TAILRACE

3.3 HYDRAULIC-FOREST ARRANGEMENT

Many SHP are located in the mountain portions of catchment basins, where the hydro-geological risk is connected with the torrential nature of rivers, and in particular with a lack of balance between sedimentation and erosion. As a consequence, typical deteriorations that involve mountain torrents are erosion of channel beds and banks, landslide, channel obstruction, inundation and mudslide. The class of intervention directed to control these phenomena are called hydraulic-forest arrangement, and comprehends both traditional structural works and bioengineering techniques too.

Bioengineering is the combination of biological, mechanical and ecological concepts to control erosion and stabilize soil through the sole use of vegetation or in combination with construction materials. Becoming now competitive even from an economic point of view, these techniques represent the most actual trend because of their accordance with an environmental sensibility to mountain habitat. The construction of SHP in these areas gives the opportunity to apply this sort of technology to control hydro-geological deterioration and qualify the fluvial habitat. Hereafter, some examples of naturalistic bioengineering are shown.

TECHNIQUE	GOAL	SCHEME
Fascines and brush mattress: sausage-shaped bundle structures made from single cuttings of living woody plant material or layer (mattress) of interlaced branches, often with rocks at the base.	Toe and strembank protection	Source: US Army Corps of Engineering  Source: Da Deppo et al.  Fascines / Brush mattress with rock toe
Gabions and reef: cylinders filled with earth or stones (gabions) or groups of big boulders (reef), reinforced through woody vegetation with a good vegetative propagation capacity like cuttings.	Strembank erosion control	Source: US Army Corps of Engineering  Source: APAT  Gabions (left) and reef (right) integrated with vegetation
Timber and stones wall: Timber wall filled with boulders	Strembank erosion control	Source: APAT  Source: APAT  Bank defence made from timber, stones and willow
Vegetated reinforced soil slope: earthen structure made from living, rootable, live-cut, woody plant material branches, bare root, tubling or container plant stock in conjunction with rock, geosynthetics, geogrids.	Strembank erosion control	Source: US Army Corps of Engineering  Source: APAT  Vegetated reinforced soil slope
Step and pool reaches: alternation of reaches with high and low slope, realized through the use of big boulders	Morphological recon-struction and riverbed stabilisation	Source: Ferro et. al:   Step and pool reach

Examples of bioengineering techniques.

4 CONCLUSIONS

As stated previously, although most renewable energy technologies are environmentally sound from a global perspective, all of them can have local negative impacts on environment if poorly planned.
In December 2000 the European Water Framework Directive (EU/60/2000) came into force setting a new frame towards the management of European river basins and with the objective to achieve good status for all surface water bodies by 2015.
The aim of this report was to give a review of some of the relevant approaches and mitigation measures in the process of harmonizing a hydropower project with the other interests in the water and ecosystem management.
Good practice examples of how to prevent, remedy or mitigate the adverse ecological effects of human alterations to the environmental and hydrological characteristics of surface water bodies were presented and it is hoped that the information contained in the report will help promote consistency in decision-making, by showing that there are ways and means to reconcile social, ecological and economic concerns.
There is no formula to develop the perfect project while preserving all interests, it is of course a challenge to balance the diversity of approaches, however we would still like to outline some relevant elements in the process of optimizing decisions:

- ✓ **territorial approach:** a hydro project manager has to systematically identify, analyse and find the locally appropriate mitigation measures to address the environmental conditions of that ecosystem or territory;
- ✓ **stakeholders involvement:** involving water users and other stakeholders in the identification of cost-effective measure options can help identify practical solutions and improve the effectiveness of the selected measures by increasing stakeholders' understanding of, and support for, them;
- ✓ **monitoring:** the implementation of the measures should be followed by a monitoring phase, in order to check the effectiveness on biological function. The result of the monitoring allows the review of the measures so as to improve their efficiency;
- ✓ **cost/efficiency:** information on the cost and effectiveness of different measures options provides a basis for comparing the relative cost efficiency of those options and allows for making judgements about the combination of measures that will produce a given improvement most cost-effectively;

A successful hydropower project is therefore not only produced by clever project management within the developer organisation, but it's a multidisciplinary piece of work, varying from preserving fauna and flora to deciding technical aspects such as the choice of materials in the power plant.
The inclusion and integration of knowledge from a variety of different special fields in all phases of planning and accomplishment will increase the probability of taking care of everything.
This is why a well-functioning regulatory framework and good practice guidelines are essential to assure sustainable hydropower projects and thereby contribute to sustainable water management.

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